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THE DYNAMICS OF CROP YIELDS IN THE U.S. CORN BELT AS
EFFECTED BY WEATHER AND TECHNOLOGICAL PROGRESS

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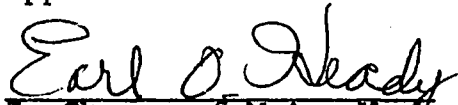effected by weather and technological progress
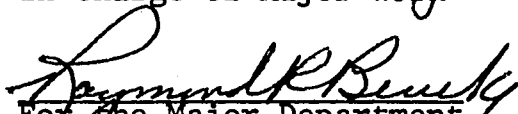
by

C. Arden Pope III

A Dissertation Submitted to the

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CHAPTER I.   INTRODUCTION

Nature of the Problem

During the 1950s and 1960s, the yields of the major
crops in the Corn Belt seemed to be increasing at a rela-
tively steady linear rate of growth with some fluctuations
due to weather. During these two decades, the United States
experienced a period of agricultural surpluses. Agricultural
researchers in general were somewhat optimistic about the
future and many expected yields to continue to increase at
the same rate of growth.

Although hunger and malnutrition were still being
experienced in many parts of the world, in the 1960s U.S.
agricultural policy, which mostly dealt with supporting
prices, controlling surpluses, and reducing supply, reflected
an interesting attitude held by many in the U.S. For example,
Auer (1963) spent some time lamenting about the hunger and
malnutrition being experienced in some parts of the world.
He said, "today more than half of the world's population
suffers from varying degrees of hunger and malnutrition."
Then, on the following page he stated, "the problem of U.S.
agriculture is not shortage but overproduction," as if the
U.S. was in some way removed from the world. This para-
doxical view of the world food problem--a sort of conditional
optimism--seems to have been prevalent in the U.S. during the

1960s.

In the early and mid-1970s, however, corn yields in the Corn Belt declined substantially. By 1973 average corn yields in Iowa had increased to about 110 bushels per acre. Then, for the next four years, 1974, 1975, 1976, and 1977, average corn yields were down from 1973 yields by an average of about 20 bushels per acre. Similar reductions occurred in the other Corn Belt states as well.

This reduction in yields, along with a world grain shortage, and huge Soviet Union purchases of feed grains resulted in a rapid decrease in the U.S. grain reserves and a rapid increase in the prices of many agricultural products. Poor harvests in some developing countries along with their inability to import enough food at the higher prices, caused an increase of hunger in some parts of the world. This caused concerns, and even alarm, to many world leaders, policy makers and humanitarians. Evenson and Kislev (1975, p. 1) writing in the mid-1970s stated, "today that optimism (of the 1960s) has disappeared . . . doomsday models are in fashion".

Partly as a result of a somewhat more pessimistic outlook on the future, many saw the lower yields experienced in the Corn Belt during the mid-1970s as strong evidence that yields were beginning to level off. However, in 1978, 1979, 1980, and 1981, yields in the Corn Belt increased again

to around the previous trend level, suggesting that no real leveling off has occurred. Now the question still remains--are yields in the Corn Belt leveling off?

In the past, expected yields have been greatly influenced by the degree of optimism or pessimism that seemed to prevail. In the 1960s, when optimism was running high, most experts expected the increases in yields to continue. Some even thought we would eradicate hunger throughout the world. In the 1970s, when "doomsday models were the fashion" yields were seen to be close to their limits. Now as we enter the 1980s after a decade of volatile yields and agricultural prices, a cautious wait-and-see attitude seems to be the norm, while a keen interest in these issues still exists. This study is an effort to at least partly address these issues.

Objectives

The three major objectives of this study are as follows:

1) Develop models that adequately explain the changes in yields of the major crops in the Corn Belt states over time and how they are affected by weather, and technological progress.

2) Project yields in the Corn Belt to the year 2000.

3) Determine if there is any evidence of a leveling

off to yields over time in the Corn Belt. This includes
looking at the most important variables that effect yields,
technological progress and weather in detail.

CHAPTER II. REVIEW OF LITERATURE
Growth in General Agricultural
Productivity

Much has been written about changes in agricultural pro-
ductivity, what causes it, and what will happen to it in
the future. Certainly, agricultural productivity has been
a major concern since the beginning of man. Any attempt to
review the literature that deals with agricultural production
in general, and changes in crop yields in specific, must be
limited.

In the English-speaking world, periods where agricultural
productivity has been viewed with generally a great deal of
pessimism can be identified. One period of pessimism can
be identified as beginning around 1800 with Malthus' essay
on the principles of population (see Malthus, 1888). Another
period of pessimism came in the late 1890s "in connection
with the German controversy about the relative merits of
agrarian and industrial national economics" (Bennett, 1949,
p. 17). During this period, wheat supplies were short and
prices were high. In 1898, Sir William Crookes (1917)
delivered an address, "The Wheat Problem," to the British
Association for the Advancement of Science, which caused
much concern about the ability of man to feed himself.
Also, for a relatively short period of time following

World War I (around 1920) concern about the world food-supply problem flourished and, in the 1940s and early 1950s, a large amount of literature pessimistically doubting the world's ability to feed itself at the accustomed levels of the day were published (see Bennett, 1949; Osborn, 1948; and Vogt, 1948).

During the late 1950s and 1960s, a more optimistic outlook on food production potential was prevalent. U.S. agricultural policy dealt more with controlling surpluses, and less with boosting agricultural productivity. However, concern about future agricultural productivity spawned again in the mid 1970s. An explosion of books, papers, and articles appeared, questioning the world's ability to feed itself (for example, see Aiken and Lafollette, 1977; Brown, 1978; George, 1978, Johnson, 1975, and Meadows et al., 1974).

As a result of the reoccurring concern about the ability of mankind to feed itself, there has been, still is, and probably will continue to be, interest about what causes greater agricultural productivity. One large body of literature dealing with agricultural productivity and technological development and adoption, emphasizes the importance of economic, educational, political, social, and institutional factors and how they interact to influence technological progress and agricultural productivity.

For example, Griliches (1957, p. 522) explored the
adoption of hybrid corn in the United States, and concluded
that "where profits from the innovation were large and clear
cut the changeover was very rapid." Both Schultz (1966) and
Mellor (1966) stressed not only the importance of economic
incentives, but also the importance of education, cultural,
social and institutional factors as well. Mellor (1966,
p. 345) called education a necessary, but not a sufficient
condition to agricultural development. Heady (1966, p. 1)
maintained that the important ingredients to increased
agricultural productivity are rather obvious. However, he
pointed out that "what is less obvious is how to overcome
the political, cultural, intellectual restraints which pre-
vent nations from boosting agricultural productivity."

Simon (1975) and George (1978), while recognizing the
need for economic incentives and education, essentially
proposed that the major obstacles to increasing agricultural
productivity and the eradication of hunger and malnutrition
are political, social, and institutional in nature. Brewster
(1961 and 1967) pointed out that people's powerful beliefs
and values regarding the modes of conduct are important
factors that effect economic progress. He noted that this
is not confined just to underdeveloped countries. Nash
(1977, p. 21) reemphasized the "social, cultural, and the

psychological framework which facilitates the application of tested knowledge to all phases and branches of production."

Another interesting body of literature deals with agricultural productivity and its limitations due to the depletion of the earth's natural resources and the adverse imbalances in its ecological system. For example, Brown (1978) argued that the dramatic advances in technology that was seen between 1940 and 1970 can not be expected to continue in the future. He maintained that we are already "outstripping the carrying capacity of biological systems" (p. 259). Similar arguments have also been proposed by Meadows et al. (1974), Mesarovic and Pestal (1974), Ayres and Kneese (1971), Forrester (1971), and others.

Ruttan (1979) suggested that growth in agricultural productivity might slow down in the future as a result of higher energy prices. He also suggested that public sector investment in research and development (R&D) is the primary source of agricultural technology. Ben-Zion and Ruttan (1978) suggested that the investment in agricultural R&D in the private sector is highly influenced by the level of economic activity. This leads to an interesting body of literature that deals with agricultural productivity and technological progress as it is effected by public expenditures on R&D.

Griliches (1958) looked at the social costs and returns to investment on R&D on hybrid corn and related research. He estimated the returns to be between 300 and 700 percent, depending on various assumptions about the nature of the investment. Griliches (1964) also used an aggregate agricultural production function approach where an index of agricultural productivity is regressed on education levels, and past real expenditures on R&D, along with other variables, to measure the effects of these variables on agricultural productivity. Although Griliches (1979) later pointed out some of the serious statistical and econometric problems and weaknesses of this approach and warned that expectations as to what the available data can tell us by using this approach should be lowered, this approach and its extensions have become a fairly popular way of trying to explain technological progress and changes in agricultural productivity (see Evenson and Kislev, 1975; Miranowski, 1980; Norton et al., 1981; and Otto and Havlicek, 1981).

Lu, Cline, and Quance (1979) regressed an index of agricultural productivity on real lagged values of public research and extension expenditures, education levels, and a weather index and used the results to estimate the rate of return to public investment on agricultural research and extension. They also incorporated assumptions about various technological break throughs and used the results to

project future productivity under various levels of real public expenditures. The estimated rate of return on agricultural research and extension ranged between 14 to 45 percent, depending on the region. The projections of future productivity were not surprising--the higher the public investment the higher the projected agricultural productivity.

Growth in Crop Yields

The concept of crop yields, although imperfect, is easily understood and generally excepted as one measure of agricultural productivity. Much research dealing with crop yields and the effects of weather and technological progress on them has been undertaken.

In the early 1900s, Jevons (1909) postulated that the number of sunspots followed a cyclical pattern, and that these patterns effect the weather, yields, and the business community. Since then, many others have looked at the effects of weather on crop yields and tried to determine if they are random or not.

Foote and Bean (1951) studied U.S. corn yields over time and could find no significant evidence of cycles in weather as it effected these yields. Shaw (1965) pointed out that attempts to look at the effects of technological

progress on yields without looking at weather effects are
very limited in their application. He developed a weather
index and regressed corn yields on that index, the percent
of total acres planted to hybrid seed, the use of nitrogen
fertilizer on corn as a percentage of its use in 1962,
and the plant population as a percentage of the 1962 popula-
tion. He concluded that farm output should be expected to
increase more rapidly in the future than it did in the
past because of the rapid structural changes in agriculture
and that corn yields will rise.

Thompson (1969) analyzed corn yields in the U.S. Corn
Belt from 1930 to 1967 by regressing state average corn
yields on a grafted time trend and on departures from
normal monthly precipitation and temperatures. He noted a
significant increase in yields over time and that weather
variability as it effected corn yields, had gradually de-
creased since 1930. He cautioned against any attempts to
extrapolate this trend because of the possibility of entering
into a period of less favorable weather.

In 1973, Sharples (see Black and Thompson, 1978) was
unable to find any significant differences in corn yields
between the increasing half of the sunspot cycle and the
remainder of the cycle. Luttrell and Gilbert (1967) also
were unable to find much evidence of cyclical or bunchy

crop yields in the U.S. However, Harrison (1976) also
studied U.S. yield data and concluded that there is some
evidence that lower-than-average corn yields, and higher-
than-average corn yileds are associated with low and high
sunspot activity, respectively. Black and Thompson (1978,
p. 540) noted that "climatologists have observed striking
differences in the general circulation of the earth's
atmosphere from one 11-year period to the next." They also
pointed out that one of several sunspot cycles that have
been suggested is an 11-year cycle that varies between 9
to 14 years. They then looked at corn and soybean yields
for Iowa, Missouri, Illinois, Indiana, and Ohio and wheat
yields in North Dakota, South Dakota, Kansas, and Oklahoma,
and concluded that there is some empirical evidence that
there are drought cycles for corn, soybeans, and wheat
yields that correspond with this 11-year cycle.

The literature seems to be inconclusive as to whether
weather effects on crop yields are random or not, but there
does appear to be enough evidence that they are to
keep the issue alive. There is no disagreement however, that
weather has an important impact on crop yields, and that
any attempts to look at the effects of technological progress
on yields over time must also incorporate the effects of
weather.

For example, Heady and Auer (1965) studied increases in
U.S. yields. They tried to impute the increases in these
yields by explaining them as a function of seed varieties,
the fertilizer rate, crop acreage, weather, and other vari-
ables. They developed an index of seed varieties, crop
acreage, and weather, and estimated fertilizer rates.
Coefficients for seed varieties and fertilizer were derived
separately and then incorporated into a least-squares
regression function estimated for acreage, weather, and
time. It was concluded that most of the increases in wheat,
corn, soybean, oats, barley, and sorghum, between 1939-1960
could be attributed to increased fertilizer use, and im-
proved seed varieties.

Aggregate crop yield functions for corn yields in Iowa
and Illinois, and grain sorghum yields in Kansas and Nebraska,
were estimated by Perrin (1968) as a simple polynomial in
time, average nitrogen application rates, an index of
hybrid adoption, an hybrid index, and various weather vari-
ables. He similarly studied wheat yields in Kansas, Nebraska,
and North Dakota. He used time series data from 1931-1967
and concluded that forecasted yields would have a continued
upward trend.

Wittwer (1977) outlined some of the possible techno-
logical advances that could be used to boost yields such
as technologies that increase photosynthetic efficiency,

nitrogen fixation, nutrient absorption and improved fertilizer
utilization, the ability to withstand stress, pest and
disease resistance, chemical growth regulants, and others.
Wittwer implied that, given the host of possible yield-
increasing technologies, it is reasonable to believe that
large increases in yields are still possible.

Average U.S. yields for 19 crops between 1960-1977
were studied by Lin and Seaver (1978). They concluded that
12 crops, including corn, cotton, rice, tobacco, and wheat
were stationary in recent years, which indicated a yield
plateau. The yields of hay, potatoes, soybeans, sugarbeets,
and sweet potatoes had a significant rising trend, but
the rate of growth was found to have slowed down.

Swanson and Nyankori (1979) studied corn and soybean
yields on the Allerton Trust Farms, Paitt County, Illinois
between 1950-1976. These farms were well-managed to reach
maximum income, and generally averaged about 13 percent
higher corn yields and 8 percent higher soybean yields
than county averages, even with soils typical to that county.
It was determined that with or without adjusting yields for
weather, increases in yields most closely followed a linear
time trend. The ratios of the Allerton farms' yields with
Paitt County average yields were observed to have remained
constant over time, and it was concluded that a constant
stock of economical, yield-increasing technologies is

available but not generally used.

After reviewing studies by Crosson (1979), Wittwer (1977), Swanson et al. (1979) and others, Heady (1980b) observed that there is not strong evidence of yield plateaus in the United States, given the available time series, but, probably the best that we can hope for in the future is to maintain the current absolute increases in yields.

Summary

In summary, there is a vast amount of literature dealing with changes in agricultural productivity and yields, and how they are effected by technological progress and weather. While some of the authors are more optimistic than others about the future productivity of agriculture, there is common agreement regarding the extreme importance of gaining more knowledge about this topic. The present study is an attempt to use the most up-to-date data available in the Corn Belt to systematically study what has been happening to crop yields as effected by technological progress and weather, and what can be realistically expected to occur in the future.

CHAPTER III. THE THEORETICAL MODEL

Yields can be described as a function of inputs and a given level of technological progress. The number of inputs is generally extremely large, in fact, many may not be known. However, some of the most important inputs can be defined and used as independent variables in a regression analysis. This approach of explaining yields works well only if the observations on yields and the inputs are taken when technology is constant. This approach does little, however, to explain changes in yields over large periods of time when technology is changing. Even if accurate measurements on the inputs can be obtained over time, some serious problems occur.

The problem of severe multicollinearity, among time series variables, makes the estimated regression coefficients on the inputs, or so-called independent variables, almost impossible to interpret (Judge et al., 1980, pp. 452-501). This problem of multicollinearity occurs because many of the inputs are highly correlated with technology. Technological progress is a process that makes some of the inputs more productive, introduces new inputs, makes some of the old inputs obsolete, and often substantially changes their shape, form, or some other feature. For example, over the past three decades the productivity, level of use, and properties of inputs such as fertilizer, seed varieties, insecticides,

herbicides, machinery, and labor have been highly correlated with technological progress.

Multicollinearity is not the only statistical problem that the above features of technological progress cause. The regression coefficients and even the proper functional form are expected to change with technological progress.

In this study, it is assumed that the only inputs that are not highly correlated with technological progress are inputs that are associated with weather (although it is recognized that in the future if technologies such as advanced irrigation systems or methods of manipulating weather such as cloud seeding could also make weather variables correlated with technology to some extent). It is also assumed that the level of nitrogen application uniquely interacts with techno-logical progress in explaining corn yields, and although the level of nitrogen application is highly correlated with technological progress, the price of nitrogen relative to the price of corn along with the amount of spring rainfall significantly effect the rate of nitrogen application.

Therefore, a system of equations that explains the yields of the major crops of the Corn Belt, corn grain, corn silage, soybeans, small grains, and alfalfa hay, and nitrogen application rates is hypothesized as follows:

$$T_t = f_t(t, E_{1i}, E_{2j}, Ed_t, P_1, S_m, O_n) \tag{3.1a}$$

$$N_t = f_n(T_t, P_t^n/P_t^c, W_t) \tag{3.1b}$$

$$C_t = f_c(T_t, T_t \cdot N_t, W_t) \tag{3.1c}$$

$$S_t = f_s(T_t, C_t) \tag{3.1d}$$

$$B_t = f_b(T_t, W_t) \tag{3.1e}$$

$$G_t = f_o(T_t, W_t) \tag{3.1f}$$

$$M_t = f_m(T_t, W_t) \tag{3.1g}$$

where:

T_t = level of technological progress in time t;

t = time;

E_{1i} = current and lagged levels of public expenditures on agriculture R&D;

E_{2j} = current and lagged levels of private expenditures on agricultural R&D;

P_1 = political factors that effect technological progress;

S_m = social factors that effect technological progress;

O_n = other factors that effect technological progress;

Ed_t = education levels of farmers in time t;

N_t = average nitrogen applied in time t;

C_t = corn silage yields in time t;

S_t = corn silage yields in time t;

B_t = soybean yields in time t;

G_t = small grain yields in time t;

M_t = meadow yields in time t;

W_t = weather in time t;

P_t^n = price of nitrogen in time t; and

P_t^c = price of corn grain in time t.

The complete system of equations as outlined above cannot be estimated using conventional econometric analysis. This is because most of the variables in Equation (3.1a) can not be adequately defined, observed, or quantified. However, provided that a good quantifiable proxy variable for technological progress can be found, the remaining six equations can be estimated using regression analysis, assuming that technological progress, weather, and the prices of nitrogen and corn are exogenous to the system. Then Equation (3.1a) can be studied independently in a framework less restrictive than regression analysis. The following chapter deals with the issues related with quantifying technological progress and choosing a proxy variable for technological progress.

CHAPTER IV.   QUANTIFYING TECHNOLOGICAL PROGRESS

For the purpose of this study, technological progress
is defined as the process of developing, learning about, and
applying new and better techniques, methods and inputs which
in sum results in increased productivity and yields. Techno-
logical progress in agriculture, therefore, is determined
by many factors. Economic factors such as relative prices
of different inputs and commodities affect technological
progress. The level of public expenditures on agricultural
research, development, and extension has an effect on techno-
logical progress. The level of private expenditures on
agricultural research and development may be as important
or even more important than public expenditures in these
areas. Education is an important factor in determining the
rate of technological progress. The level and quality of
education received by agricultural researchers and producers
affects how quickly new technology is developed and applied.
Political and social factors also have a heavy impact on
technological progress. A political system that stifles
creative incentive, idleness, dishonesty, crime, and other
such factors have a dampening effect on technological
progress. A climate of political and social stability is a
necessary condition for rapid technological progress.

Technological progress, therefore, is some phantom

variable that is loosely used to describe the lump effects of all of these factors and others on productivity in agriculture. It is not a single variable, but a combination of many variables that cannot be completely defined. Therefore, a proxy variable for technological progress must be used in explaining yields over time.

One variable that has been proposed as a proxy for technological progress for use in regression analysis is real lagged public expenditures on agricultural research and development (R&D). The use of this variable is determined to a great extent simply by the availability of the data (Lu et al., 1979) and when not used with extreme caution can lead to erroneous conclusions.

Because technological progress over the last forty years in the U.S. has been increasing at a fairly constant linear rate (see Figures 4.1 and 4.2), any variable that is highly linearly correlated with time over this period will be statistically correlated with technological progress. As can be seen in Figure 4.3 and Appendix A, public expenditures on agricultural R&D have been highly linearly correlated with time. If this is also true, for at least some of the other factors that effect technological progress, such as private expenditures on agricultural R&D, and level of education, then the estimated relationship
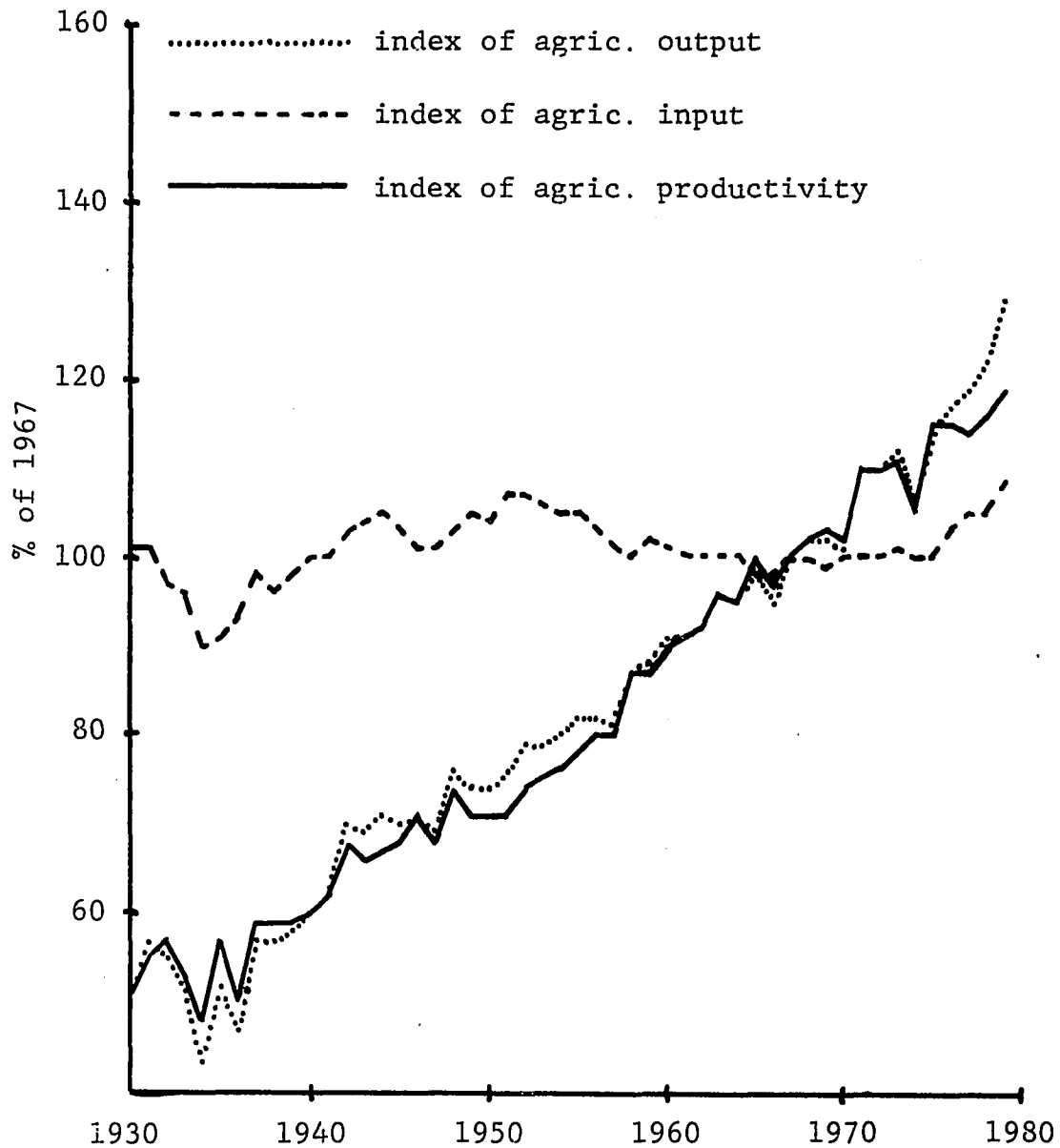
Figure 4.1. Indexes of farm output, input, and productivity
in the United States, 1930-1979 (USDA, Economic
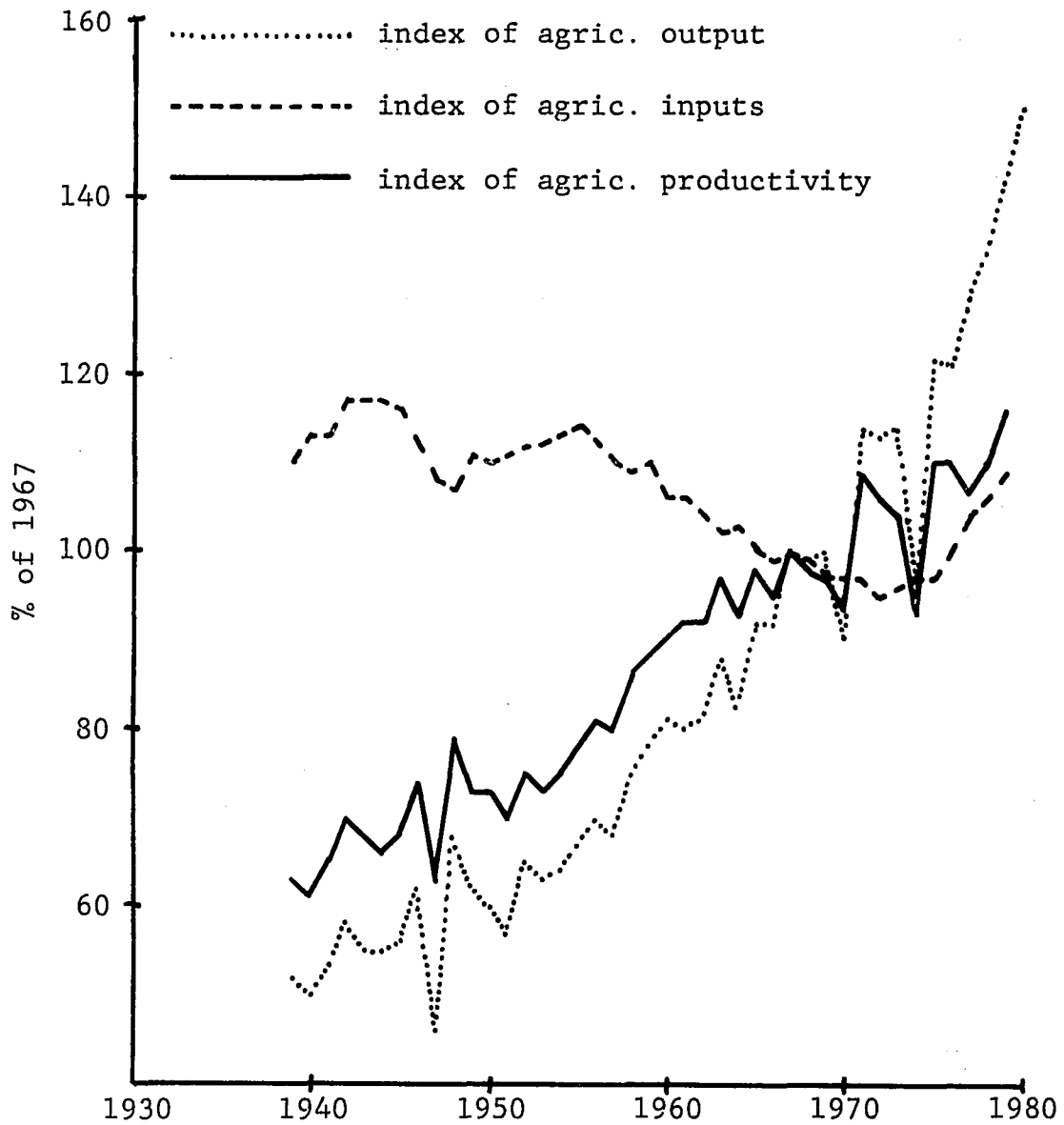Indicators of the Farm Sector, 1981)

Figure. 4.2. Indexes of farm output, input, and productivity
in the Corn Belt, 1939-1979 (USDA, Economic
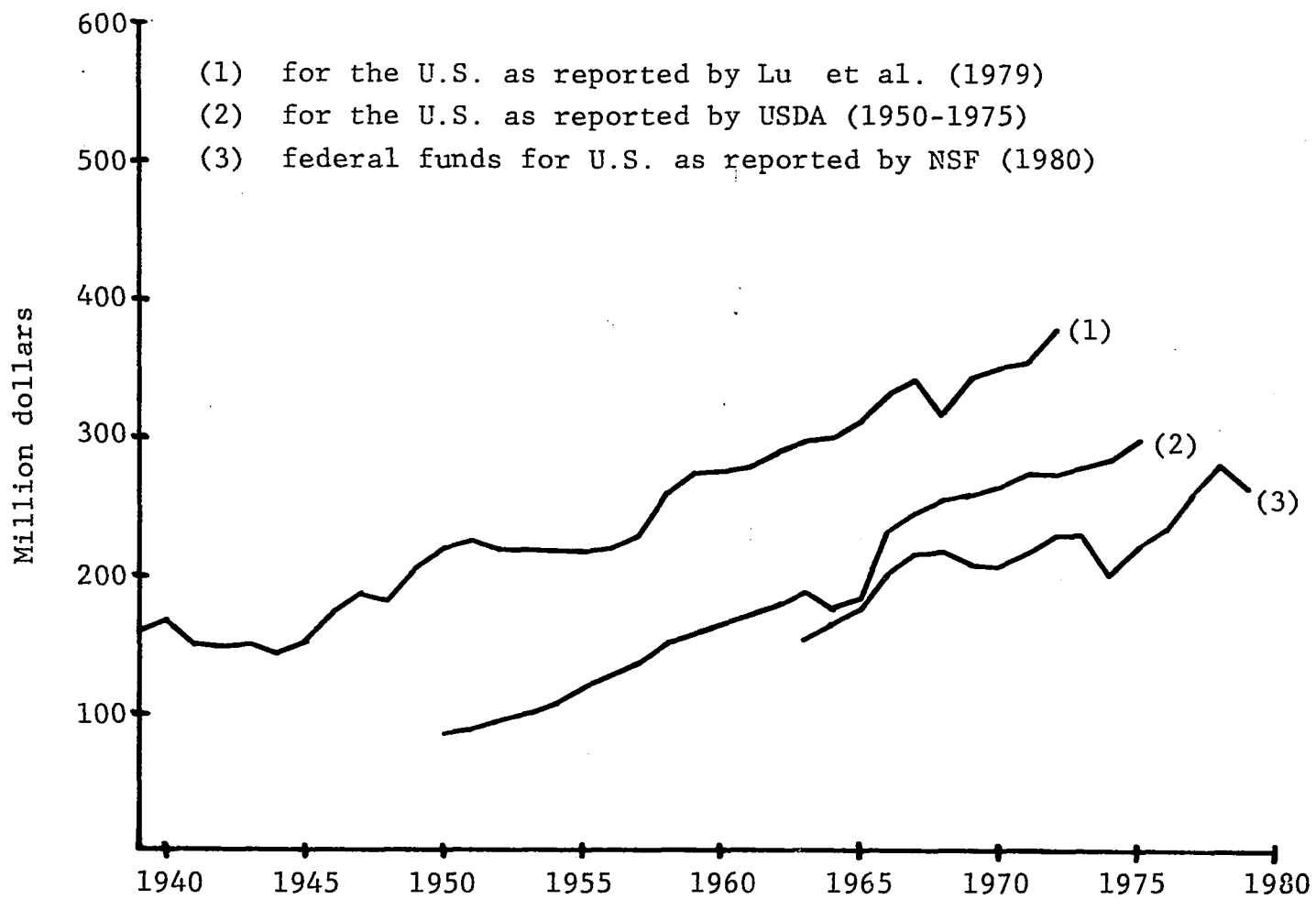Indicators of the Farm Sector, 1981)

Figure 4.3. Public expenditures on agricultural R&D (1967 dollars)

between yields and public expenditures will be biased.

For example, assume that technological progress is a simple linear function of only two variables, lagged public expenditures on agricultural R&D and lagged private expenditures on agricultural R&D. Also, assume that both public and private expenditures have been increasing linearly over time at the same rate, and therefore are linearly correlated with each other. Assume that the level of technological progress can be described by the following function:

$$T = a_1 E_1 + a_2 E_2 \qquad (4.1)$$

where:

T = level of technological progress;

E_1 = lagged public expenditures of agricultural R&D;

E_2 = lagged private expenditures on agricultural R&D; and

a_1, a_2 = coefficients that relate E_1 and E_2 with T.

If yields can be described by the following function:

$$Y = b_1 T + b_2 W \qquad (4.2)$$

where:

Y = yields;

T = level of technological progress;

W = weather; and

b_1, b_2 = coefficients that relate T and W with Y,

then, by substituting Equation (4.1) into (4.2), the following function is obtained:

$$Y = b_1(a_1E_1 + a_2E_2) + b_2W \qquad (4.3)$$

Now, if lagged public expenditures on R&D is used as a proxy variable for technological progress and if regression analysis is used to estimate Equation (4.2), the expected function is:

$$Y = b_1(a_1 + a_2')E_1 + b_2W \qquad (4.4)$$

The real effect of public expenditures on yields is not equal to the expected estimated effect. That is:

$$\frac{\delta Y}{\delta E_1} = b_1a_1 \neq b_1(a_1 + a_2) \qquad (4.5)$$

Now, if:

$$E_1 = a + dt \qquad (4.6a)$$

$$E_2 = b + dt \qquad (4.6b)$$

where;

t = time; and

a, b, d = constant coefficients that relate E_1 and E_2 with t.

Then, by substituting (4.6a) and (4.6b) into (4.3), we get:

$$Y = b_1(a + b) + b_1(a_1 + a_2)dt + b_2W \qquad (4.7)$$

If the above assumptions hold, it is obvious that yields can be just as well expressed as a function of time.

Similar problems also occur with other functional forms. For example, if we assume that technological progress can be expressed as follows:

$$T = \beta_0 E_1^{\beta_1} E_2^{\beta_2} \tag{4.8}$$

and, if we also assume that yields can be expressed as follows:

$$Y = \alpha_0 T^{\alpha_1} W^{\alpha_2} \tag{4.9}$$

then, by substituting Equation (4.8) into Equation (4.9), we get the following:

$$Y = \alpha_0 \beta_0^{\alpha_1} E_1^{\beta_1 \alpha_1} E_2^{\beta_2 \alpha_1} W^{\alpha_2} \tag{4.10}$$

Now, let's assume that E_1 and E_2 are highly correlated and that E_1 is used as a proxy variable for technological progress. It is difficult to determine what the expected estimated equation would look like. This depends on how E_1 and E_2 are correlated. If, for example, $\ln E_1$ and $\ln E_2$ are linearly correlated, the expected estimated function would look as follows:

$$Y = \alpha_0 \beta_0^{\alpha_1} E_1^{(\beta_1 \alpha_1 + \beta_2' \alpha_1')} W^{\alpha_2} \tag{4.11}$$

The real effect of public expenditures on yields is not

equal to the expected estimated effect. That is:

$$\frac{\partial Y}{\partial E_1} = \beta_1 \alpha_1 \alpha_0 \beta_0{}^{\alpha_1} E_1{}^{(\beta_1 \alpha_1 - 1)} E_2{}^{\beta_2 \alpha_1} W^{\alpha_2} \tag{4.12a}$$

$$\neq (\beta_1 \alpha_1 + \beta_2' \alpha_1') \alpha_0 \beta_0{}^{\alpha_1'} E_1{}^{(\beta_1 \alpha_1 + \beta_2' \alpha_1' - 1)} W^{\alpha_2} \tag{4.12b}$$

In an effort to measure how highly correlated public research expenditures have been with time, time series data from 1950-1975 on public expenditures on agricultural research for the entire U.S., for the Corn Belt, and for Illinois, Indiana, Iowa, Missouri, and Ohio are collected. These data are reported by the United States Department of Agriculture (USDA), in "Funds for Research at State Agricultural Experiment Stations and other state institutions" (1950-1975). These expenditures are all discounted using the GNP price deflator and time is regressed on them. As is expected, a very strong and significant linear correlation between time and these expenditures is observed for the U.S., the Corn Belt, and all five states, and the results are reported in Table 4.1. However, by studying the error terms of these regressions, a very interesting observation can be made. The error terms are not only highly autocorrelated, but they also seem to have cyclical patterns that seen roughly 10-14 years in length (see Appendix A). This also appears to be true for the time series data on public expenditures used

Table 4.1. Results of regressions of time on public expenditures on agricultural R&D for the U.S., the Corn Belt, and five Corn Belt states

	OLS Models					Autoregressive Models			
	Int.[a]	β[a]	R^2	MSE	D.W.[b]	Int.[a]	β[a]	R^2	MSE
U.S.	1942.20	0.1076	0.979	1.268	0.85	1942.2	0.1064	0.991	0.477
Corn Belt	1940.48	0.8852	0.951	3.009	0.74	1939.33	0.9267	0.980	0.877
Illinois	1941.89	3.6846	0.905	5.814	0.50	1940.15	3.9842	0.945	2.112
Indiana	1932.29	6.2949	0.865	8.206	0.54	1929.03	6.8721	0.862	3.469
Iowa	1934.31	5.3597	0.948	3.144	1.18	1935.10	5.1983	0.964	1.312
Missouri	1948.57	5.3515	0.924	4.655	0.50	1947.72	3.7123	0.955	1.222
Ohio	1944.80	3.3536	0.847	9.345	1.15	1944.47	3.4135	0.874	5.338

[a]All regression coefficients are significant at the one percent level of probability.

[b]All Durbin-Watson tests for autocorrelation are significant at the five percent level of probability.

by Lu et al. (1979, see Figure 4.3). Therefore, when a function of public expenditures on agricultural R&D that incorporates the autoregressive nature of these expenditures is used, a linear function of time can be even more closely approximated. For example, the following function is estimated for the United States, the Corn Belt, and for Illinois, Indiana, Iowa, Missouri, and Ohio:

$$Y_t = \beta E_t - \sum_{i=1}^{14} \alpha_i (Y_{t-i} - E_{t-i}\beta) \qquad (4.13)$$

where:

Y_t = the year in time t;

E_t = the real level of public expenditures in millions of dollars spent on agricultural R&D in time t;

β, α_i = regression parameters, i = 1,2,3,...14.

These results are also summarized in Table 4.1.

Given the near linear trends in agricultural productivity over the past few decades (see Figures 4.1 and 4.2), it is no wonder that a distributed lag, or an autoregressive function of public expenditures on agricultural R&D works well as a proxy for technological progress. A distributed lag on these expenditures that is between 10-14 years in length and that peaks out at 5-7 years, will simply create a variable that increases at a fairly smooth and linear rate over time (see Appendix A). It must be wondered if studies

that attempt to identify the lagged structure of the effects
of public expenditures on agricultural R&D by finding a
distributed lag on these expenditures that perform well in
a regression analysis are in reality finding this structure,
or one that simply does a good job of approximating a smooth
linear trend over time.

In reality, few will argue seriously that public
expenditures on agricultural R&D are perfectly linearly
correlated with time or all other factors that effect
technological progress. Also, few will argue that there
is a direct causal relationship between time and public
expenditures on agricultural R&D. However, the fact re-
mains that over the past forty or so years real public
expenditures on agricultural R&D have been generally in-
creasing at a fairly steady rate over time (see Figure 4.3
and Appendix A). Because agricultural productivity also has
been increasing at a fairly constant rate over the same
period of time, it is no wonder that by using time series
data, a strong correlation between agricultural productivity
and public expenditures on agricultural R&D can be measured.
Actually in the time series data, there is in some sense
little more than one observation. That is, increasing
public expenditures on R&D is coupled with increasing
agricultural productivity. Several questions remain: What

would have happened to the rate of technological progress if real public expenditures on R&D had stayed constant over time? What if they had fallen?

In an effort to answer these questions, some researchers have included cross-sectional data using different states, regions or producing areas into their studies (Griliches, 1957, Otto and Havlicek, 1981). There are several serious problems associated with the introduction of these cross section data. One problem deals with what has been called the spill-over problem (see Griliches, 1979). It is difficult to measure the spill-over effects of research in one area on the productivity of another area. Certainly, research in one location often has some effect on the productivity of a neighboring location.

Another problem is that of simultaneity. For example, do high levels of public expenditures on R&D cause rapid increases in productivity, or do rapid increases in productivity cause greater demand for public expenditures on R&D? The answer to this question is that agricultural productivity and the levels of public expenditures on R&D are simultaneously determined (see Huffman and Miranowski, 1981). Methods of estimating the effects of public expenditures on agricultural R&D on agricultural productivity without recognizing and treating this simultaneity in a nontrivial manner, are doomed to near meaningless

conclusions (Griliches, 1979).

One final problem that should be mentioned is the well-known but often ignored problem of errors in variables. The seriousness of this problem in this context is not known; however, it is expected to be significant. In addition to the obvious measurement error problems associated with measuring productivity and public expenditures, some conceptually more difficult problems occur. For example, when relating lagged yearly expenditures on agricultural R&D to agricultural productivity, it is recognized that these lagged expenditures must be weighted in some way to reflect the differing impacts on productivity depending on how long ago the expenditures were made. Shouldn't expenditures on different types of research be similarly weighted? Research expenditures on production oriented research may need to be weighted higher than research expenditures on rural development or environmental quality. Expenditures for research in other fields such as chemistry, electronics, physics and others also effect agricultural productivity. Historically in the U.S., less than two percent of federal research and development expenditures has gone to agriculture (National Science Foundation, 1980). Certainly the expenditures spent in other areas must have a significant impact on agricultural productivity. Of course the weighting scheme on lagged expenditures would need to be different for

expenditures in different areas of research. Also, the inter-
action effects of expenditures in different areas of research
are extremely difficult to determine.

It is argued, therefore, that there are three necessary
conditions that should be met before a variable can be
considered as a good proxy for technological progress: 1)
reasonably accurate data on the variable can be obtained
over time, 2) it is highly correlated with technological
progress, 3) it is not highly correlated with time. If
these conditions are met then the variable should explain a
significant amount of the variance in yields, even if a time
trend is included. When the first two conditions hold, but
the third one does not, then there is little gained by using
that variable rather than a function of time as a proxy for
technological progress,

Therefore, if a variable such as lagged public expendi-
tures on agricultural R&D is used as a proxy variable for
technological progress in a regression analysis, it must be
understood that agricultural productivity or yields cannot
be realistically estimated for different future levels of
these expenditures.

Before yields, or agricultural productivity can be
realistically estimated under different levels of real
public expenditures on agricultural research and extension,

at least one of the following two conditions must be met: 1) changes in real public expenditures on research and extension is the only factor that effects technological progress, 2) the effects of the other factors that effect technological progress will continue to change over different levels of these expenditures exactly as they did in the past.

The first condition is obviously not met, and the second condition is exactly the same condition that must hold with respect to time if a function of time is used as the proxy variable for technological progress. If one of these two conditions does not hold then any attempts to project yields or agricultural productivity under different levels of real public expenditures on agricultural research and extension or to measure the rate of return on these expenditures is invalid.

Because of the above problems with using proxy variables that are correlated with time, because all of the factors that affect technological progress cannot be quantified, because accurate data on those that can be quantified often cannot be obtained, and because of the extremely complex interaction between these factors, it is determined that the best way to treat technological progress in this study, is to use a function of time as a proxy variable for technological progress. When projecting yields, the slope or shape

of this function over time can be modified to match any
number of assumptions that might be imposed on these pro-
jections. These assumptions must be based on further study
of the factors that effect technological progress and the
effects that these factors might have in the future on
technological progress, in a framework less rigid than re-
gression analysis.

CHAPTER V.   MODEL ESTIMATION

Data Used

Time series data from 1951-1980 were collected on total production and total harvested acres of corn, silage, soybeans, wheat, oats and alfalfa hay for Illinois, Indiana, Iowa, Missouri, and Ohio. Also, time series data from 1951-1980 were collected on corn grain and nitrogen prices, and total nitrogen application for the same states. Weather data for these states were collected for the years 1930-1980.

Data on total crop production, harvested acres, and yields from 1951-1979 are reported by USDA in Agricultural Statistics (1952-1980). Preliminary estimates of 1980 total crop production, harvested acres, and yields were provided by the Crop Reporting Service for the various states, and preliminary estimates of 1981 state average yields for corn grain, soybeans, oats, and wheat are reported by USDA in Crop Production (September 11, 1981).

Data on nitrogen and corn prices are reported by USDA in Agricultural Prices (1950-1980). Data on total nitrogen application are reported by USDA in Agricultural Statistics (1952-1980) and in The Fertilizer Situation (1972-1980). Nitrogen application rates for corn is approximated by dividing the total nitrogen application of each of the five

Corn Belt states by the total acres of corn grain and corn silage harvested in the corresponding state.

The weather data consist of state average September-June precipitation, July rainfall, August rainfall, June temperature, July temperature, and August temperature for Illinois, Indiana, Iowa, Missouri, and Ohio. These data are derived from data reported by the United States Department of Commerce (USDA, 1930-1980) and are furnished by Louis M. Thompson, Iowa State University.

Ordinary least squares regression (OLS) is first used to tentatively determine the functional forms of the individual equations in each of the models for the various states. Three stage least squares regression (3SLS) is used to determine the final function forms and ultimately estimate each system. Because of the simultaneous nature of the first three equations in this system, and because it is expected that the residuals between equations are correlated, 3SLS is expected to give efficient estimators of the models (see Johnston, 1972, Kmenta, 1971, or Theil, 1971). The system of equations for Illinois is estimated as follows (absolute t-values are reported in parentheses below the estimated regression coefficients).

Illinois

$$\hat{N} = 16.2509 + 0 \text{ (PR)} - 3.8302 \text{ (Z1)} + 0.5287 \text{ (Z2)}$$
$$(2.846) \qquad (2.892) \qquad (8.259)$$

$$+ 4.0785 \text{ (Z3)} - 1.1658 \text{ (DPRESP)} \qquad (5.1a)$$
$$(8.409) \qquad (3.915)$$

$$\hat{C} = 46.7865 + 12.4735 \text{ (lnt)} + 0.005725 \text{ } (\hat{N} \cdot t)$$
$$(8.899) \qquad (4.643) \qquad (4.245)$$

$$+ 0.4711 \text{ (DPRESP)} - 0.0676 \text{ (DPRESP)}^2$$
$$(1.497) \qquad (1.618)$$

$$+ 0.7499 \text{ (DJUNET)} + 5.0119 \text{ (DJULYR)}$$
$$(1.162) \qquad (4.001)$$

$$- 1.2728 \text{ (DJULYR)}^2 \qquad (5.1b)$$
$$(2.258)$$

$$\hat{S} = 0.1109 \text{ } (\hat{C}) + 0.7864 \text{ (ln } \hat{C}) - 0.1781 \text{ (t)}$$
$$(6.095) \qquad (2.935) \qquad (3.841)$$

$$+ 1.2385 \text{ (ln t)} \qquad (5.1c)$$
$$(3.272)$$

$$\hat{B} = 22.8846 + 0.4563 \text{ (t)} - 0.0279 \text{ (DPRESP)}^2$$
$$(33.175) \quad (11.513) \qquad (3.087)$$

$$+ 0.1982 \text{ (DJUNET)} + 1.1932 \text{ (DJULYR)}$$
$$(1.507) \qquad (4.711)$$

$$+ 0.6703 \text{ (DAUGR)} \qquad (5.1d)$$
$$(2.789)$$

$$\hat{W} = 17.6165 + 7.2174 \text{ (ln t)} - 0.5771 \text{ (DPRESP)}$$
$$(8.359) \quad (8.974) \qquad (3.926)$$

$$- 0.0290 \text{ (DPRESP)}^2 \qquad\qquad (5.1e)$$
$$(1.454)$$

$$\hat{M} = 2.2909 + 0.0684 \text{ (t)} - 0.1488 \text{ (ln t)}$$
$$(29.194) \quad (11.374) \qquad (2.459)$$

$$+ 0.006275 \text{ (OPRESP)} - 0.002008 \text{ (DPRESP)}^2$$
$$(1.351) \qquad\qquad (3.274)$$

$$+ 0.0315 \text{ (DJULYR)} - 0.02044 \text{ (DJULYR)}^2$$
$$(1.731) \qquad\qquad (2.761)$$

$$+ 0.04331 \text{ (DAUGR)} \qquad\qquad (5.1f)$$
$$(2.895)$$

where:

N = nitrogen used per corn acre;

C = average corn grain yields in bushels per acre;

S = average corn silage yields in tons per acre;

B = average soybean yields in bushels per acre;

W = average wheat yields in bushels per acre;

M = average meadow (legume hay) yields in tons per acre;

t = time, where: 1951 = 1, 1952 = 2,... 1980 = 30;

Z_1 = t when t $\leq$ 18, and Z_1 = 18 when t > 18;

Z_2 = t^2 when t $\leq$ 18, and Z_2 = 324 when t > 18;

Z_3 = 0 when t $\leq$ 18, and Z_3 = t - 18 when t > 18;

PR = the price ratio of the price of nitrogen per ton over the price of corn grain per bushel;

DRESP = departure from normal September to June total precipitation (note: normal refers to the average between 1950-1980);

DJUNET = departure from normal June temperature;

DJULYR = departure from normal July rainfall;

DJULYT = departure from normal July temperature;

DAUGR = departure from normal August temperature; and

DAUGT = departure from normal August temperature.

The variables t, Z_1, Z_2, Z_3, PR, DPRESP, DJUNET, DJULYR, DJULYT, DAUGR, and DAUGT are treated as exogenous to the system. The weighted R^2 value for the system is .989, and the weighted MSE for the system is 1.407.

In Figures 5.1-5.4, actual Illinois crop yields for corn grain, soybeans, wheat, and meadow, as reported by USDA, are plotted over time. The model is used to project yields using actual weather and to project yields assuming normal or average weather. These are also plotted over time in Figures 5.1-5.4.

Because the weather variables are not all linearly related with yields and because average or normal weather is close to optimal weather in terms of its effects on yields in the Corn Belt, yields projected using normal weather are generally greater than expected yields. For this reason, projected yields are unbiased only if future weather is known. If it is not known, yields can be projected assuming normal weather conditions. These projections
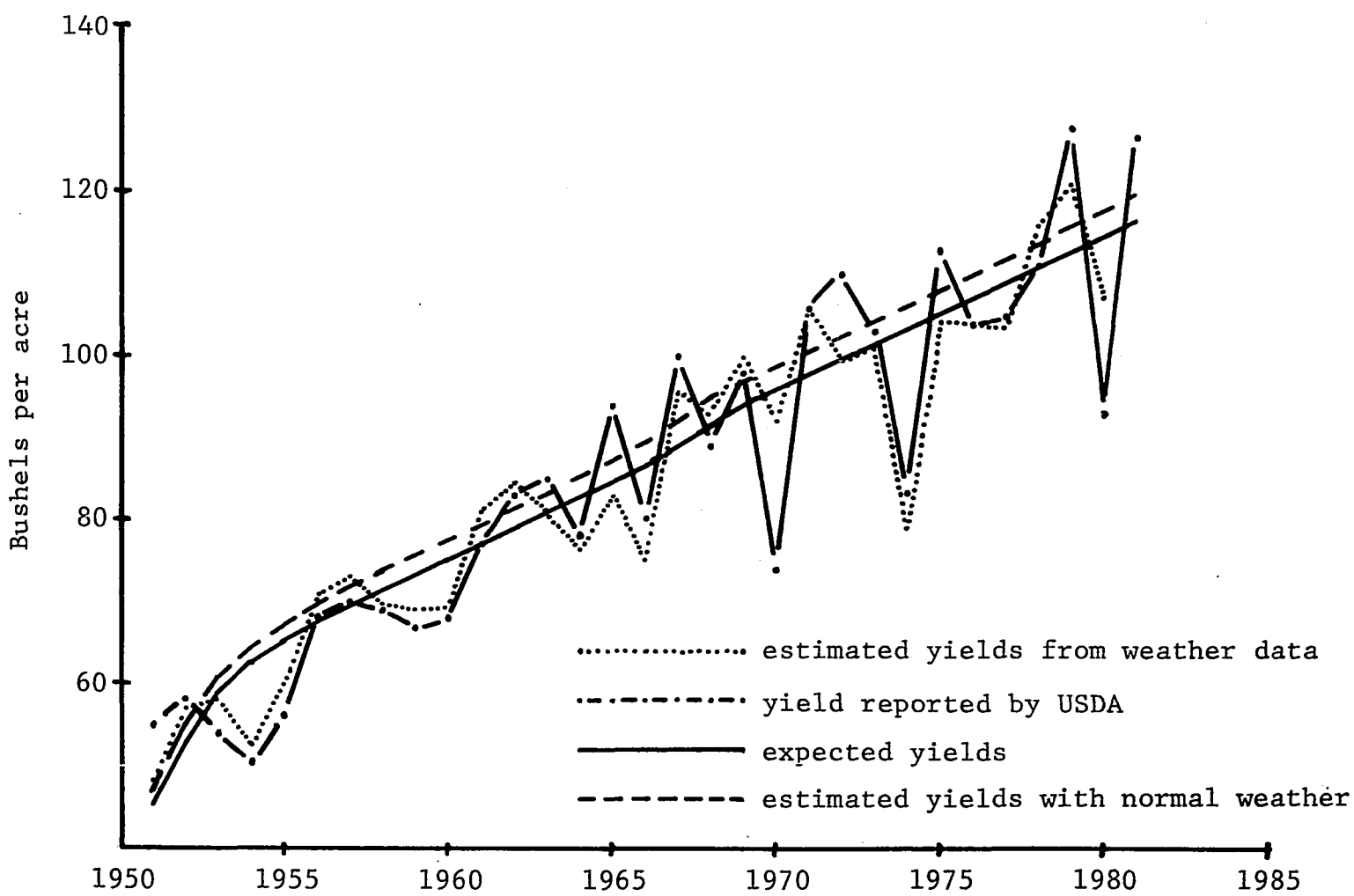
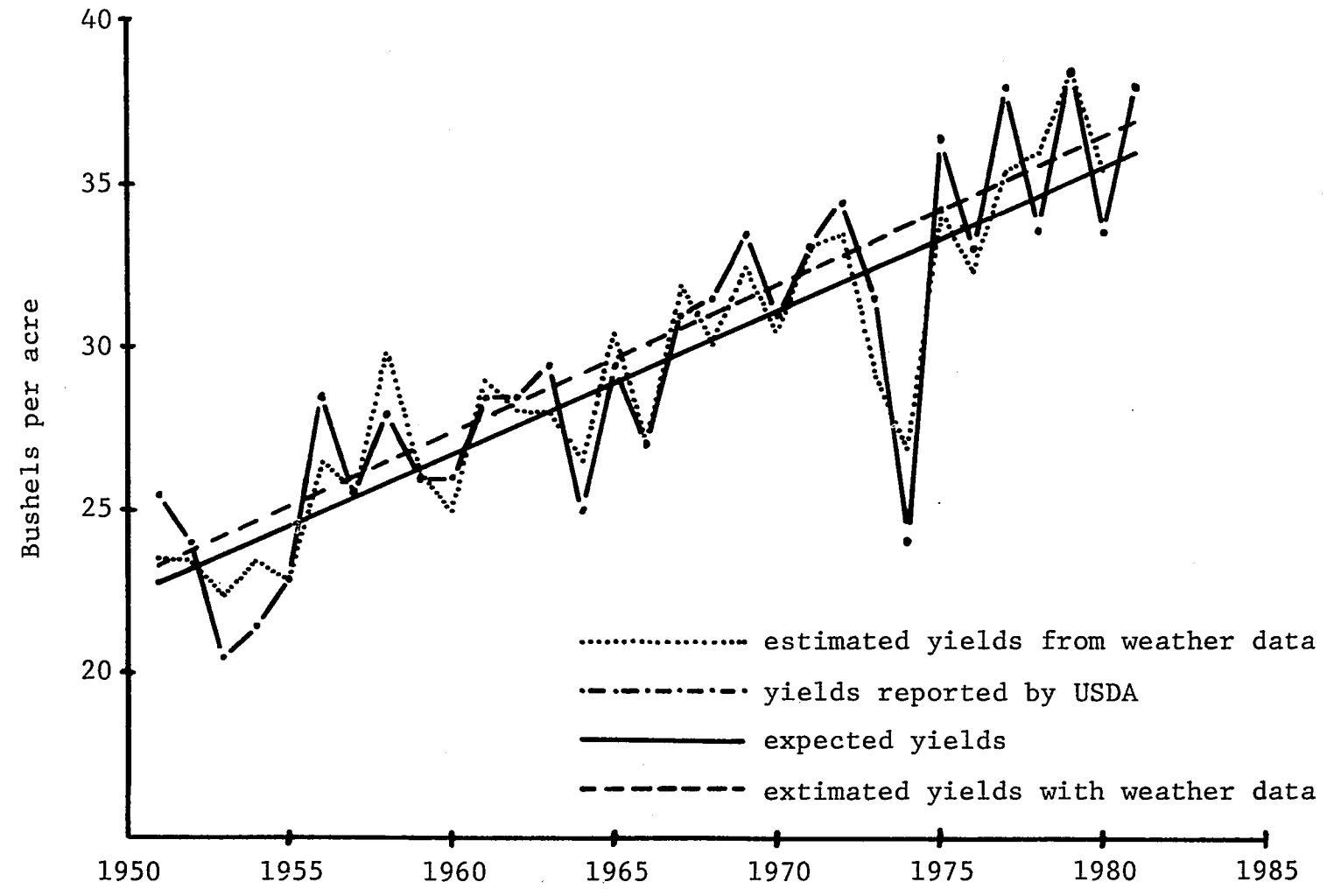Figure 5.1. Corn yields per acre in Illinois, 1951-1981

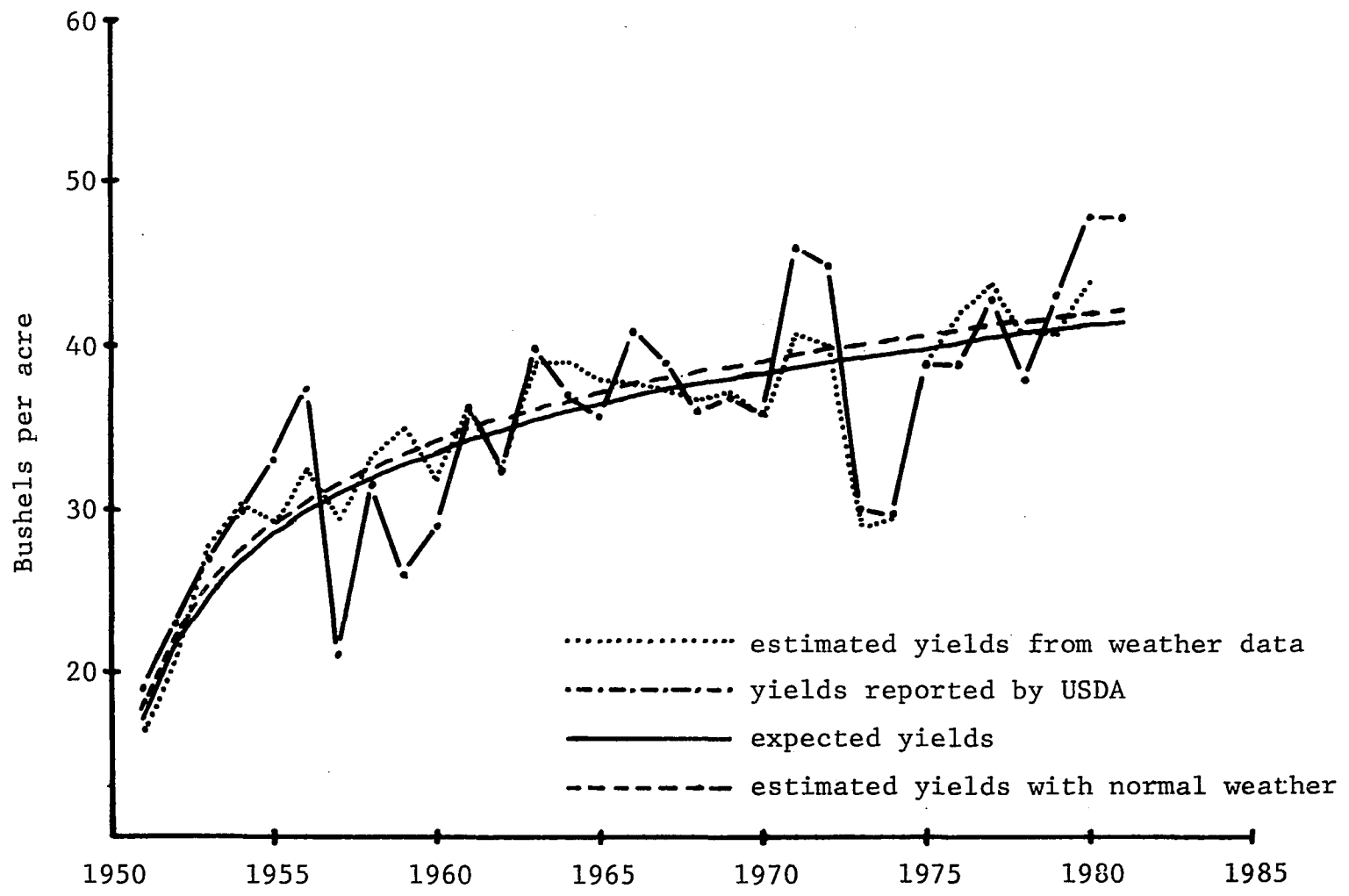Figure. 5.2.   Soybean yields per acre in Illinois, 1951-1981

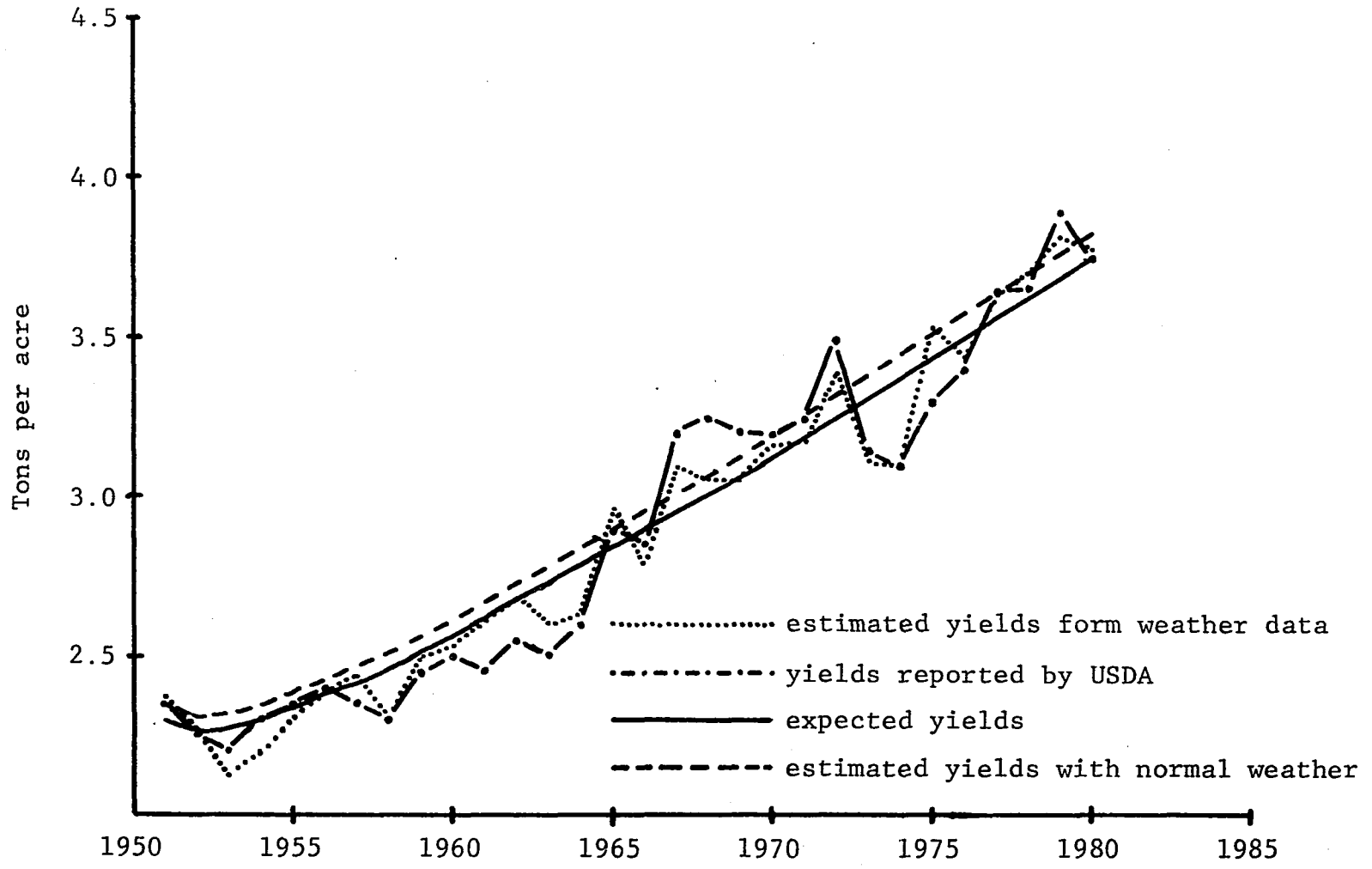Figure 5.3. Wheat yields per acre in Illinois, 1951-1981

Legend:
- ················ estimated yields from weather data
- —·—·—·—·— yields reported by USDA
- ———————— expected yields
- — — — — — estimated yields with normal weather

Y-axis: Bushels per acre (20, 30, 40, 50, 60)

X-axis: 1950, 1955, 1960, 1965, 1970, 1975, 1980, 1985

Figure 5.4. Meadow yields per acre in Illinois, 1951-1980

are biased upward and a means for adjusting them to reflect expected yields is needed.

To see how these projections are adjusted, see Appendix B. Corn yields are estimated using weather data from 1951-1980 and assuming 1980 technology for all the years. The expected corn yield for 1980 is the mean of these estimates. The 1980 corn yield is also estimated by using normal or average weather. The ratio of these two estimated yields is multiplied by the yields that are projected using normal weather to get expected or average yields. This is done for all crops, and the resulting expected yields are plotted over time in Figures 5.1-5.4.

Indiana

The system of equations for Indiana is estimated as follows:

$$\hat{N} = 35.3767 - 0.08174 \text{ (PR)} + 0.3284 \text{ (Z2)}$$
$$(2.409) \quad (0.779) \qquad\quad (14.189)$$

$$+ 1.3664 \text{ (Z3)} - 1.6835 \text{ (DPRESP)}$$
$$(2.858) \qquad\quad (4.372)$$

$$+ 0.1232 \text{ (DPRESP)}^2 \qquad\qquad (5.2a)$$
$$(1.870)$$

$$\hat{C} = 52.0960 + 8.1639 \ (\ln t) + 0.005849 \ (\hat{N} \cdot t)$$
$$\quad (9.114) \quad (2.664) \qquad\qquad (3.142)$$

$$+ 0.8362 \ (DPRESP) + 0.3010 \ (DJUNET)^2$$
$$\quad (2.140) \qquad\qquad (1.407)$$

$$+ 4.9499 \ (DJULYR) - 2.3384 \ (DJULYR)^2$$
$$\quad (4.254) \qquad\qquad (3.720)$$

$$- 1.3502 \ (DJULYT) + 4.3851 \ (DAUGR)$$
$$\quad (1.615) \qquad\qquad (2.600)$$

$$- 2.6867 \ (DAUGT) \qquad\qquad\qquad\qquad (5.2b)$$
$$\quad (3.124)$$

$$\hat{S} = 0.1129 \ (\hat{C}) + 0.6631 \ (\ln \hat{C}) - 0.1305 \ (t)$$
$$\quad (4.800) \qquad (2.049) \qquad\qquad (2.426)$$

$$+ 1.3228 \ (\ln t) \qquad\qquad\qquad\qquad (5.2c)$$
$$\quad (3.151)$$

$$\hat{B} = 23.1128 + 0.3942 \ (t) + 0.1143 \ (DPRESP)$$
$$\quad (26.629) \quad (8.538) \qquad (1.376)$$

$$+ 0.1701 \ (DJUNET) + 1.3903 \ (DJULYR)$$
$$\quad (1.317) \qquad\qquad (5.004)$$

$$- 0.4123 \ (DJULYR)^2 + 1.2429 \ (DAUGR) \quad (5.2d)$$
$$\quad (3.269) \qquad\qquad\quad (3.589)$$

$$\hat{W} = 13.8675 + 8.3526 \ (\ln t) - 0.4438 \ (DPRESP)$$
$$\quad (5.518) \quad (9.620) \qquad\qquad (2.761)$$

$$+ 0.2047 \ (DJUNET)^2 \qquad\qquad\qquad (5.2e)$$
$$\quad (2.165)$$

$$\hat{M} = \begin{matrix} 1.8787 \\ (22.898) \end{matrix} + \begin{matrix} 0.0653 \\ (11.022) \end{matrix} - \begin{matrix} 0.1377 \\ (2.388) \end{matrix} (\ln t)$$

$$+ \begin{matrix} 0.0364 \\ (2.215) \end{matrix} (DJULYR) - \begin{matrix} 0.0230 \\ (3.174) \end{matrix} (DJULYR)^2$$

$$+ \begin{matrix} 0.01615 \\ (1.524) \end{matrix} (DJULYT) + \begin{matrix} 0.02149 \\ (1.013) \end{matrix} (DAUGR) \quad (5.2f)$$

The variables in this model are defined exactly as they were in the model for Illinois. The weighted R^2 for this system is .986, and the weighted MSE for the system is 1.395. In Figures 5.5-5.8, corn, soybean, wheat, and meadow yields, as reported by USDA, along with yields projected with both actual and normal weather, along with expected yields, are plotted over time for Indiana.

Iowa

The system of equations for Iowa is estimated as follows:

$$\hat{N} = \begin{matrix} 30.6366 \\ (2.539) \end{matrix} - \begin{matrix} 0.0601 \\ (1.374) \end{matrix} (PR) - \begin{matrix} 2.9247 \\ (1.783) \end{matrix} (Z1) + \begin{matrix} 0.4419 \\ (4.800) \end{matrix} (Z2)$$

$$+ \begin{matrix} 3.3473 \\ (8.270) \end{matrix} (Z3) - \begin{matrix} 0.6692 \\ (2.451) \end{matrix} (DPRESP)$$

$$- \begin{matrix} 0.1342 \\ (2.545) \end{matrix} (DPRESP)^2 \quad (5.3a)$$
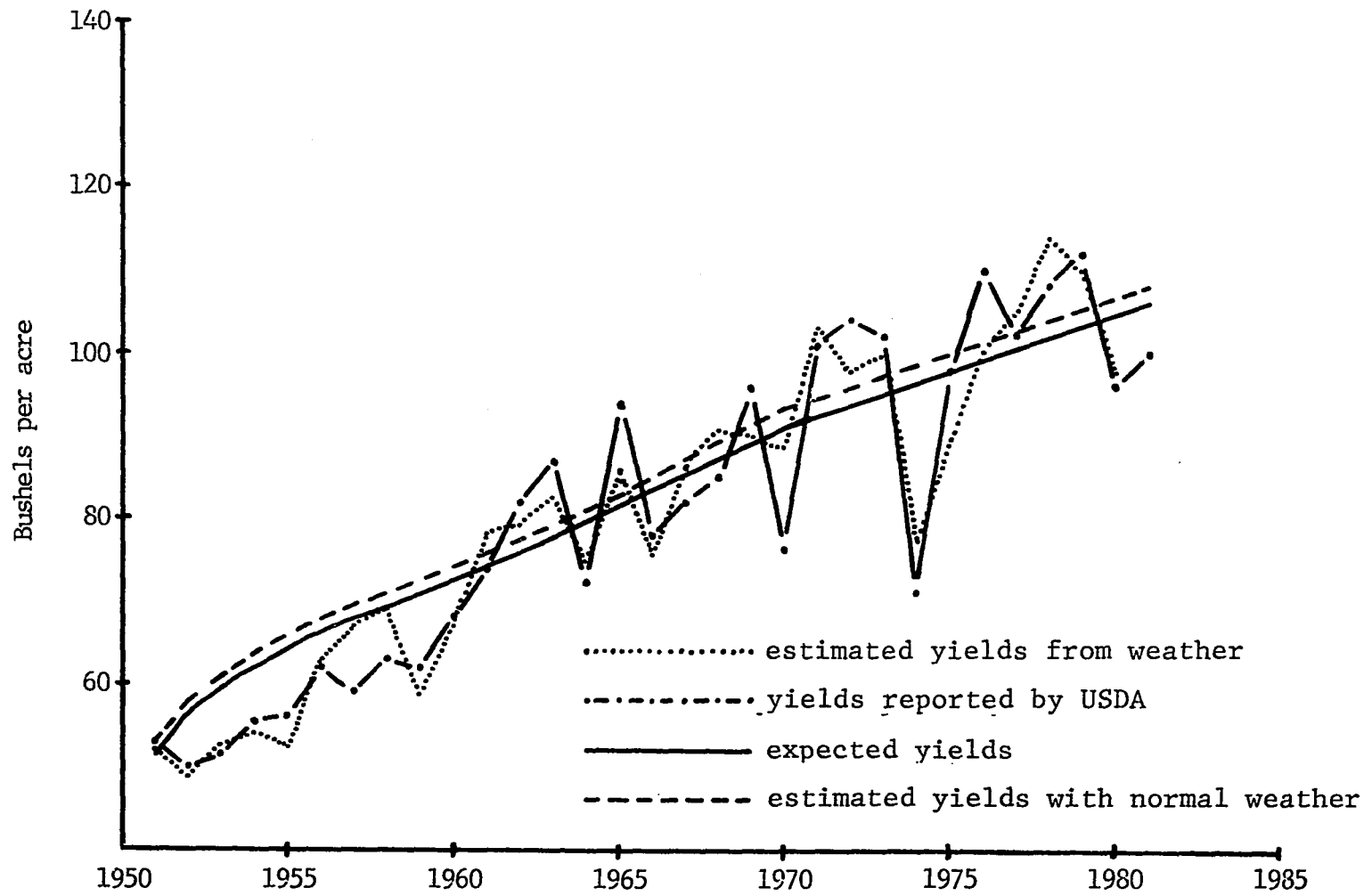
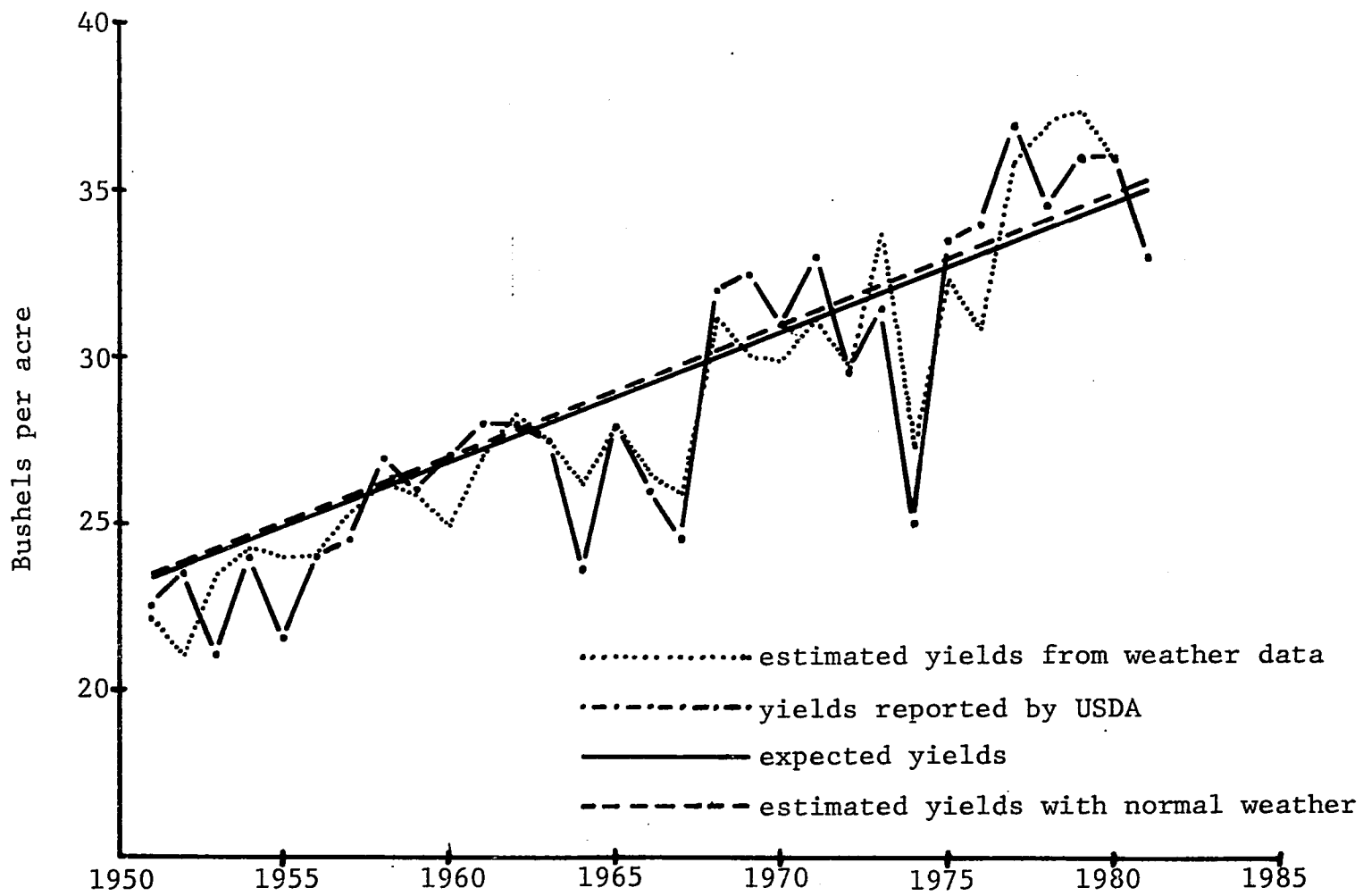Figure 5.5. Corn yields per acre in Indiana, 1951-1981

Figure 5.6. Soybean yields per acre in Indiana, 1951-1981
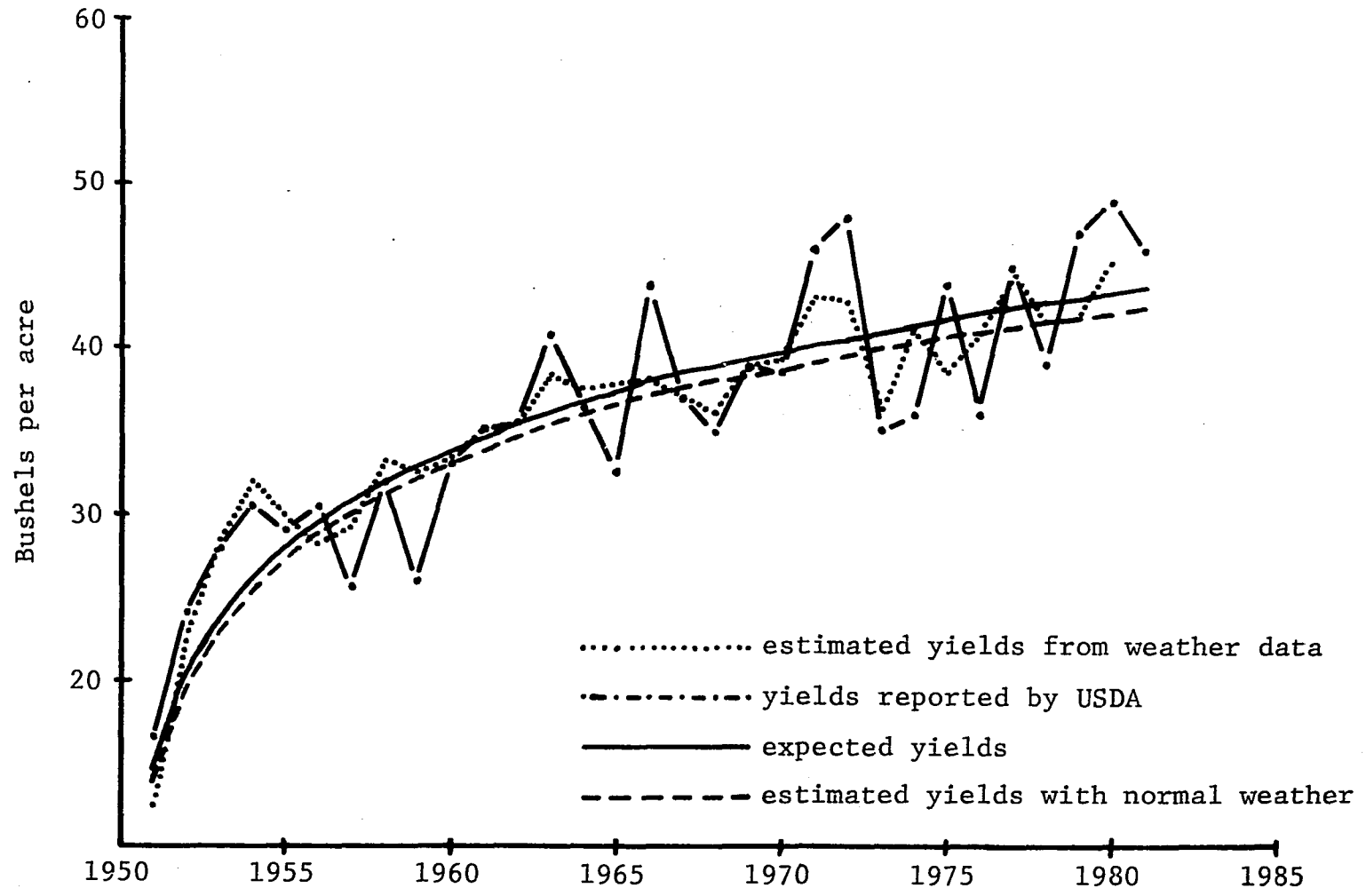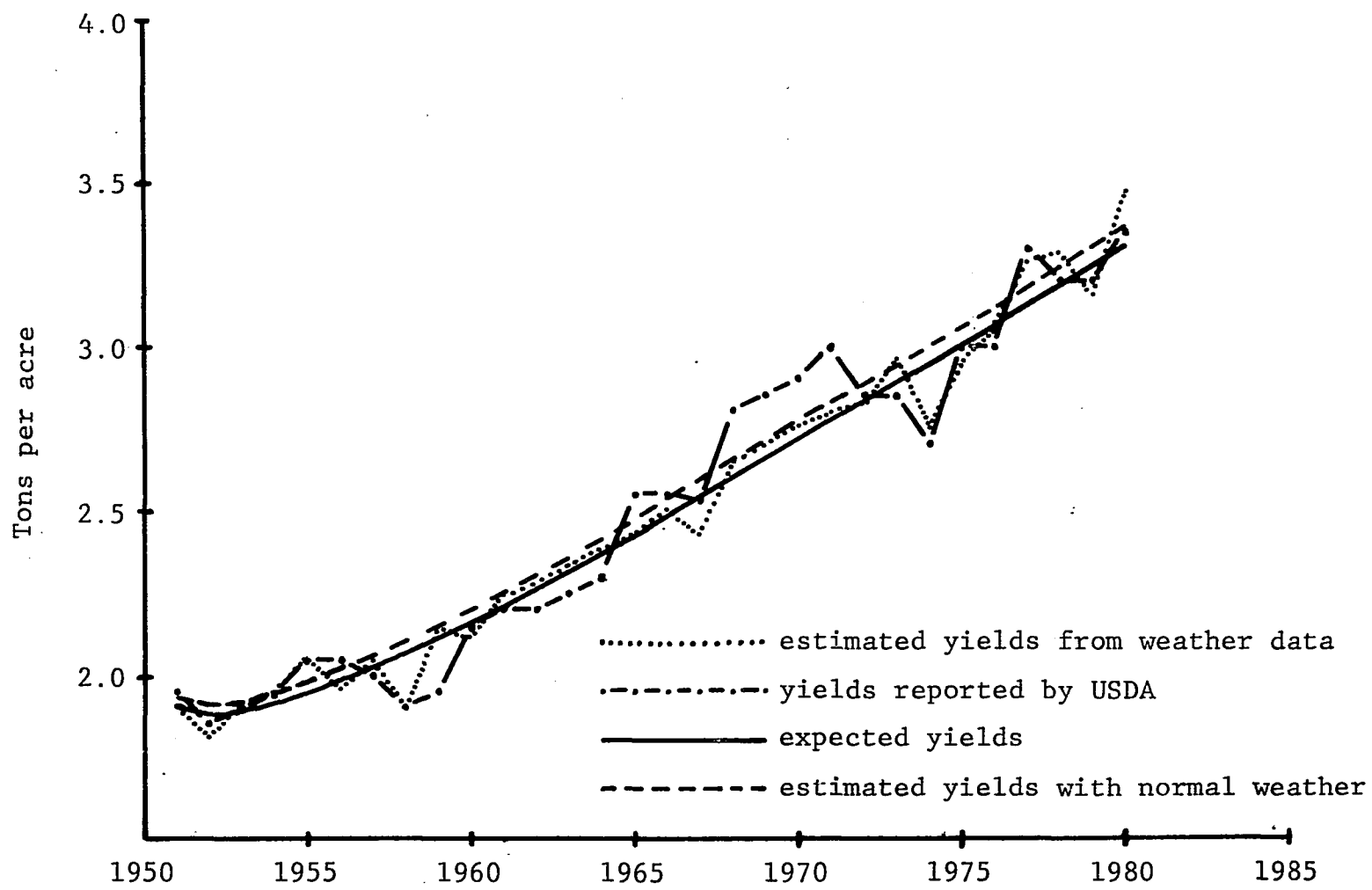
Figure 5.7. Wheat yields per acre in Indiana, 1951-1981

Figure 5.8. Meadow yields per acre in Indiana, 1951-1980

$$\hat{C} = 46.3318 + 11.5886 \ (\ln t) + 0.006973 \ (\hat{N}.t)$$
$$(12.235) \qquad\qquad\qquad (6.456)$$

$$+ \ 1.1081 \ (DPRESP) - 0.1711 \ (DPRESP)^2$$
$$(4.395) \qquad\qquad (3.834)$$

$$+ \ 1.2683 \ (DJUNET) + 4.3992 \ (DJULYR)$$
$$(3.154) \qquad\qquad (5.948)$$

$$- \ 0.5765 \ (DJULYR)^2 \qquad\qquad\qquad\qquad (5.3b)$$
$$(1.616)$$

$$\hat{S} = 0.1352 \ (\hat{C}) + 0.6609 \ (\ln \hat{C}) - 0.1844 \ (t)$$
$$(9.540) \qquad\quad (3.338) \qquad\qquad (5.042)$$

$$+ \ 0.7572 \ (\ln t) \qquad\qquad\qquad\qquad (5.3c)$$
$$(2.625)$$

$$\hat{B} = 21.9871 + 0.546 \ (t) + 0.1958 \ (DPRESP)$$
$$(35.005) \ (16.434) \qquad\quad (2.808)$$

$$- \ 0.0588 \ (DPRESP)^2 + 0.5001 \ (DJUNET)$$
$$(4.883) \qquad\qquad\quad (4.628)$$

$$+ \ 1.2581 \ (DJULYR) + 0.2888 \ (DJULYT)$$
$$(5.762) \qquad\qquad\quad (2.454)$$

$$+ \ 0.6044 \ (DAUGR) + 0.2126 \ (DAUGT) \qquad (5.3d)$$
$$(4.009) \qquad\qquad\quad (1.771)$$

$$\hat{O} = 30.8683 + 1.0995 \ (t) - 0.0621 \ (DPRESP)^2$$
$$(22.032) \ (15.809) \qquad\quad (2.663)$$

$$+ \ 0.6838 \ (DJULYR) + 0.3057 \ (DJULYR)^2 \ (5.3e)$$
$$(1.730) \qquad\qquad\quad (3.952)$$

$$\hat{M} = 2.1215 + 0.05752 \ (t) + 0.01698 \ (DPRESP)$$
$$(31.075) \ (16.383) \qquad (2.779)$$

$$- \ 0.004609 \ (DPRESP)^2 + 0.09529 \ (DJULYR)$$
$$(3.873) \qquad (4.605)$$

$$- \ 0.03146 \ (DJULYR)^2 + 0.06619 \ (DAUGR) \qquad (5.3f)$$
$$(3.661) \qquad (4.625)$$

where:

O = average oat yield in bushels per acre; and all
other variables are defined as they were for
Illinois.

The weighted R^2 value for this system is .990, and the

weighted MSE for this system is 1.877. In Figures 5.9-

5.13, corn, silage, soybean, oat, and meadow yields, as

reported by USDA, along with yields projected with both

actual and normal weather, along with expected yields, are

plotted over time for Iowa.

Missouri

The system of equations for Missouri is estimated

as follows:

$$\hat{N} = 55.0046 - 0.2795 \ (PR) + 0.4320 \ (Z2)$$
$$(1.921) \quad (1.326) \qquad (8.747)$$

$$+ \ 11.3538 \ (Z3) - 1.1308 \ (DPRESP) \qquad (5.4a)$$
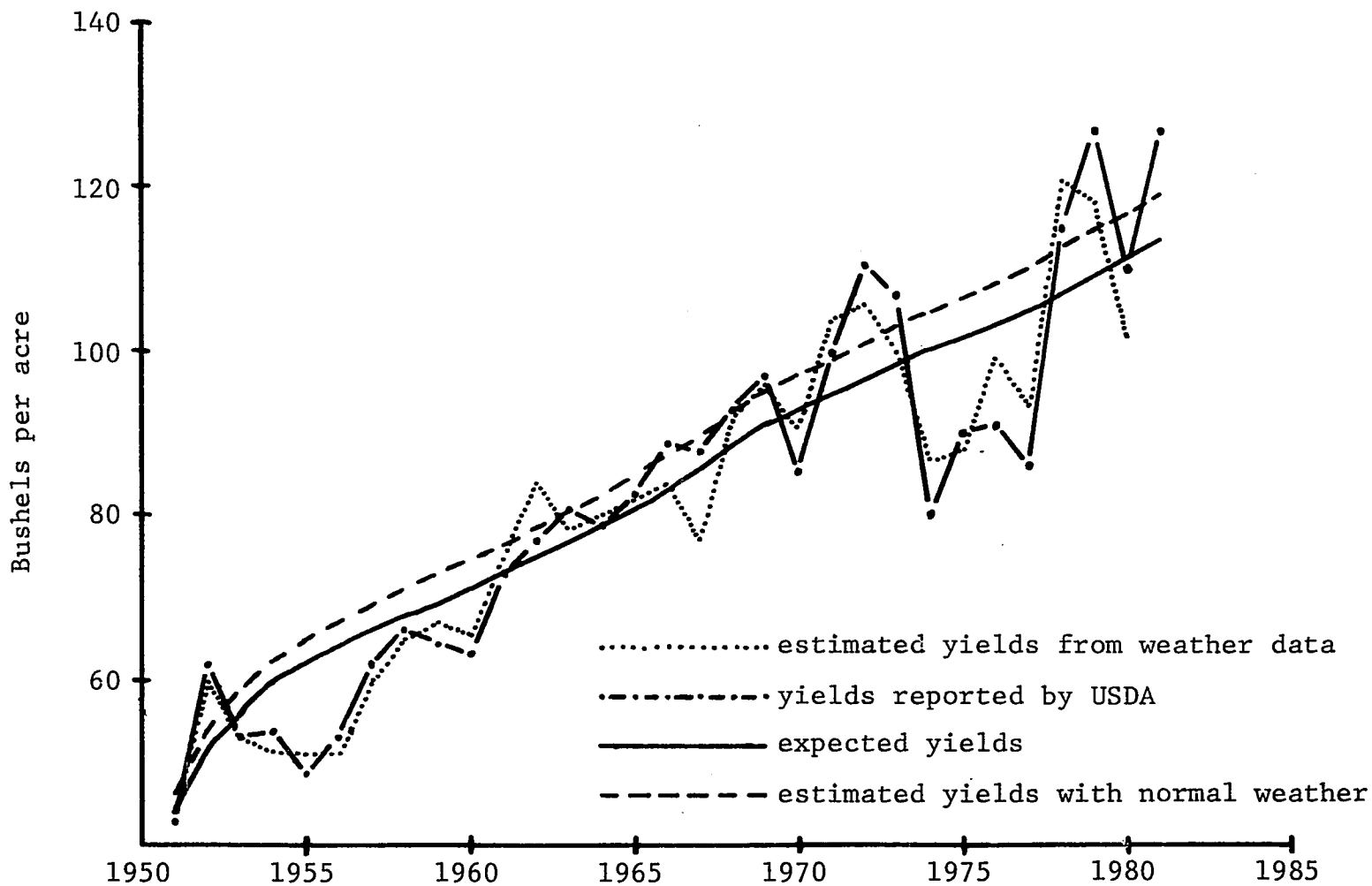$$(10.495) \qquad (1.625)$$

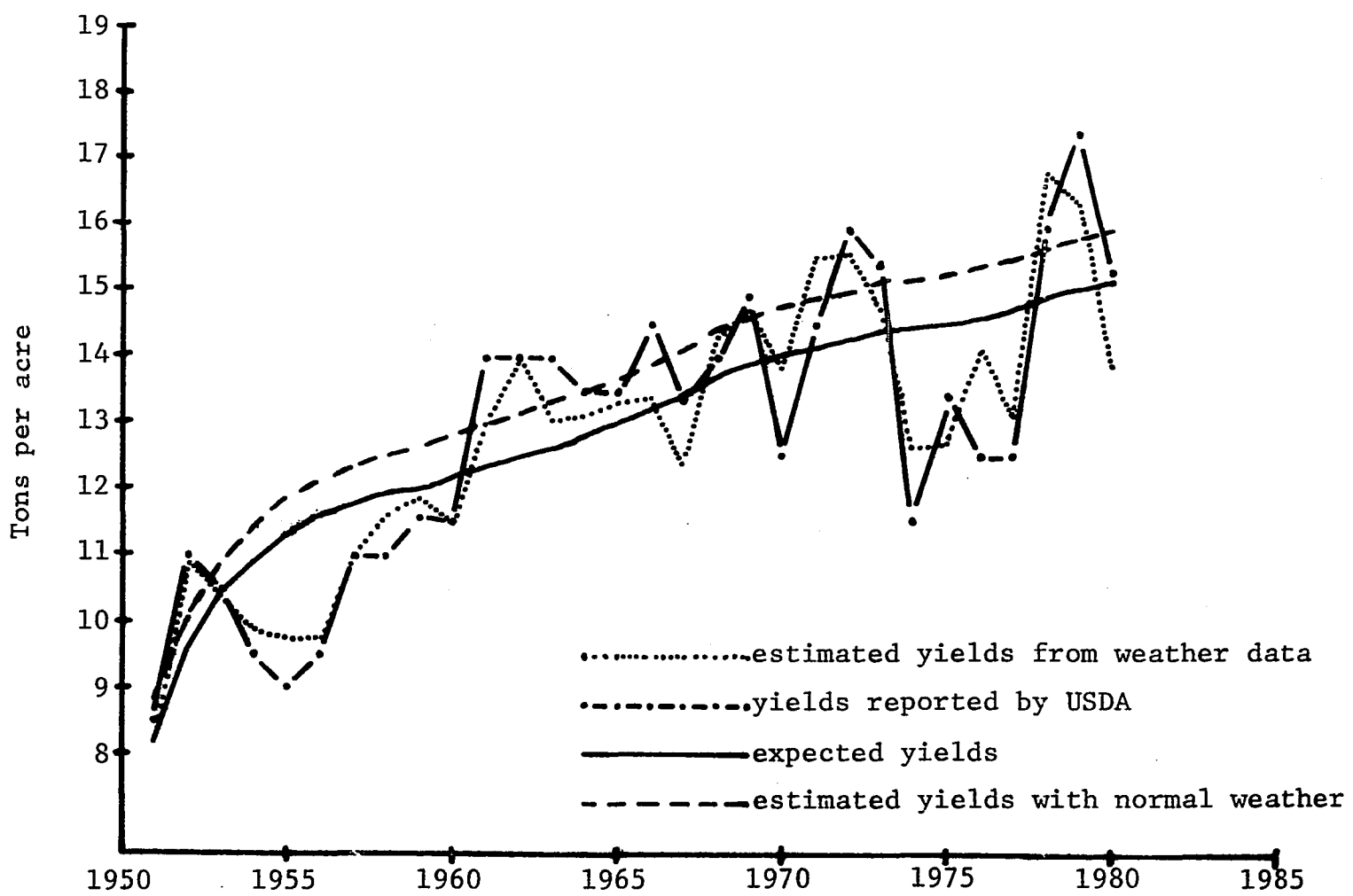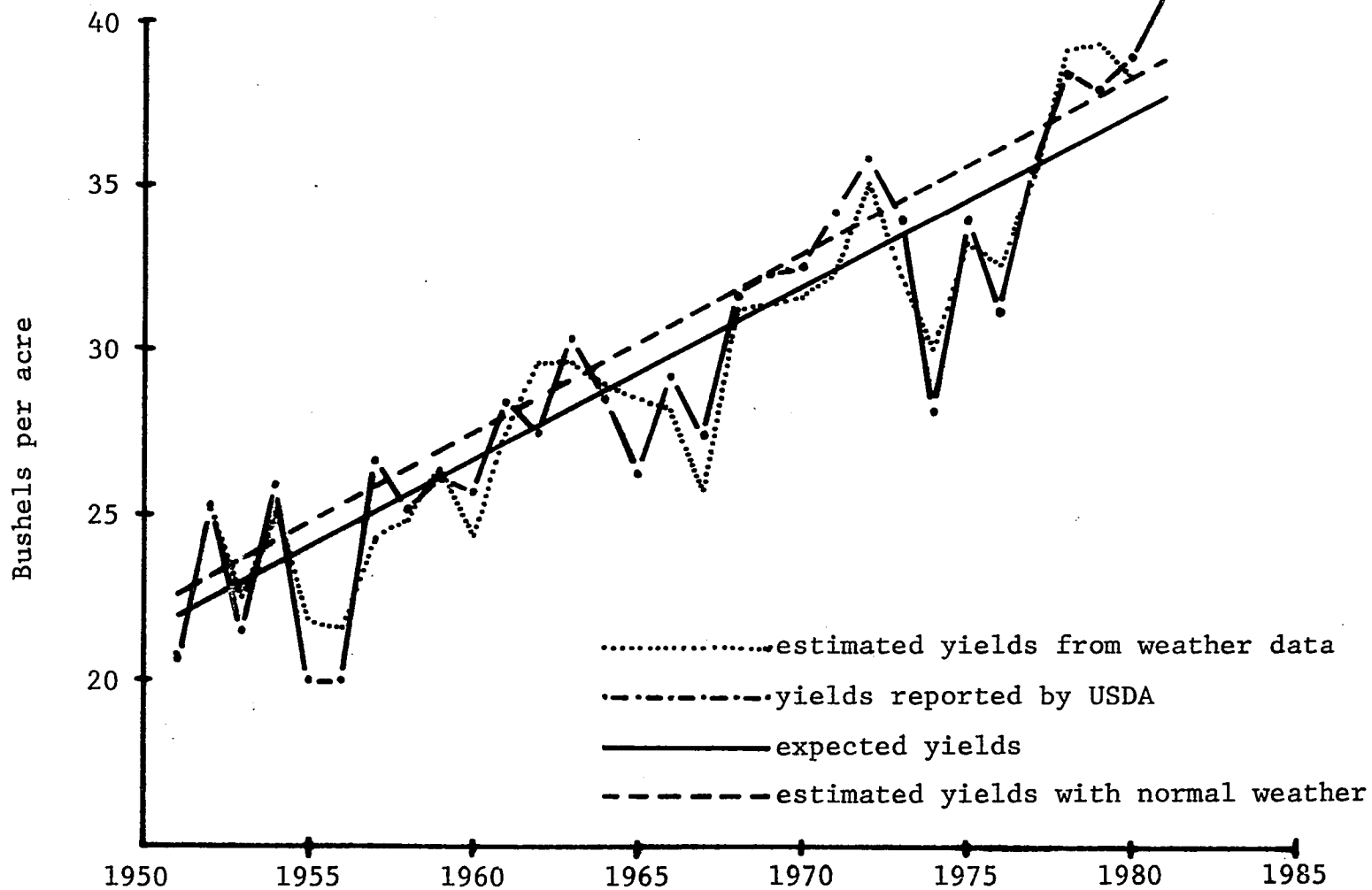Figure 5.9. Corn yields per acre in Iowa, 1951-1981

Figure 5.10. Silage yields per acre in Iowa, 1951-1980

Figure 5.11.   Soybean yields per acre in Iowa, 1951-1981
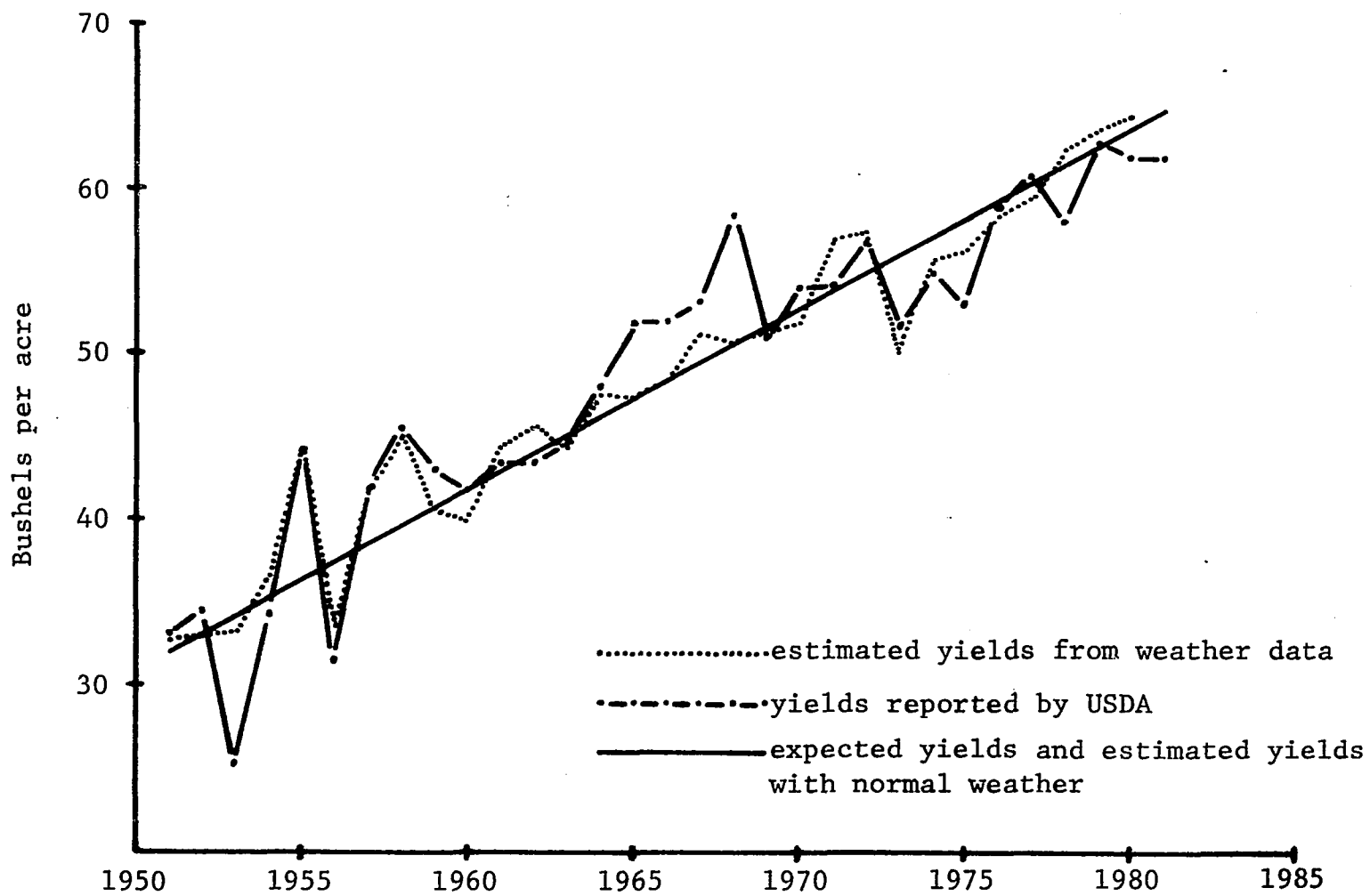
Figure 5.12.   Oat yields per acre in Iowa, 1951-1981

Tons per acre

4.0

3.5

3.0

2.5

2.0

·················estimated yields from weather data

—·—·—·—·—·yields reported by USDA

————————expected yields

— — — — — —estimated yields with normal weather

1950   1955   1960   1965   1970   1975   1980   1985
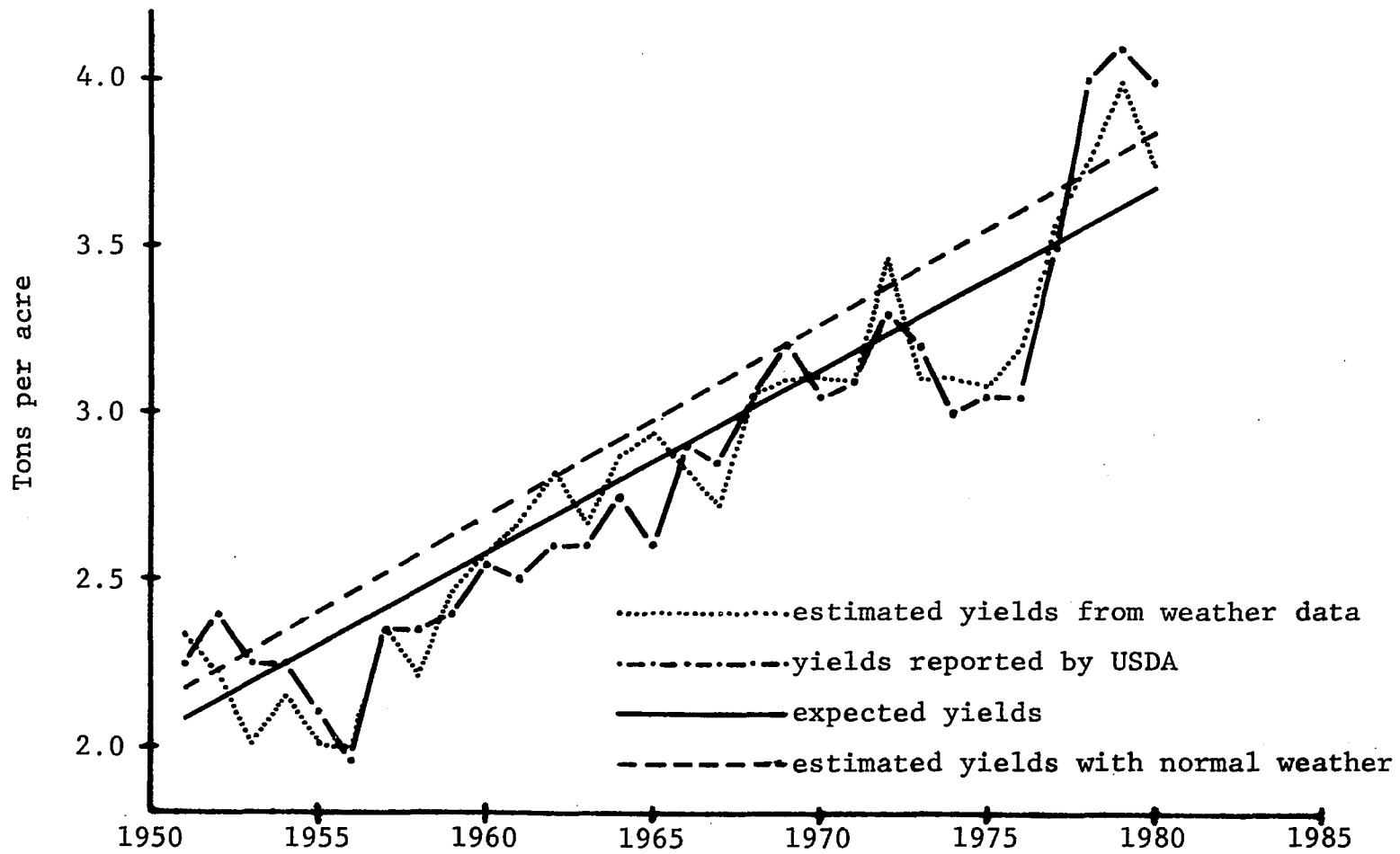
Figure 5.13.   Meadow yields per acre in Iowa, 1951-1980

$$\hat{C} = 28.4306 + 12.7170 \ (\ln t) + 0.001192 \ (\hat{N} \cdot t)$$
$$(6.918) \quad (6.534) \qquad\qquad (2.260)$$

$$+ \ 0.5253 \ (DPRESP) + 0.9954 \ (DJUNET)$$
$$(2.452) \qquad\qquad (2.538)$$

$$+ \ 4.6739 \ (DJULYR) - 0.7299 \ (DJULYR)^2$$
$$(6.255) \qquad\qquad (5.051)$$

$$- \ 1.7059 \ (DJULYT) + 1.4733 \ (DAUGR)$$
$$(3.936) \qquad\qquad (1.831)$$

$$- \ 0.8738 \ (DAUGT) \qquad\qquad\qquad\qquad (5.4b)$$
$$(1.772)$$

$$\hat{S} = 0.1022 \ (\hat{C}) + 0.0782 \ (\ln \hat{C}) - 0.03793 \ (t) \qquad (5.4c)$$
$$(10.953) \qquad (8.385) \qquad\qquad (2.269)$$

$$\hat{B} = 20.3279 + 0.3032 \ (t) + 0.2540 \ (DPRESP)$$
$$(24.673) \quad (7.260) \qquad (3.609)$$

$$- \ 0.01916 \ (DPRESP)^2 + 0.5993 \ (DJUNET)$$
$$(3.440) \qquad\qquad (4.702)$$

$$- \ 0.1356 \ (DJUNET)^2 + 0.7984 \ (DJULYR)$$
$$(4.847) \qquad\qquad (4.404)$$

$$+ \ 0.6439 \ (DAUGR) \qquad\qquad\qquad\qquad (5.4d)$$
$$(2.883)$$

$$\hat{W} = 16.7219 + 5.8684 \ (\ln t) - 0.3234 \ (DPRESP) \qquad (5.4e)$$
$$(9.198) \quad (8.476) \qquad\qquad (3.304)$$

$$\hat{M} = 2.4512 - 0.0145 \ (t) + 0.163 \ (\ln t)$$
$$\phantom{\hat{M} = } (16.096) \quad (1.688) \quad\quad (1.738)$$

$$+ \ 0.02153 \ (DPRESP) - 0.000794 \ (DPRESP)^2$$
$$ (3.070) \quad\quad\quad\quad (1.203)$$

$$- \ 0.005338 \ (DJUNET)^2 + 0.05155 \ (DJULYR)$$
$$ (1.794) \quad\quad\quad\quad\quad (2.804)$$

$$- \ 0.03169 \ (DJULYT) + 0.007099 \ (DJULYT)^2$$
$$ (2.237) \quad\quad\quad\quad\quad (2.172)$$

$$+ \ 0.05649 \ (DAUGR) - 0.02302 \ (DAUGT) \quad (5.4f)$$
$$ (2.340) \quad\quad\quad\quad (1.425)$$

The variables in this model are defined exactly as they were for Illinois. The weighted R^2 for this system is .985 and the weighted MSE is 1.413. In Figures 5.14-5.17, corn, soybean, wheat, and meadow yields, as reported by USDA, along with yields projected with both actual and normal weather, along with expected yields, are plotted over time for Missouri.

Ohio

The system of equations for Ohio is estimated as follows:

$$\hat{N} = 40.1144 - 0.1097 \ (PR) + 0.2766 \ (Z2) + 6.8824 \ (Z3)$$
$$\phantom{\hat{N} = } (3.735) \quad (1.490) \quad\quad (15.791) \quad\quad (21.955)$$

$$- \ 1.1371 \ (DPRESP) - 0.1024 \ (DPRESP)^2 \quad (5.5a)$$
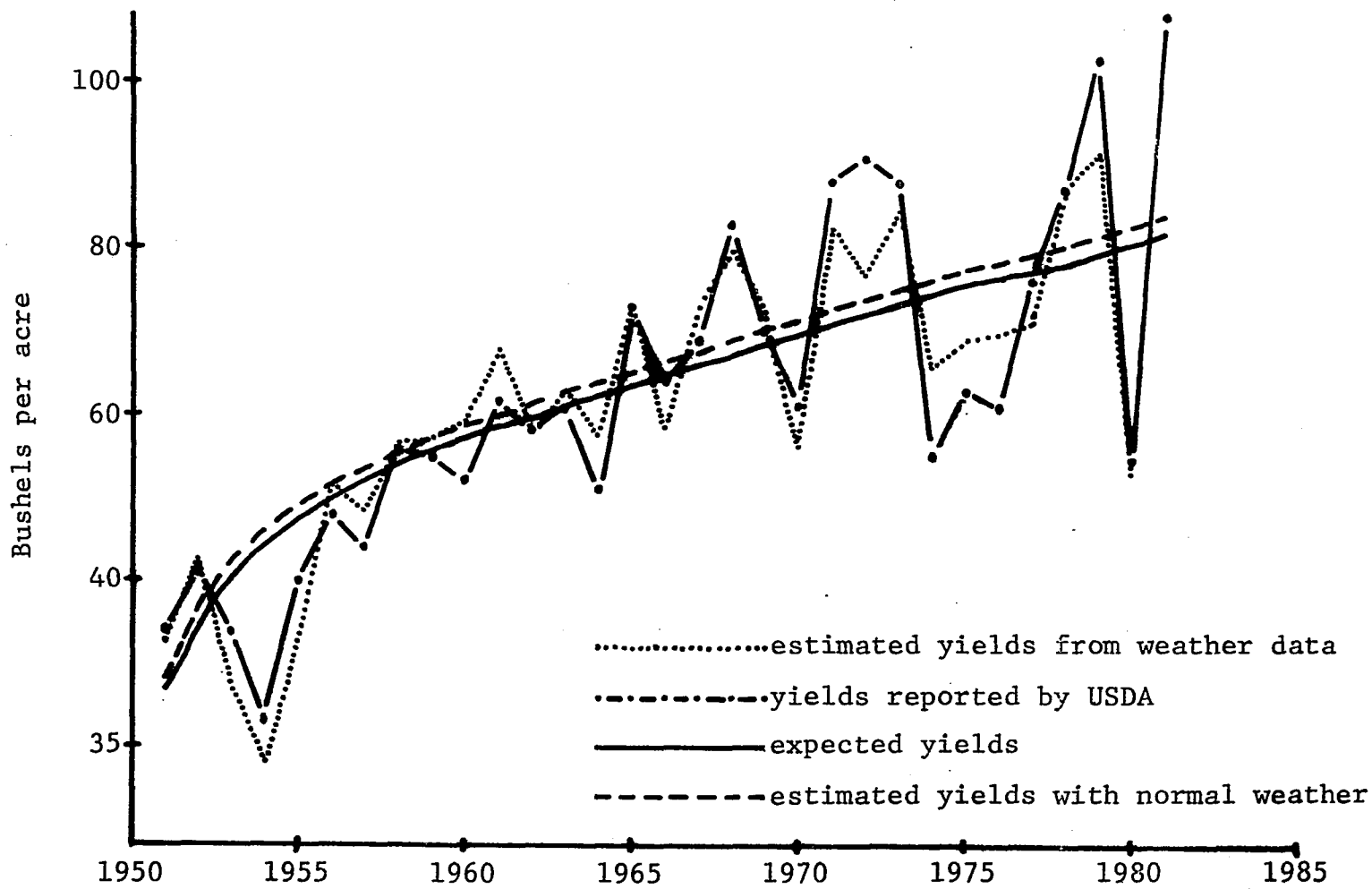$$ (3.902) \quad\quad\quad\quad (1.398)$$

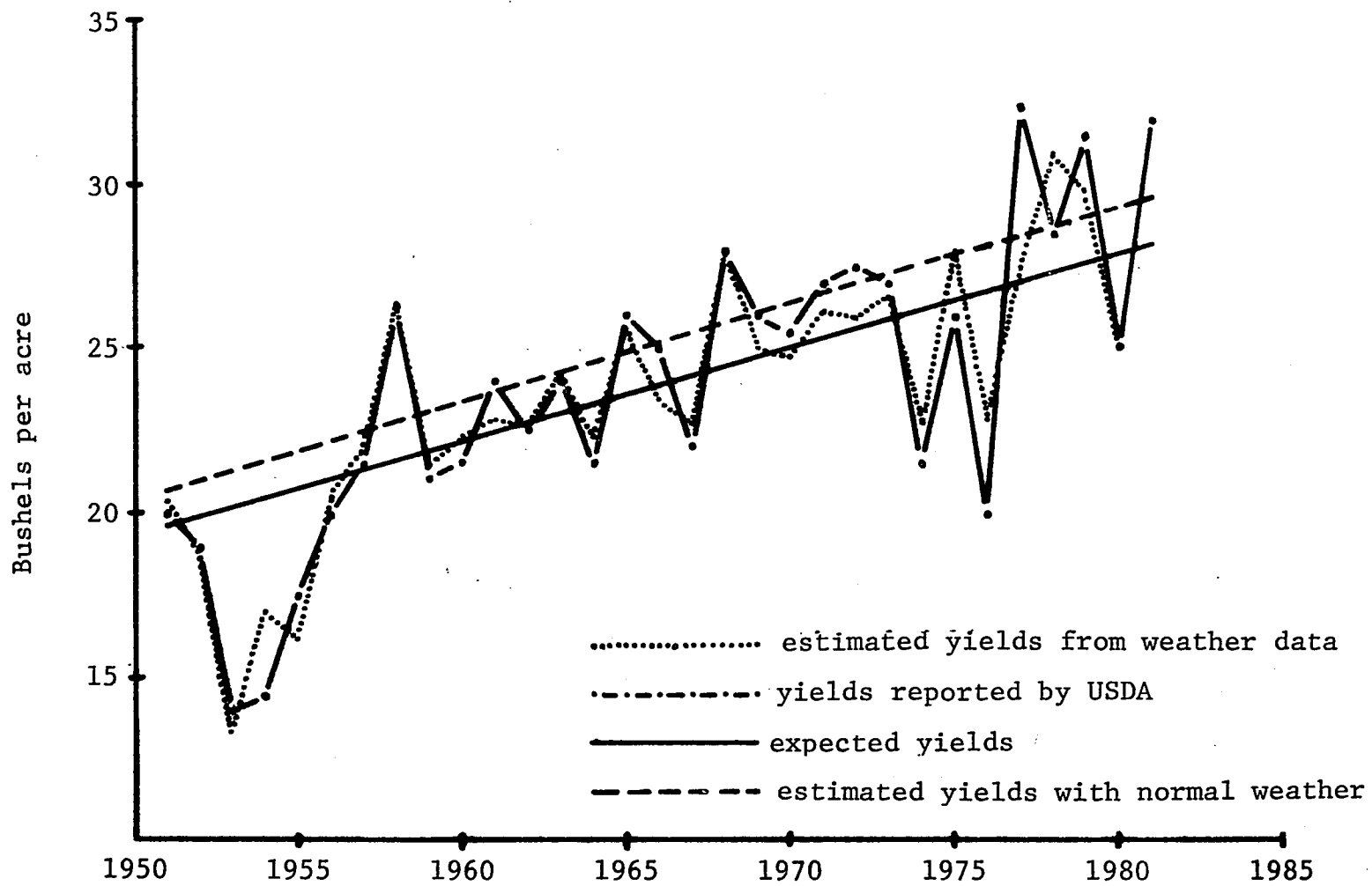Figure 5.14.   Corn yields per acre in Missouri, 1951-1980
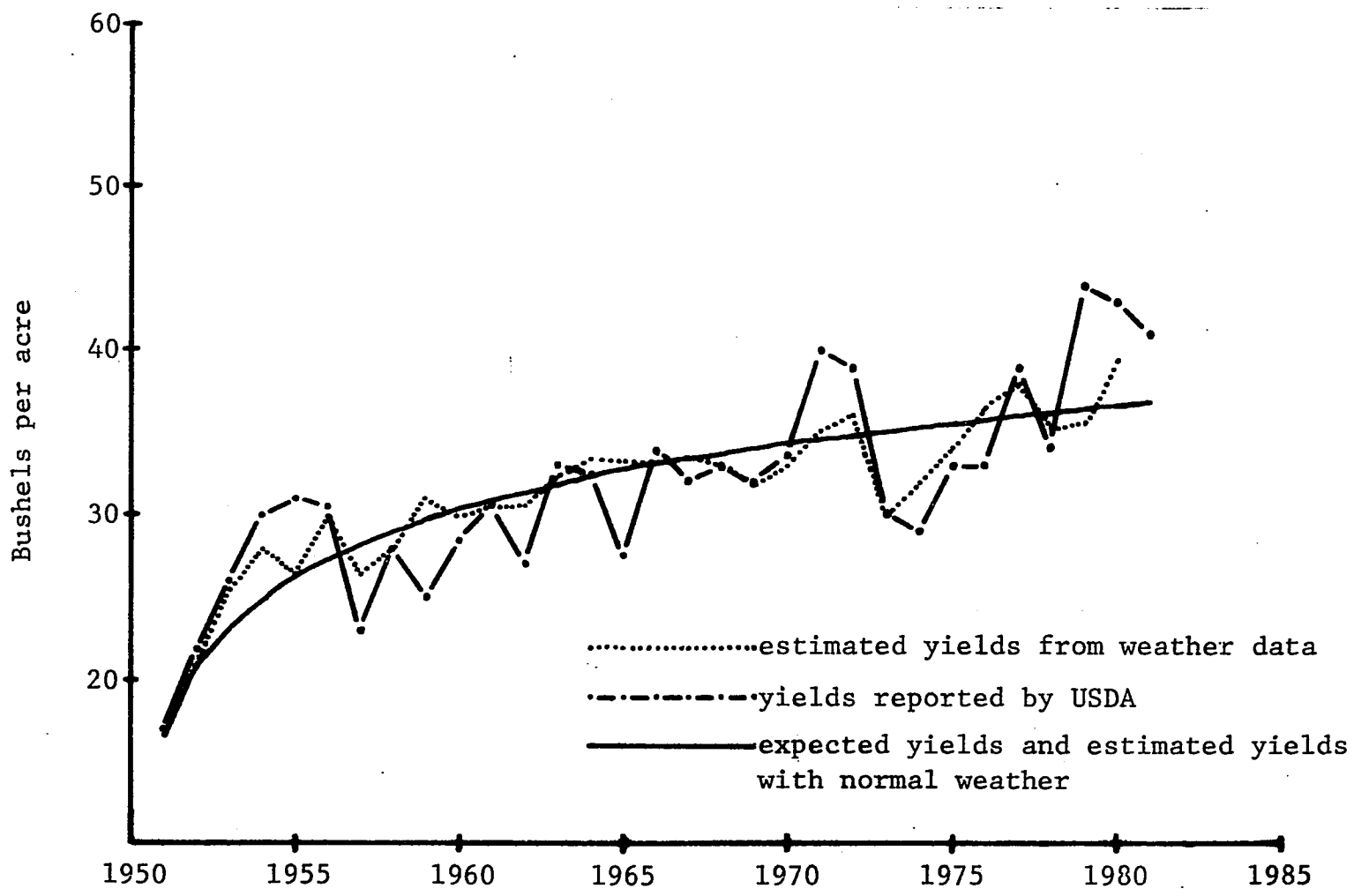
Figure 5.15.   Soybean yields per acre in Missouri, 1951-1981

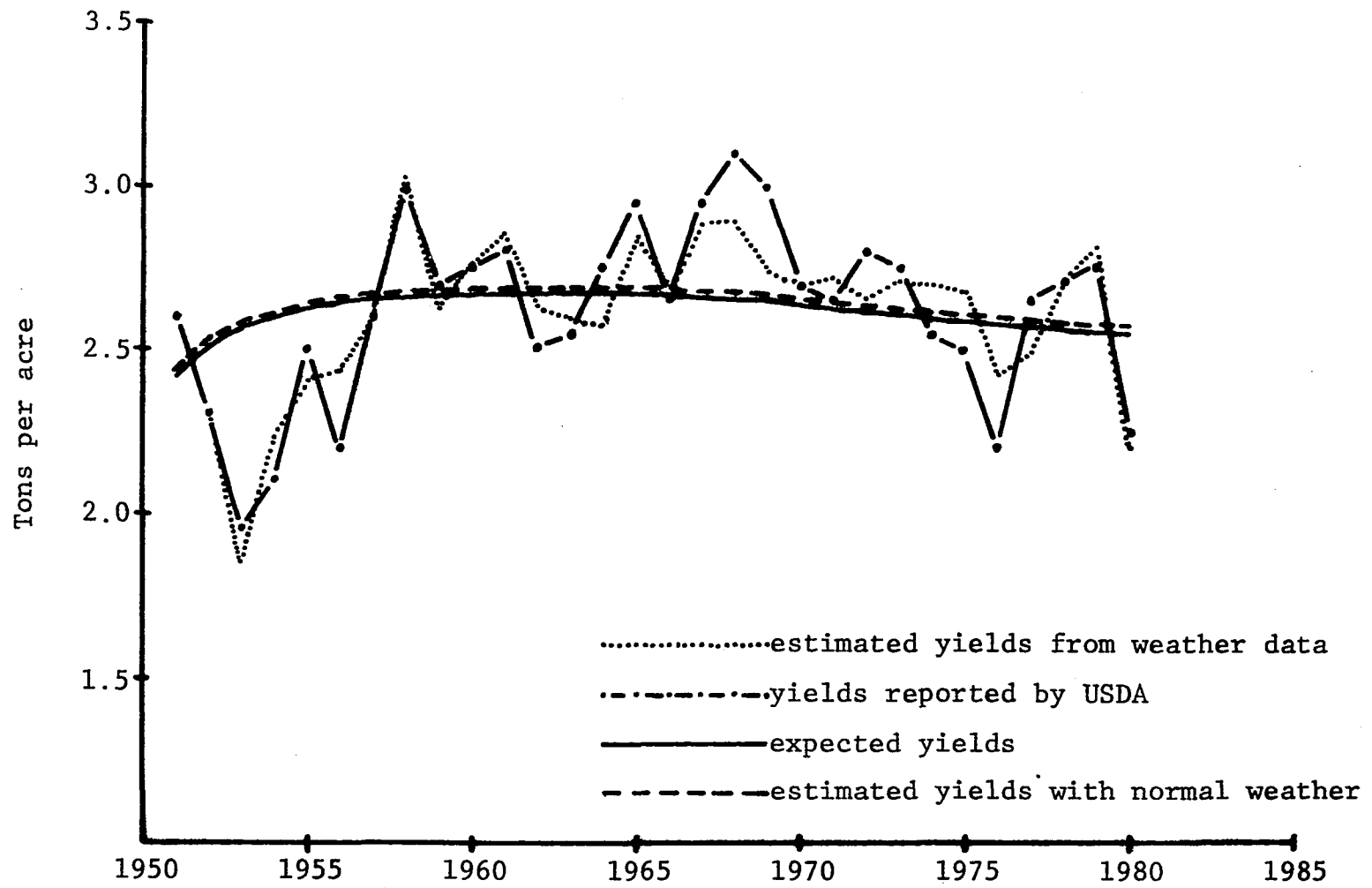Figure 5.16. Wheat yields per acre in Missouri, 1951-1981

Figure 5.17. Meadow yields per acre in Missouri, 1951-1980

$$\hat{C} = 63.8154 + 0.008296 \ (\hat{N} \cdot t) - 0.4253 \ (DPRESP)$$
$$(44.123) \quad (19.362) \qquad\qquad (1.888)$$

$$- 0.1066 \ (DPRESP)^2 - 0.4902 \ (DJUNET)$$
$$(2.149) \qquad\qquad (1.345)$$

$$+ 3.5174 \ (DJULYR) - 1.5875 \ (DJULYR)^2$$
$$(4.951) \qquad\qquad (4.802)$$

$$- 1.2306 \ (DAUGT) \qquad\qquad\qquad (5.5b)$$
$$(3.600)$$

$$\hat{S} = 0.09837 \ (\hat{C}) + 0.9851 \ (\ln \hat{C}) - 0.1308 \ (t)$$
$$(3.113) \qquad\quad (2.188) \qquad\qquad (1.702)$$

$$+ 0.8786 \ (\ln t) \qquad\qquad\qquad (5.5c)$$
$$(1.713)$$

$$\hat{B} = 28.0697 + 0.5982 \ (t) - 3.6042 \ (\ln t)$$
$$(15.642) \quad (5.207) \qquad\quad (3.079)$$

$$- 0.1599 \ (DPRESP) - 0.0598 \ (DPRESP)^2$$
$$(1.724) \qquad\qquad (2.377)$$

$$+ 1.5233 \ (DJULYR) - 0.4581 \ (DJULYR)^2$$
$$(4.510) \qquad\qquad (3.659)$$

$$+ 1.1298 \ (DAUGR) \qquad\qquad\qquad (5.5d)$$
$$(3.659)$$

$$\hat{W} = 21.9429 + 0.8017 \ (t) - 0.5043 \ (DPRESP)$$
$$(16.953) \quad (13.047) \qquad\quad (3.345)$$

$$- 0.0594 \ (DPRESP)^2 + 0.2388 \ (DJUNET)^2 \ (5.5e)$$
$$(1.751) \qquad\qquad (3.208)$$

$$\hat{M} = \underset{(19.364)}{2.0942} + \underset{(10.039)}{0.06569} \ (t) - \underset{(4.116)}{0.2823} \ (\ln t)$$

$$- \underset{(1.133)}{0.001656} \ (DPRESP)^2 + \underset{(1.022)}{0.01924} \ (DJULYR)$$

$$- \underset{(2.310)}{0.01937} \ (DJULYR)^2 + \underset{(3.488)}{0.06418} \ (DAUGR) \qquad (5.5f)$$

The variables of this model are also defined exactly as they were for Illinois. The weighted R^2 for this system is .989 and the weighted MSE is 1.283. In Figures 5.18-5.21, corn grain, soybeans, wheat, and meadow yields, as reported by USDA, along with yields projected with both actual and normal weather, along with expected yields, are plotted over time for Ohio.

Autocorrelation

Each of the models is tested for autocorrelation by computing the residuals over time for each equation and by regressing the residuals on their lagged values. Two-tailed t-tests are used to test if the autocorrelation coefficients are significant. With the sporadic exceptions of the meadow equation in the Illinois model, the nitrogen equation in the Indiana model, the soybean equation in the Missouri model, and the silage and wheat equations in the Ohio model, there is no evidence of first order
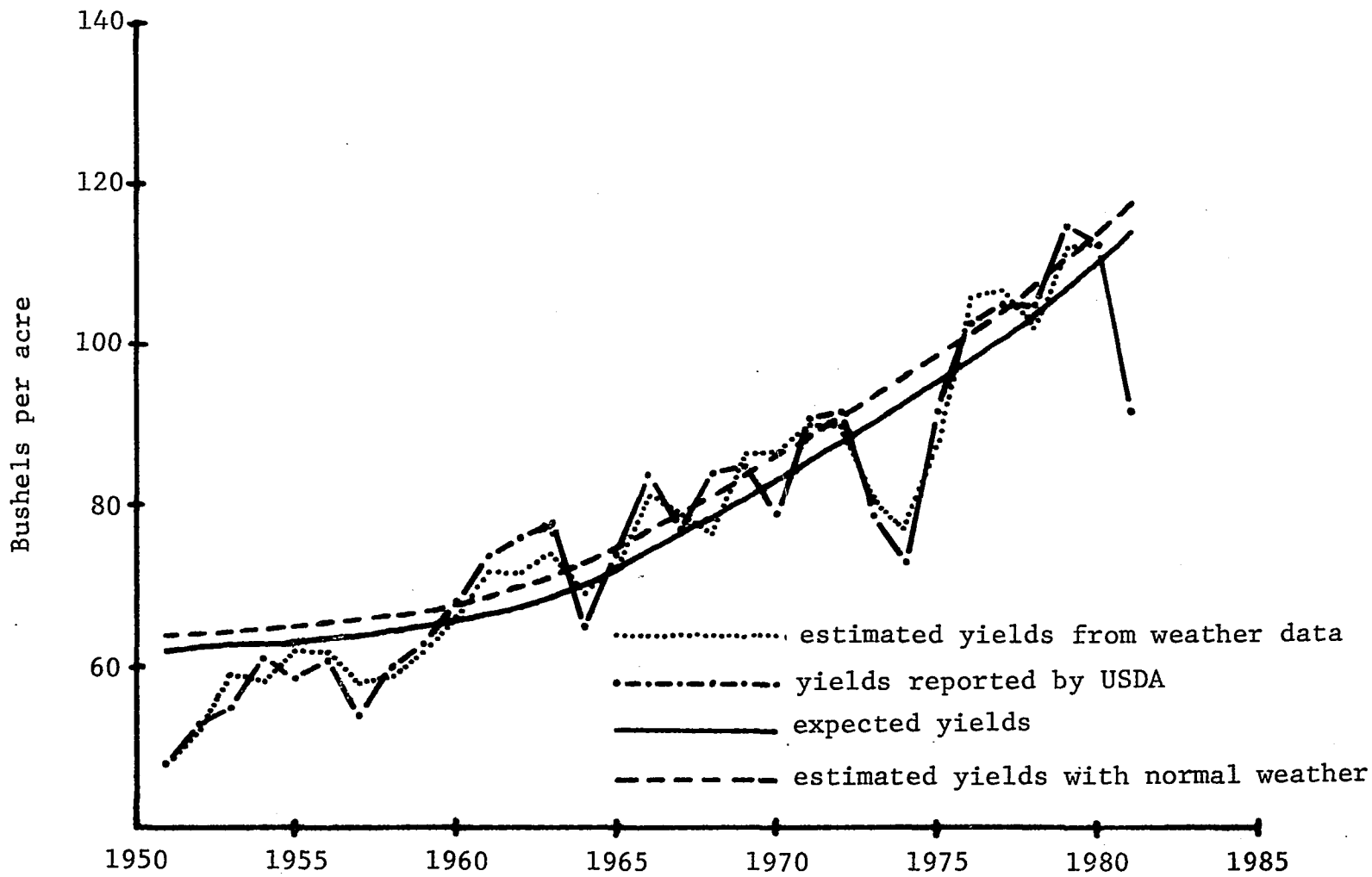
Figure 5.18.   Corn yields per acre in Ohio, 1951-1981
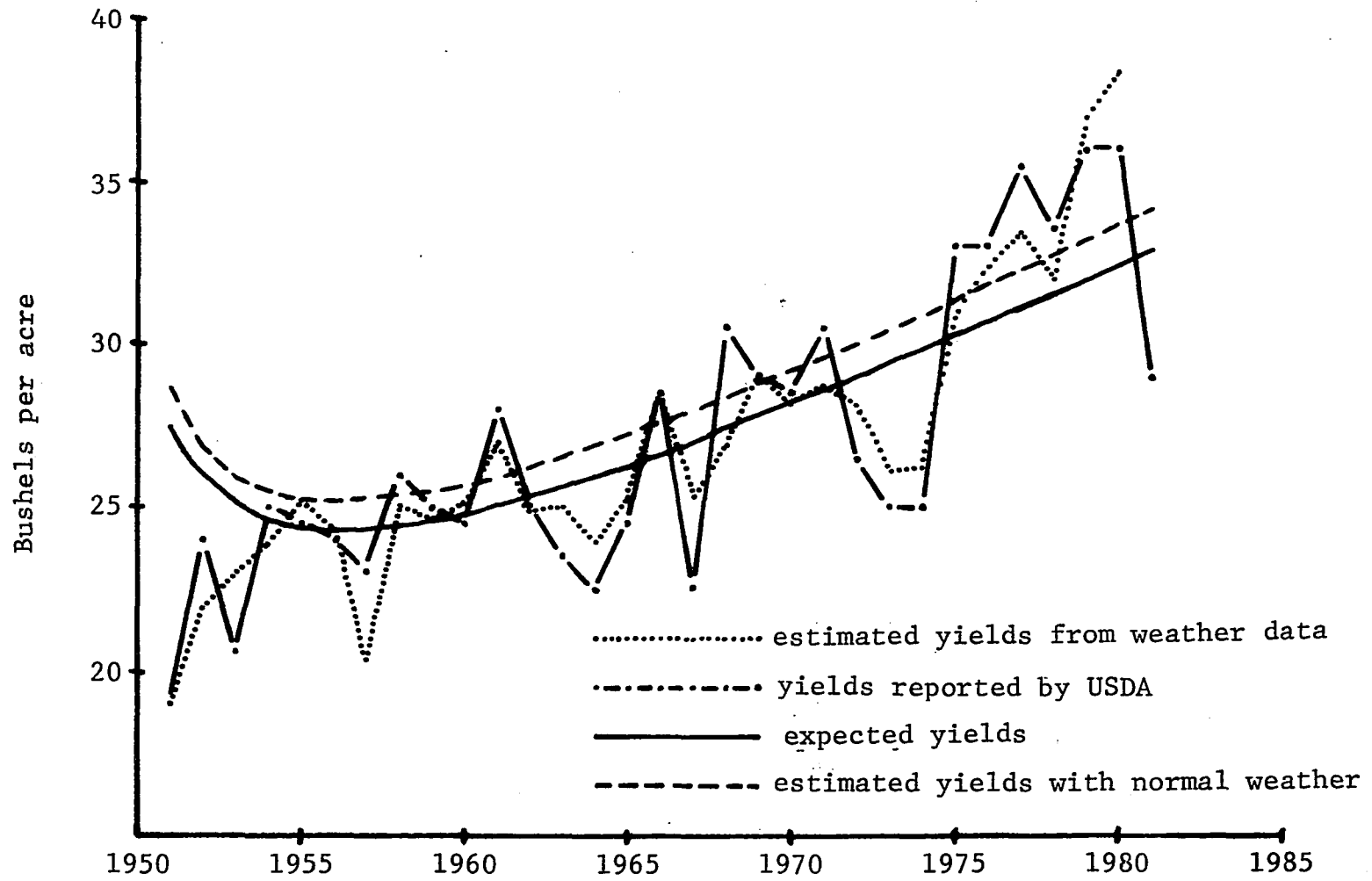
Figure 5.19.   Soybean yields per acre in Ohio, 1951-1981
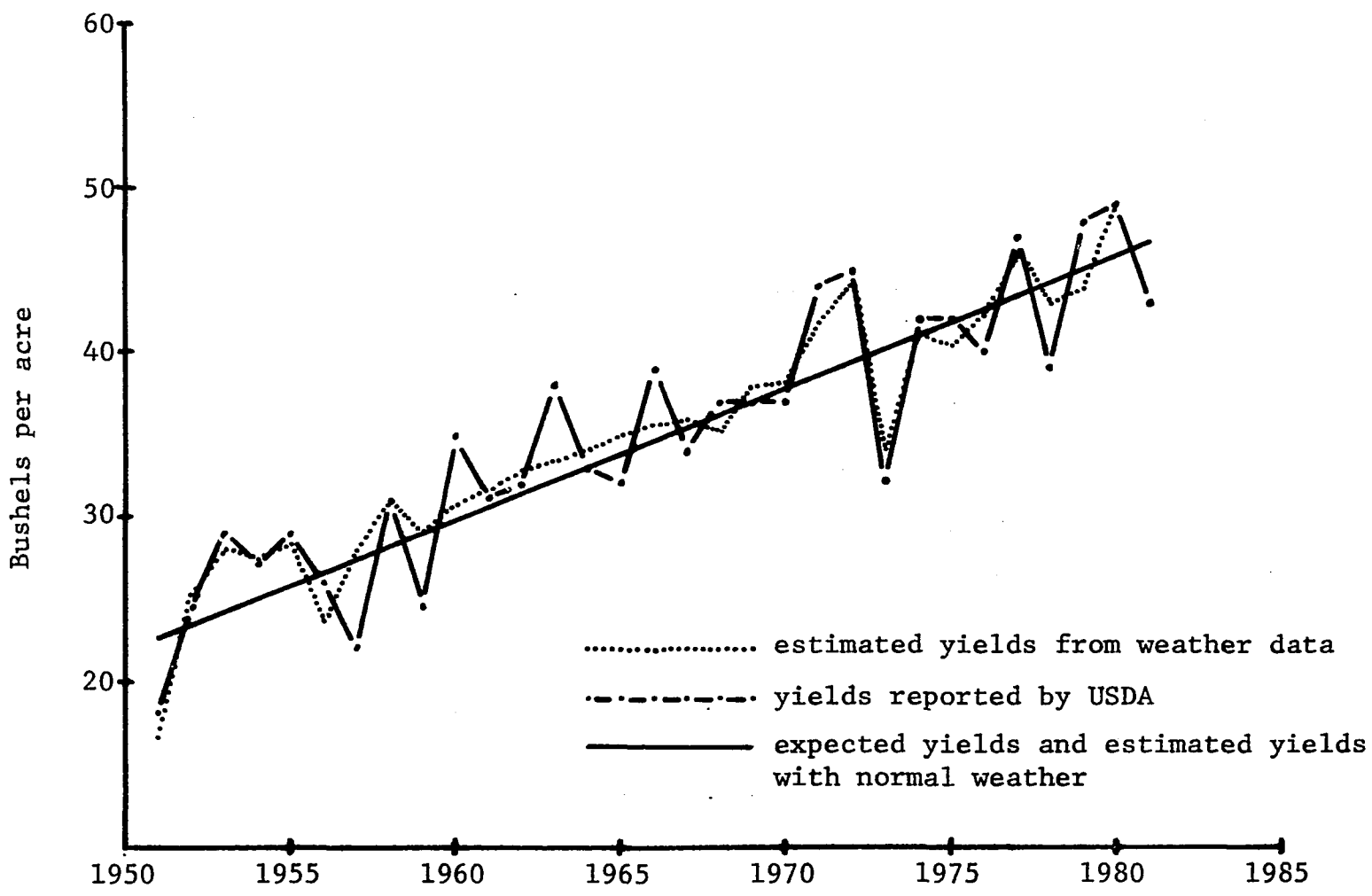
Figure 5.20.   Wheat yields per acre in Ohio, 1951-1981

4.0 ········· estimated yields from weather data

········· yields reported by USDA

━━━━━ expected yields

━ ━ ━ ━ estimated yields with normal weather

Figure 5.21.   Meadow yields per acre in Ohio, 1951-1980

autocorrelation in the residuals of each of the six equations of all five models at the 10 percent level of probability.

CHAPTER VI. PROSPECTS OF FAVORABLE
FUTURE WEATHER

As can be seen in the models and in Figures 5.1-5.21,
outside of technological progress, weather explains most
of the year-to-year variance in Corn Belt crop yields.
The weather variables used in these models are crude at
best. If more biologically accurate and refined weather
variables could be developed and used in models of this
type, it is almost certain that even more of the variance
in yields could be explained. Of course, such things as
abnormal pest or disease problems can and do affect yields
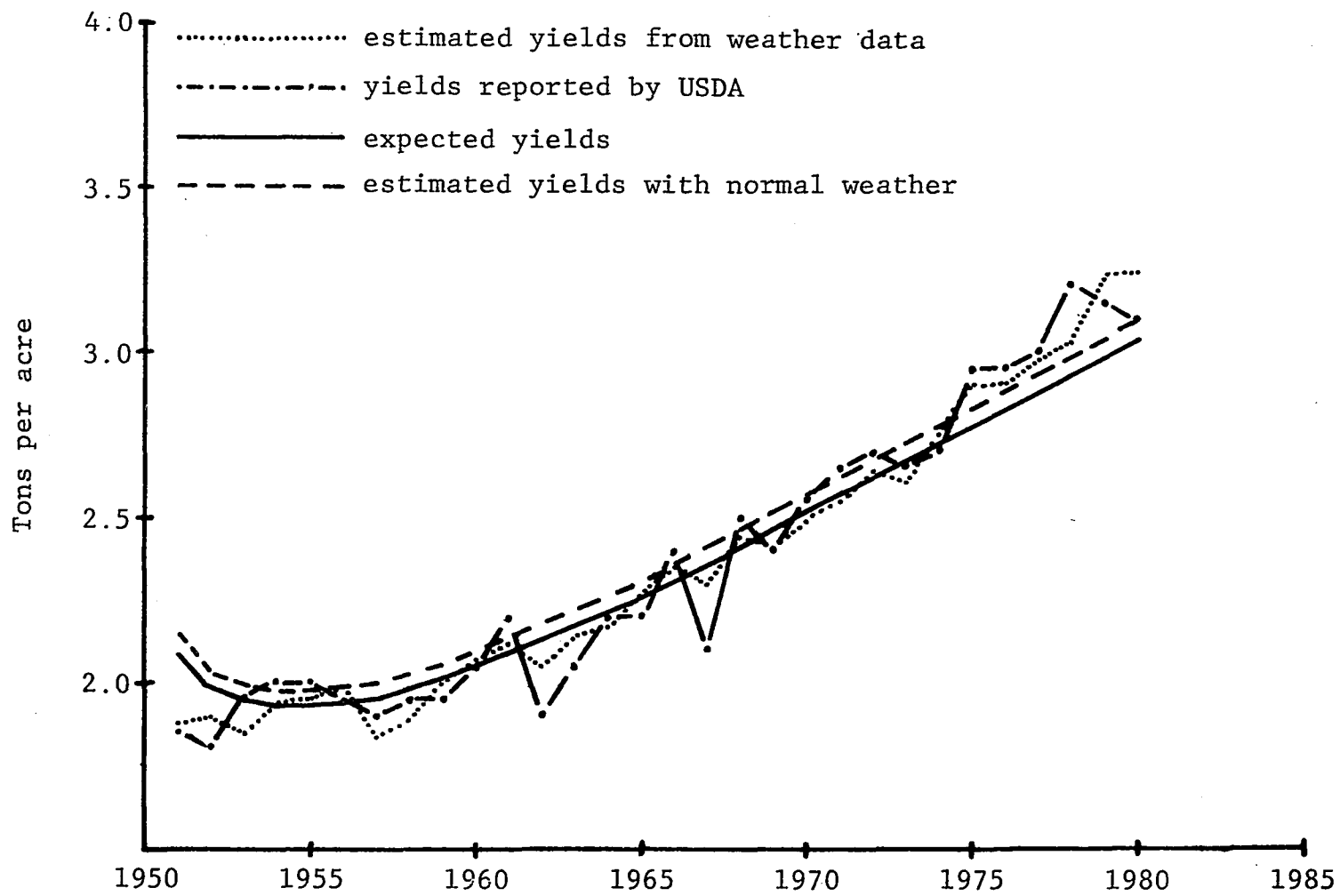(even some of these problems are correlated with weather)
but, due to developments and improvements in agricultural
chemicals and field husbandry, their effects on yields are
generally minimal compared to the effects of weather.

For example, in the mid-1970s the dramatic drop in
yields that caused much concern that yields were leveling
off as a result of yield barriers, high energy prices or
other reasons, can be explained almost entirely by abnormally
poor weather. As can be seen in Figures 5.1-5.21, the vola-
tile yields of the 1970s were largely a result of volatile
weather conditions.

Weather Cycles and Projecting Future Weather

As a result of the great importance that weather has
on yields, there is much interest in explaining weather
cycles and projecting yields. In 1969, Louis M. Thompson
pointed out that records in the U.S. Corn Belt show irregular
weather cycles and that the 1930s and 1950s were character-
ized by warm dry summers. He stated that, "if such patterns
persist, one might expect warmer and drier summers in the
U.S. Corn Belt in the '70s and a temporary halt in the up-
trend of corn yields" (Thompson, 1969, p. 456).

In order to try to determine if there is any evidence
to believe that such weather patterns do in fact exist,
the information illustrated in Figures 5.1-5.21 is studied,
and periods that average roughly eleven years in duration
of favorable and unfavorable weather in terms of their
effects on yields are identified. The weather data for
Illinois, Indiana, Iowa, Missouri, and Ohio for the years
1930-1980 are pooled together and total precipitation (TP),
September to June precipitation (PRESP), July rainfall (JULYR),
August rainfall (AUGR), June temperature (JUNET), July
temperature (JULYT), and August temperature (AUGT), are
all regressed on the following dummy variables where:

D = 1 during the years 1942-1952 and 1961-1973;

    = 0 otherwise;

S1 = 1 when the state is Illinois;

    0 otherwise;

S2 = 1 when the state is Indiana;

    0 otherwise;

S4 = 1 when the state is Missouri;

    0 otherwise;

S5 = 1 when the state is Ohio; and

    0 otherwise.

The results of these regressions are summarized in Table 6.1. The first thing that should be noticed is that very little of the variance in weather is explained by weather cycles. However, by using this rather interesting but crude a posteriori analysis, it does appear that over the last 50 years there have been periods that can be characterized as more favorable than average in terms of their effects on crop yields. This is illustrated in Figure 6.1. July temperature and total precipitation for Iowa are plotted over time along with July temperature and total precipitation as projected using the models reported in Table 6.1. It can be seen that the periods during 1930-1941, 1953-1960, and 1974-1980, can be characterized as generally more hot and dry than normal. The periods during

Table 6.1. Results of regressions of weather variables[a]

Dependent variable	Int.	D	S1	S2	S4	S5	R^2
TP	30.461 (37.2)	2.662 (3.9)	5.706 (5.4)	7.877 (7.4)	7.826 (7.3)	5.817 (5.5)	0.262
PRESP	22.867 (29.9)	2.745 (4.4)	6.143 (6.2)	8.218 (8.3)	8.391 (8.4)	6.018 (6.1)	0.311
JULYR	3.440 (16.3)	0.450 (2.6)	-.025 (.1)	0.134 (.5)	-0.213 (.8)	0.242 (.9)	0.038
AUGR	4.153 (20.3)	-0.534 (3.2)	-0.413 (1.6)	-0.475 (1.8)	-0.352 (1.3)	-0.443 (1.7)	0.054
JUNET	70.423 (175.0)	-0.261 (.8)	2.267 (4.3)	1.200 (2.3)	3.637 (7.0)	-0.363 (.7)	0.242
JULYT	75.829 (224.6)	-1.953 (7.0)	1.508 (3.4)	0.284 (.7)	3.602 (8.2)	-1.431 (3.3)	0.441
AUGT	73.375 (212.2)	-1.622 (5.7)	1.978 (4.4)	0.849 (1.9)	4.227 (9.4)	-0.616 (1.4)	0.414

[a] t-values are given in parentheses below the estimated regression coefficients.

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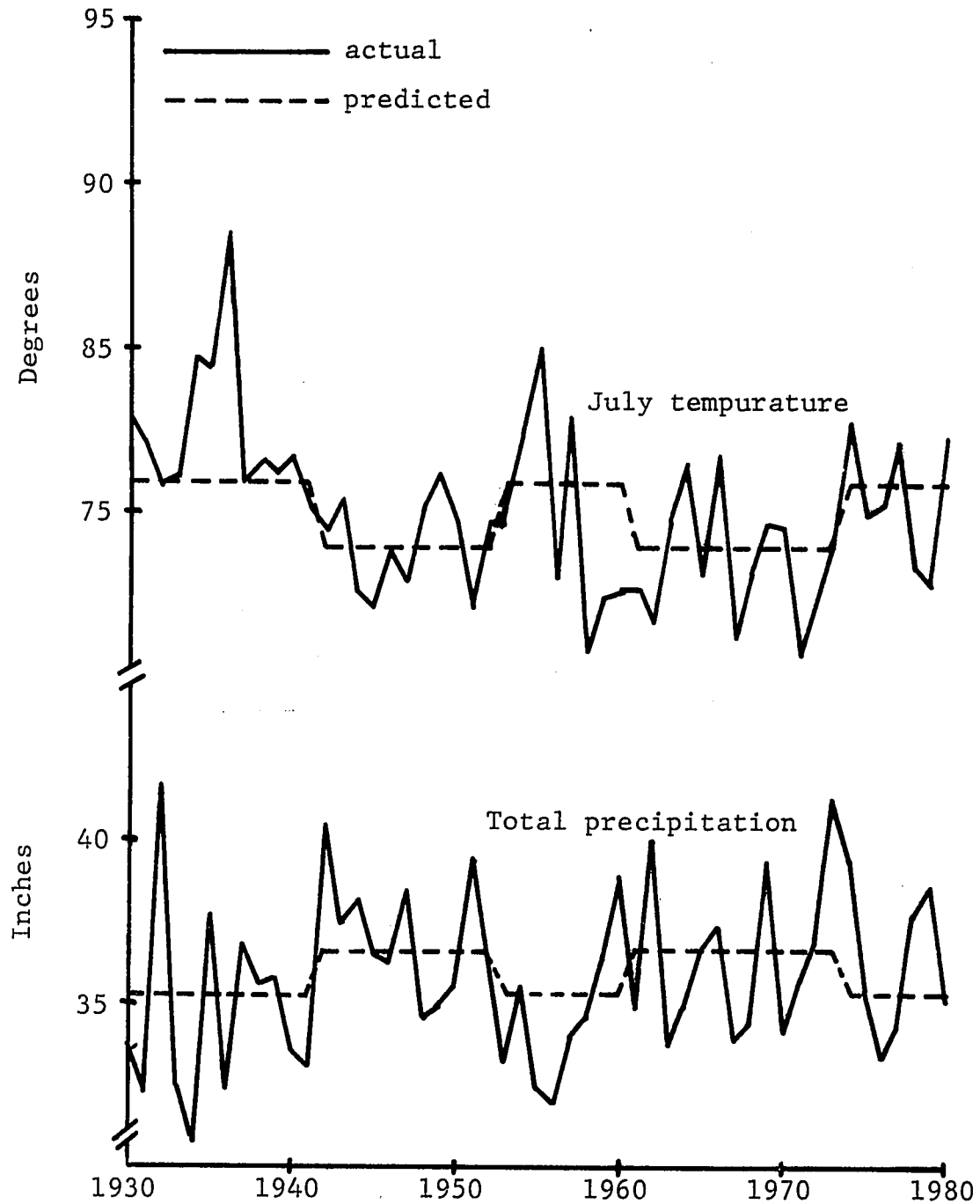
Figure 6.1. Total precipitaion and July tempurature for
Iowa, 1930-1980

1942-1952 and 1961-1973 can be characterized as generally more cool and wet. It can also be seen that a great deal of year-to-year variability is still unexplained.

In conclusion, although weather in the 1970s was very variable in terms of its effects on yields, and on the average not as favorable to crop production as the 1960s, it does not follow that this will continue to be true through the 1980s. In fact, if the past weather cycles continue, there is some reason to hope--not predict--that we will enter into a period of more favorable weather conditions sometime during the next decade. It appears, however, that any attempt to project future weather is at best, a very risky proposition.

CHAPTER VII. PROSPECTS OF FUTURE YIELD INCREASES AS
A RESULT OF TECHNOLOGICAL PROGRESS

For the purposes of this study, a very broad definition of technological progress is used. As already stated in Chapter III, technological progress is defined in this study as the process of developing, learning about, and applying new and better techniques, methods, and inputs which in sum results in increased productivity and yields. Theoretically, this is not a very usable definition of technological progress (Hacche, 1979). However, because this study is not devoted to an analytical analysis of what technological progress is, but rather an analysis of what has been and is causing the general uptrend in yields over time, this general definition of technological progress is used for this study. Schultz (1966, pp. 72-73) points out that, "To attribute it [rises in agricultural productivity] to technology is an empty gesture, a slight of the hand at which economists are all too adept, but it only conceals their ignorance." Therefore, in order to review what types of things are actually involved in causing increased agricultural productivity, i.e., what types of things make up technological progress as defined in this study, a general discussion of the factors involved in causing increased agricultural productivity and yields follows.

Biological Limits to Yields

Opinions vary as to how high yields can go. It is argued by some that there are biological limits to crop yields and that we are nearing those limits now. When one Iowa farmer was asked how high he thought corn yields could go, he said with a smile, "the sky's the limit", optimistically implying that with advances in technology, the yield limits or barriers can be continually broken down or extended.

It is certainly not clear to what extent crop yields can be increased; it is unlikely that they can be increased indefinitely. It does seem clear, however, that there is a great deal of potential left in increasing crop yields over the next ten or twenty years. For example, corn yields around 300 bushels per acre, soybean yields around 100 bushels per acre, and alfalfa hay yields around 15 tons per acre are currently being grown on test plots and by highly skilled and motivated farmers (Elam, 1980, Gogerty, 1981, Henkes, 1981). This certainly does not mean that it is possible for state average crop yields to be that high, but it does show that there is a potential for much higher state average crop yields under the right conditions, under highly skilled and motivated management, and with the right inputs.

When discussing advances in technology with respect to the effects on agricultural productivity and crop yields, an extension agronomist mentioned that nonbiological people often tend to talk about breakthroughs, but in reality, they rarely occur. In general, the increases in yields have come and are coming from gradually improved inputs, management, and conducive economic, social, and political conditions. Just because no so-called breakthrough can not be seen on the horizon, this does not imply that further increases in yields are not probable. Simon (1975, p. 23) states that, "the biggest and most dramatic gains in food production probably lie ahead. The evidence so far, however, tells us to expect most of these to occur along fairly conventional lines."

Improved Seeds

One advance in technology that has often been referred to as a breakthrough, is the development of corn hybrids. Sprague (1980, p. 2) stresses that during the early period of corn hybrid development, "the future of hybrid corn was largely speculative." Even after successful hybrids were developed, there was really no breakthrough in terms of its effects on yields. New and better hybrid varieties of corn have been developed for over 60 years, and although the

resulting increases in corn yields has been substantial,
it has been gradual and coupled with other advances such
as more and better fertilizers, herbicides, insecticides,
etc. (see Russell, 1974). These improvements in corn seed
varieties can be expected to continue into at least the
near future.

Technological advances in genetic engineering and
selection promise to give new varieties with improved photo-
synthetic efficiency, nitrogen fixation, nutrient absorption,
ability to withstand stress, and pest and disease resistance
(see Wittwer, 1977). John Schillinger says that, "genetic
selection for these varieties that have better emergence,
as well as better disease resistance, can increase our
soybean yields 10 to 20 percent in the next few years"
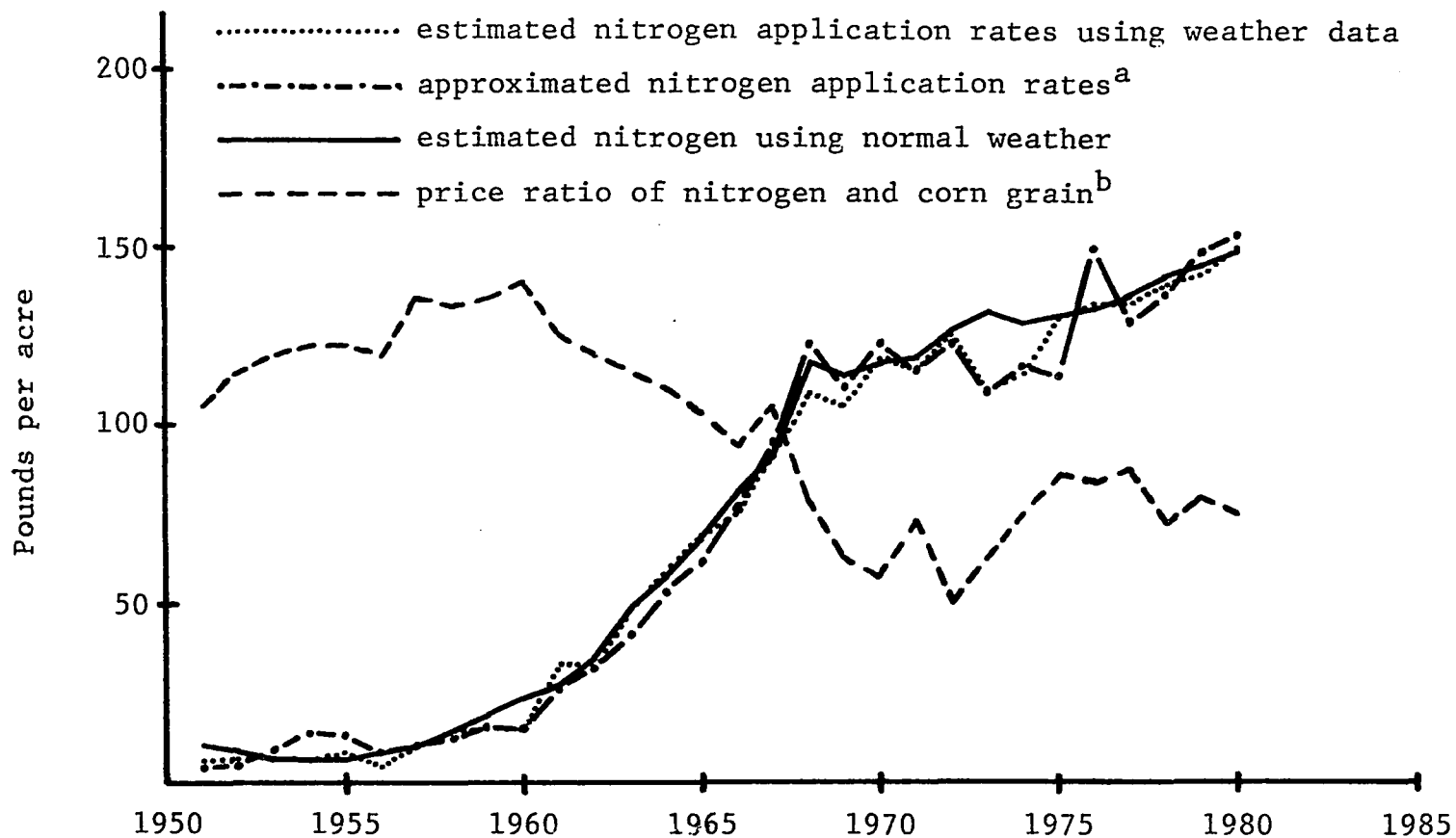(Gogerty, 1981).

Seeds have received and are receiving improvements in
ways that are not necessarily genetic. Seeds are, and can
be, wrapped in gels, fungicides, insecticides, and other
chemicals. In the future, seeds might be coated with
special strains of growth promoting bacteria, or a starch-
based coating that can attract water and hold it around the
seed (see Henkes, 1981).

Fertilizer

Another input that has a significant influence on crop yields is fertilizer. Nitrogen is generally recognized as the first major mineral nutrient that becomes limiting to normal plant growth in many crops. As can be seen in Figure 7.1, nitrogen application rates increased in Iowa at an expotential rate of growth until about 1968, then the rate of growth became more linear and increased at a much slower rate. The same thing happened in all five states. The increase in nitrogen use undoubtedly has had and will continue to have an important impact on corn yields.

It is important, however, to understand that there is a large amount of interaction between the level of nitrogen use and seed varieties in terms of their effects on crop yields. As seed varieties are developed that are capable of giving higher and higher yields, more nitrogen per acre is needed in order to reach the yield potential of these varieties. The same is also true with other nutrients such as phosphorus and potassium.

·················· estimated nitrogen application rates using weather data
·—·—·—·—·—· approximated nitrogen application rates[a]
————————— estimated nitrogen using normal weather
— — — — — — price ratio of nitrogen and corn grain[b]

[a]Approximated by dividing Iowa's total nitrogen application by its total harvested acres of corn.

[b]Price of nitrogen per ton over the price of corn grain.

Figure 7.1. Average pounds of nitrogen applied per acre of corn and price ratio of nitrogen and corn grain in Iowa, 1950-1980

Machinery

When discussing technological progress, machinery is one set of inputs in crop production that has obviously been changing rapidly over time. The effect of better, more sophisticated, machinery on crop yields is hard to measure, but it is undoubtedly important. Examples of important advances are planters that give more uniform planting and better seed-to-soil contact, better cultivators that allow for better weed control with less crop damage, better fertilizer, herbicide and insecticide applicators that give a more properly placed application, and better harvesting equipment that wastes less and is able to quickly harvest in the peak season.

As with most, if not all of the inputs of crop production, the effect of improved machinery is highly interacted with other inputs. An applicator that does a more efficient job of side-banding fertilizer at planting, a fluid drill, i.e., a drill that can plant germinated seeds without injuring the shoots (see Henkes, 1981) or a larger combine are examples of advancements in machinery technology that interacts with other inputs such as fertilizer, seeds, and labor.

Insecticides, Herbicides, and Fungicides

Weed, pest, and disease control are essential to reaching higher yields. New and improved agricultural chemicals have done much in the recent past to contribute to higher yields and certainly will be an important part of future efforts for even greater yields. As some pests are becoming resistant to some chemicals, alternative technologies are being developed and used. New and better ways of detecting and destroying insects and weeds, through timely tillage, and crop rotations are and will be developed and used more. Today it is widely believed by agronomists, entomologists, and other biological scientists that the best way to control weeds, insects and disease is through an integrated management system where chemical, biological, mechanical, and cultural practices are combined. Again, this points out the interaction there is between crop production inputs in terms of their effects on yields.

Management and Labor

One of the most important inputs in crop production is management and labor. Few will dispute the fact that, in general, Corn Belt farmers have been and are becoming more and more educated and skilled. As can be seen in Figure 7.2, the education level of American farmers had been

Figure 7.2. Index of educational attainment by farmers and farm workers (Lu et al., 1979)

rising steadily for many years. In addition, public
extension and private advertising, seminars, and publica-
tions have helped further educate and distribute knowledge
about new technologies to farmers. As farms have been
and are getting larger, and as fewer and fewer people
are producing more and more of the crops in the Corn Belt,
there is reason to believe that in general the more pro-
ductive farmers are those that "make it" farming and there-
fore continue farming. This weeding out process that has
occurred may continue. Today, using similar types of soils,
some farm managers are able to get much higher yields than
average. If, in the future, these types of farmers make
up a larger proportion of their profession, then this alone
should cause aggregate yield averages to rise.

Because of the new, more sophisticated technologies
that have been, and are being introduced, it is essential
that in order to experience higher yields as a result of
them, farm managers and laborers must become more and more
educated and skilled.

Soil

The soil may be the one major input in Corn Belt crop
production that has worsened over the last thirty years.
Although as a result of increased fertilizer, soil fertility

tends to be fairly high, the introduction of more and more
marginal land to crop production, coupled with the detri-
mental effects of excessive soil erosion in many areas, has
resulted in crops being raised on land that is not as well-
suited for crop production and that has less and less top-
soil. As can be seen in Appendix C, the total acres of
row crops in all five states have been increasing. Also,
it is estimated that average annual soil loss in Iowa,
Illinois, and Missouri has been 9.9, 6.7, and 10.9 tons per
acre, respectively (USDA, SCS, 1980). This is well above
the levels believed to be acceptable for maintaining soil
productivity. It is not certain how much effect this has
on yields because its effect is overshadowed by other factors
such as increased fertilizer, but it is certain that this
erosion must be controlled if the productivity of the soil is
to be maintained. The prospects of tomorrow's yield in-
creases may be determined by our commitment to controlling
soil erosion today.

Public and Private Expenditures
on R&D

Large amounts of funds generated in both the public
and private sectors are needed in order to finance the
research and education needed to simply maintain current
levels of agricultural productivity. Even larger amounts

of funds are needed to reach higher levels of agricultural
productivity.

The roles of public and private expenditures on agri-
cultural R&D differ. For example, G. F. Sprague (1980, p.
3), when discussing the advances of corn hybrids, points
out that, "The private sector has made all of the important
advances in production related areas, advances which were
of immediate usefulness. These include such developments
as simplification of detasseling procedures, improvements
in drying, shelling and all aspects of processing to assure
maximum quality and performance of the finished product."
Sprague (1980, p. 4) goes on to point out that, "All of the
important developments in both the theory and practice of
corn breeding have come from the public sector." When
asked about the roles of the public and private sector in
research and development of better seed varieties, Jim
Fentrow (Asgrow Seed Company,Ames, Iowa, personal
communication, 1981), General Manager of Asgrow Seed Company,
reemphasized the major contributions by the private sector.
He went on to point out, however, the need for public re-
search as a way of accomplishing the needed basic research
and as a way to support the training of new plant breeders.

Most of the important basic research and the training
of entomologists, agronomists, and other biological
scientists dealing with pest, weed, and disease control also

have been performed in the public sector. However, the
private sector has again played the important role of the
development and production of new and better chemicals
used for pesticides, herbicides, and fungicides. The private
sector has also been the major contributor to the develop-
ment of more advanced farm machinery. The public sector,
on the other hand, has and must continue to help educate
scientists, and develop and promote measures and practices
of soil erosion control.

In summary, it is clear that both the private and public
sectors have important research and development roles to
perform, and that large investments into research and develop-
ment by both sectors are needed in order to continue to
experience increases in agricultural productivity and yields.
However, these investments must be well-planned and well-
executed, with an understanding that the efforts of the
public and private sectors should and can complement each
other.

Social and Political Stability

In order for a country to experience rapid and continual
technological progress, it is necessary for that country to
experience a high degree of social and political stability.
Few countries have experienced such a degree of stability
as has the U.S. over the last thirty years. Many of the

countries that have experienced relatively good stability,
such as Japan, Australia, Canada, Denmark, Sweden and others,
have also experienced significant advances in technological
progress as well. It is almost impossible for a country
that is embroiled in internal social and political up-
heavals and conflicts to develop the cooperation and to
dedicate the resources needed to make important advances
in technology. In order for agricultural productivity and
yields to increase in the U.S. Corn Belt in the future,
as they have in the past, it is necessary that the U.S.
maintain the political and social stability that it has
had in the past.

Economic Incentives

Another condition that is necessary for rapid techno-
logical progress is, as Schultz (1966, p. 77) puts it,
"a system of economic incentives that will permit and induce
farm people to modernize agriculture." U.S. agriculture has
had an economic system that has not only induced farmers to
be more productive, but one that has almost forced farmers
to be more productive. In general, U.S. agriculture is a
competitive market oriented system where individual farmers
must accept the market price for their commodities and also
must pay the market price for land. Even when the government

supports the prices of agricultural commodities as has been done in the U.S., the only way for individual farmers to increase their incomes is to produce more output with less inputs. If prices of farm products are high, the value of farmland also tends to be higher. This of course is a great incentive to farmers to try and increase yields on this land. In the future, the world's growing population will expand the demand for food along with the demand for land for non-agricultural uses. Under a market-oriented economic system similar to what the U.S. has had in the past, the prices of agricultural products and land will rise, giving further incentives for farmers to increase yields. This, of course, will cause more land saving technologies to be adopted in place of labor-saving technologies that have been prevalent in the U.S. Corn Belt.

An economic system that will promote technological progress in the long run must not only induce farmers to search for and adopt new technologies, but must also induce supporting industries to search for, develop, and market new technologies. Seed, chemical, machinery, and other such industries must also experience the incentives needed to induce them to make the investments in research and development needed to develop and market new and better seed varieties, pesticides, machinery, and other such inputs.

Although good data on private expenditures on R&D are difficult to find, it does appear that over the last few decades the amount of private investment on agricultural R&D has been increasing in real terms, as has public investment, and today large private investments in R&D are being made. For example, in 1980, Deere and Company, a major farm machinery manufacturer, is reported as spending more than 230 million dollars on R&D. Monsanto and UpJohn, two chemical companies that develop and market agricultural chemicals, among many other products, (about 15 percent of total sales are agricultural products), are reported as spending a total of over 400 million dollars on R&D. Also, DeKalb, Pioneer[1], O's Gold, and Asgrow[1], just four of the many seed companies developing and marketing new seed varieties, are estimated to have spent a sum total of. around 40 million dollars on R&D (Moody's Investors Fact Sheets, 1980). Of course, these are just a few of the private companies that support technological progress in agriculture by developing and providing better inputs. In order for these and other such companies to make such large investments in R&D, they too must experience the same types of economic incentives as the farmers themselves.

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[1]Information on expenditures for R&D for Pioneer and Asgrow was obtained by personal communication with the general office of these companies.

Summary

Technological progress is certainly not a magical phenomenon that simply causes increased agricultural productivity. Technological progress is not an occurrence that is caused by any one thing, such as public expenditures on R&D, or increased education levels. Technological progress is an extremely large and complex set of interacting conditions, occurrences, and activities. It comes about because of the action and efforts of many groups of people and interests such as, farmers, educators, public and private scientists, extension workers, seed, chemical and other agribusiness firms, and etc.

It is no wonder that attempts to model, or quantify technological progress are bound to be trivial and generally uninformative. For example, the models presented in Chapter IV can only project past time trends, they can't project what will in fact happen to the levels of technological progress. The answer to this question is simply not in the time series data. The answer is in the soil, in the weather, in the economy, in the abilities of American agriculturists, and in the dedication and support of the American public.

CHAPTER VIII. PROJECTED YIELDS

Future yields cannot be realistically projected with-
out first either projecting or making assumptions about
future technological progress and weather. Because there is
no available means of accurately projecting weather in future
years, and because, by its nature, technological progress
is unpredictable, it is necessary that future yields in the
Corn Belt states be projected under various sets of assump-
tions. Therefore, the models presented in Chapter IV are
used to project expected 2000 yields in Illinois, Indiana,
Iowa, Missouri, and Ohio, under six different scenarios.
The six scenarios are defined as follows:

Scenario one assumes average weather effects on yields
and that past trends in technological progress and nitrogen
fertilizer application persist.

Scenario two assumes that favorable weather conditions
in terms of its effects on yields, such as occurred in 1979
for Ohio, and 1978 for all other states, will be experienced
in the year 2000. It is also assumed that past trends in
technological progress and nitrogen fertilizer persist.

Scenario three assumes that unfavorable weather condi-
tions, such as occurred in 1974, for all states, will be
experienced in the year 2000. It is also assumed that past
trends in technological progress and nitrogen fertilizer

application persist.

Scenario four assumes that average past weather effects persists. However, it is assumed that technological progress does not continue to increase yields or nitrogen application rates at the same rate in the future as it has in the past. It is assumed that yields and nitrogen application rates increase as a result of technological progress at only one-half the rate as in the past.

Scenario five assumes that average past weather conditions and past trends in technological progress persist. But, it is assumed, that as a result of energy shortages, environmental concerns, or some other reason, nitrogen application rates do not continue to rise but are held constant at current 1980 levels.

Scenario six assumes that past weather conditions persist, but that nitrogen application rates are held at current 1980 levels and that yields, as a result of technological, increase at only one-half the rate as in the past.

For all the scenarios the projected 2000 yields are calculated and reported in Tables 8.1-8.5. Notice that projected yields under scenarios five and six are not given for soybeans, wheat, oats, or meadow because nitrogen does not appear in those equations. It can be seen that a great deal of variation in these projections persists,

Table 8.1. Illinois yields projected for 2000

	Corn	Silage	Soybeans	Wheat	Meadow
1980 Expected	114.3	15.28	35.92	41.49	3.75
Scenario 1	161.9	17.90	44.80	45.12	5.01
Scenario 2	169.6	18.78	46.12	45.33	5.12
Scenario 3	141.2	15.49	38.72	35.06	4.76
Scenario 4	136.2	16.46	40.40	43.53	4.38
Scenario 5	139.1	16.75	-	-	-
Scenario 6	129.8	15.66	-	-	-

Table 8.2. Indiana yields projected for 2000

	Corn	Silage	Soybeans	Wheat	Meadow
1980 Expected	104.6	15.30	34.73	43.42	3.32
Scenario 1	134.0	16.86	42.57	47.80	4.54
Scenario 2	146.9	18.54	45.76	46.58	4.65
Scenario 3	117.2	15.04	37.10	47.68	4.35
Scenario 4	118.8	16.06	38.65	45.89	3.93
Scenario 5	125.9	16.06	-	-	-
Scenario 6	115.4	15.83	-	-	-

Table 8.3. Iowa yields projected for 2000

	Corn	Silage	Soybeans	Oats	Meadow
1980 Expected	111.5	15.22	37.14	63.85	3.68
Scenario 1	159.2	18.74	48.60	85.84	4.78
Scenario 2	175.4	20.87	51.16	87.00	5.02
Scenario 3	151.6	17.55	44.24	84.33	4.61
Scenario 4	133.5	16.75	42.42	74.85	4.23
Scenario 5	143.7	16.45	-	-	-
Scenario 6	130.7	16.30	-	-	-

Table 8.4. Missouri yields projected for 2000

	Corn	Silage	Soybeans	Oats	Meadow
1980 Expected	80.5	11.38	27.92	36.68	2.55
Scenario 1	107.1	13.65	33.68	39.68	2.35
Scenario 2	117.2	14.74	37.96	38.60	2.49
Scenario 3	100.9	12.93	30.63	36.33	2.45
Scenario 4	92.9	12.42	30.80	38.37	2.46
Scenario 5	96.7	12.46	-	-	-
Scenario 6	90.1	12.10	-	-	-

Table 8.5. Ohio yields projected for 2000

	Corn	Silage	Soybeans	Wheat	Meadow
1980 Expected	110.7	15.59	32.37	45.99	3.06
Scenario 1	198.6	21.74	42.08	62.03	4.21
Scenario 2	207.6	22.58	47.53	60.72	4.47
Scenario 3	184.6	20.38	39.21	61.78	4.26
Scenario 4	149.1	17.65	37.11	54.01	3.63
Scenario 5	143.4	15.90	-	-	-
Scenario 6	127.1	14.90	-	-	-

depending on what assumptions about weather, technological progress, and nitrogen application are made.

CHAPTER IX.   SUMMARY AND CONCLUSIONS

Producers of agricultural products, policy makers, and consumers alike have a keen interest in what will happen to crop yields in the future. In the past, expected yields have been highly influenced by the degree of optimism or pessimism that seemed to prevail, and not always on a careful analysis of past trends in technological progress and weather conditions. The present study is an attempt to carefully analyze past trends in crop yields in five Corn Belt states, Illinois, Indiana, Iowa, Missouri, and Ohio, and how they have been effected by weather and technological progress over time.

It is hypothesized that state average yields for corn grain, corn silage, soybeans, small grains, and meadow (leguminous hay) can be theoretically modeled as a system of equations where yields are functions of weather, technological progress, and nitrogen application rates. Nitrogen application rates are functions of technological progress, prices of corn and nitrogen, and weather. Technological progress is a function of a long list of variables such as time, public and private expenditures on agricultural R&D, education level of farmers and other such variables.

Because most of the variables in the technological progress equation can not be adequately defined, observed,

or quantified, a proxy variable for technological progress
is needed so that the remaining six equations can be esti-
mated using regression analysis assuming that technological
progress, weather, and the prices of nitrogen and corn are
exogenous to the system.

Real lagged public expenditures on agricultural R&D are
considered and rejected as a proxy variable for technological
progress. These expenditures have generally been increasing
over time, and a distributed lag on these expenditures
tends to simply approximate a smooth linear trend over time.
Little is gained by using lagged public expenditures on
agricultural R&D instead of a function of time as a proxy
variable for technological progress except for the tempta-
tion to view future technological progress as being solely
dependent on these expenditures. Even in other studies
where cross sectional data are introduced efforts to estimate
the effects of public expenditures on agricultural R&D by
using regression analysis, are plagued with serious problems
such as the problems of spill-over effects, simultaneously,
and errors in variables.

Because no other more suitable variable can be found,
because all the factors that affect technological progress
cannot be quantified, because accurate data on those that
can be quantified often cannot be obtained, and because
of the extremely complex interaction between the factors,

it is determined that the best available way to treat technological progress in this study is to use a function of time as a proxy variable for technological progress. Technological progress is then discussed in a framework that is less rigid than regression analysis.

Time series data on yields, nitrogen and corn prices, nitrogen application and weather are collected, and the models for all five states are estimated using three stage least squares regression. The estimated models do a good job of fitting the 1951-1980 time series data.

The models also do a good job of illustrating that technological progress and weather are the most important factors that effect yields. They do nothing, however, to project future weather. The prospects of favorable future weather are analyzed by regressing weather variables from 1930-1980 on dummy variables for each state and for periods of abnormally favorable weather. Although these models are able to explain only a small portion of the variance in the weather variables, they do show that the periods during 1942-1952, and 1961-1973 can be characterized as more cool and wet, and generally more favorable to crop yields than average. Attempts to use this information to project future weather would be ludicrous. There is little to indicate that future weather will differ greatly from the

past, and any attempt to project future weather is a very
risky proposition at best.

The prospects of future yield increases as a result
of technological progress are examined by looking at some
of the major factors that effect crop yields. It is
determined that there is a potential for much higher state
average yields under the right conditions, under highly
skilled and motivated management and with the right inputs.

Some of the traditional inputs discussed are seeds,
fertilizer, machinery, insecticides, herbicides, fungicides,
management, labor, and soil. All of these inputs except
soil have been and can be expected to improve over time
in terms of their effects on yields. Soil is the only
input that has not improved, but has in fact gotten worse
over time as a result of more and more land being brought
into crop production and as a result of excessive soil
erosion. This trend cannot continue indefinitely if soil
productivity is to be maintained and crop yields boosted.

Some of the more unconventional inputs that are
necessary for future increased in yields that are discussed
are public and private investments in agricultural R&D,
social and political stability, and strong economic incen-
tives for farmers and supporting industries. It can be seen
that technological progress as it affects yields is a large and

complex set of interacting conditions occurrences and activities, and that attempts to project future yields must be based on various assumptions about future technological progress and weather.

Yields are projected for the year 2000 using the models presented in this study under six different scenarios. Scenario one simply allows the models to project past trends. It is a fairly optimistic scenario which assumes average weather effects on yields and that past trends in technological progress and nitrogen fertilizer application persist. Note that, in the time series data itself, there is no evidence to the contrary.

Under this first scenario, expected 2000, average corn, soybean, wheat and meadow yields for the Corn Belt are projected to increase over expected 1980 yields by approximately[1] 43, 26, 15, and 27 percent, respectively. Between 1960 and 1980, expected corn, soybean, wheat, and meadow yields increased by approximately 53, 33, 30, and 39 percent, respectively. As it can be seen, even under this optimistic scenario, yields are not projected to increase by the same percent in the next twenty years as they have

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[1]Average yield increases for all five states are weighted by 1980 harvested acres to get aggregate average yields for these five Corn Belt states.

done in the past. However, under this scenario, 2000 corn, soybean, wheat and meadow yields are expected to increase over 1980 yields in absolute terms by approximately 47 bushels, 8.9 bushels, 6.3 bushels, and .98 tons per acre, respectively. Corn, soybeans, and oat (in Iowa) yields are projected to increase just as fast over the next twenty years in terms of absolute gains in yields as they have over the last twenty years. In all five states, except for Missouri where meadow yields have leveled off, meadow yields are also projected to rise in absolute terms the same as they have in the past twenty years. Absolute gains in wheat yields in these Corn Belt states are projected to be smaller in the next twenty years than in the past. In general, there is no evidence in the time series data that absolute increases in corn and soybean yields are leveling off. It does appear that wheat yields are leveling off, and that in at least one state, Missouri, meadow yields are leveling off.

In scenario two, three, four, five and six, assumptions that cannot be substantiated by the time series data are made. The assumptions in effect are purely subjective conditions that are forced upon the models. The results are not surprising. When abnormally favorable weather is assumed, higher yields are projected; when abnormally

unfavorable weather is assumed, lower yields are projected; when technological progress is assumed to slow down, projected yields increases are lower; and when fertilizer application is constrained, so are yield increases.

Winston Churchill is quoted as saying that, "it is always wise to look ahead, but difficult to look further than you can see" (Jantsch, 1967). Although this may be somewhat trite, it is certainly true in the context of projecting crop yields. It would certainly be helpful to policy-makers, farmers, and consumers, to be able to foresee what will happen to yields in the future. On the other hand, it is very difficult to project yields that far into the future with any degree of reliability.

Projections of yields such as have been made for the five Corn Belt states in this study, can only be viewed with a great deal of caution because these projections depend on so many things, some of which we can control, some of which we can't. However, these projections do illustrate that, even in the Corn Belt where great increases in yields have already been experienced, there is little evidence in the past trends to project a general leveling off of crop yields. What will happen to Corn Belt yields in the next twenty years depends on the motivation and ability of American agriculturists, the dedication and support of the American

public, and the economic, social, and political conditions
that prevail.

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APPENDIX A: PUBLIC EXPENDITURES
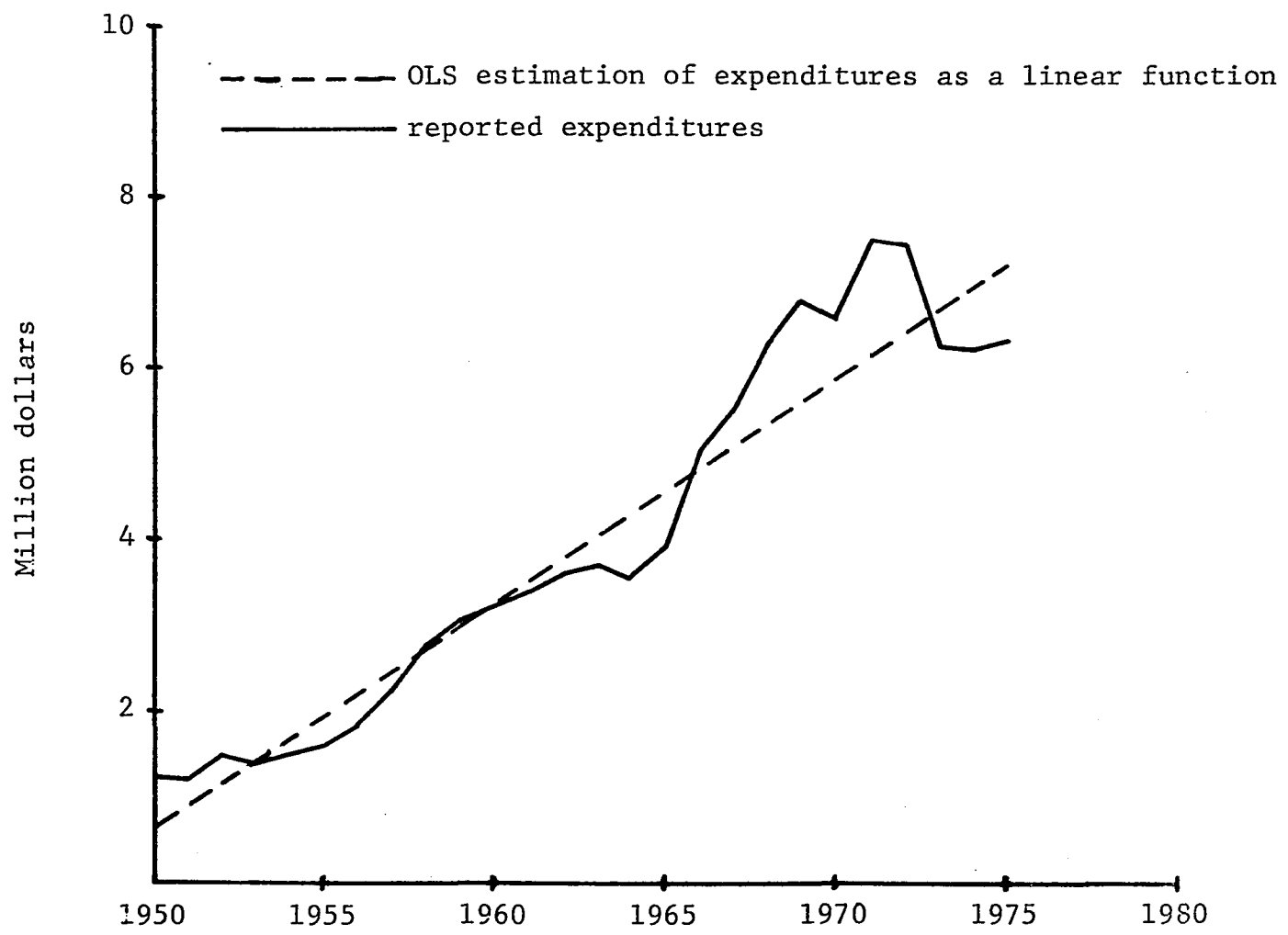
FOR AGRICULTURAL R&D
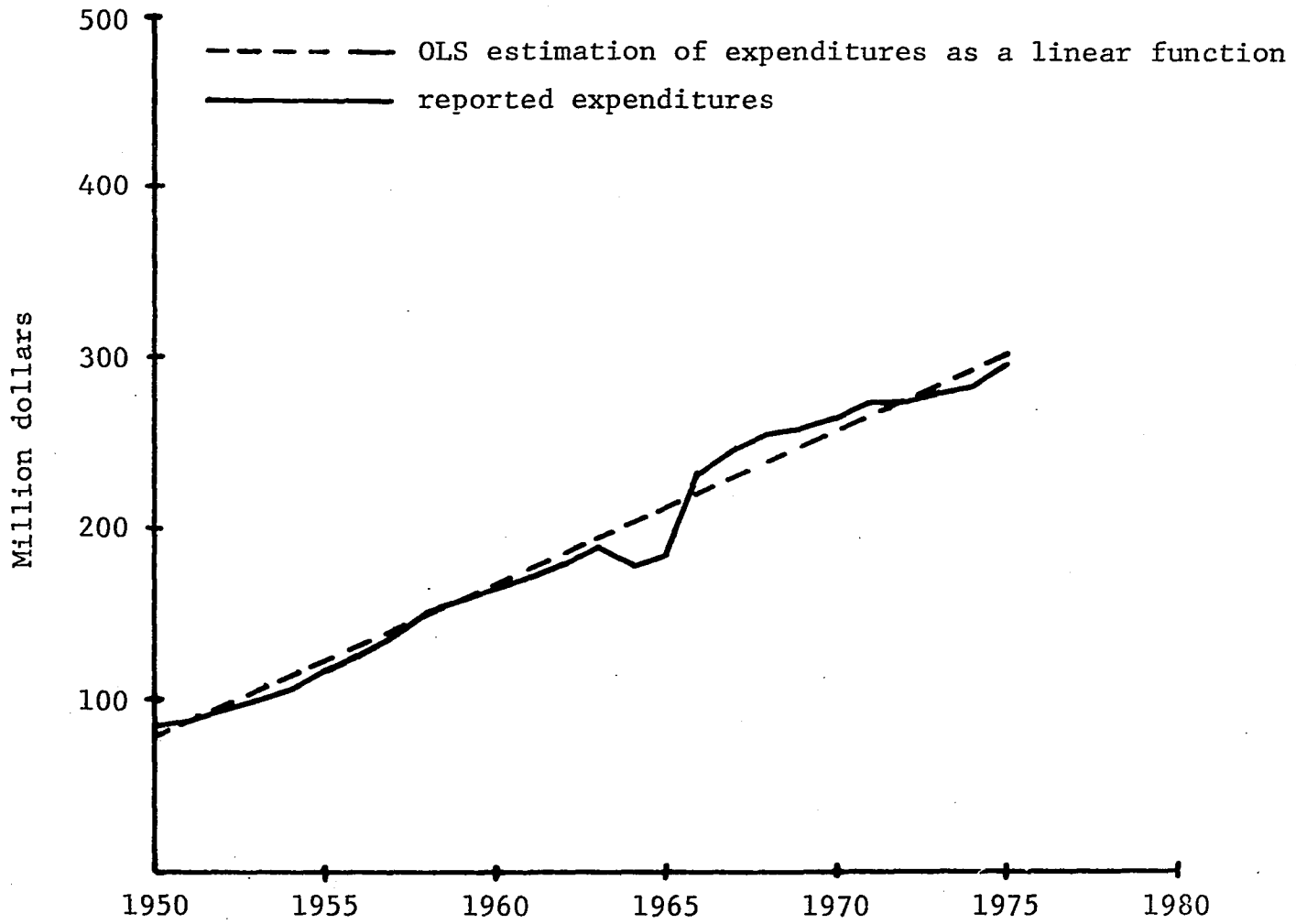
Figure A.1. Real (1967 dollars) public expenditures on agricultural R&D in the U.S., 1950-1975 (USDA, 1950-1975)
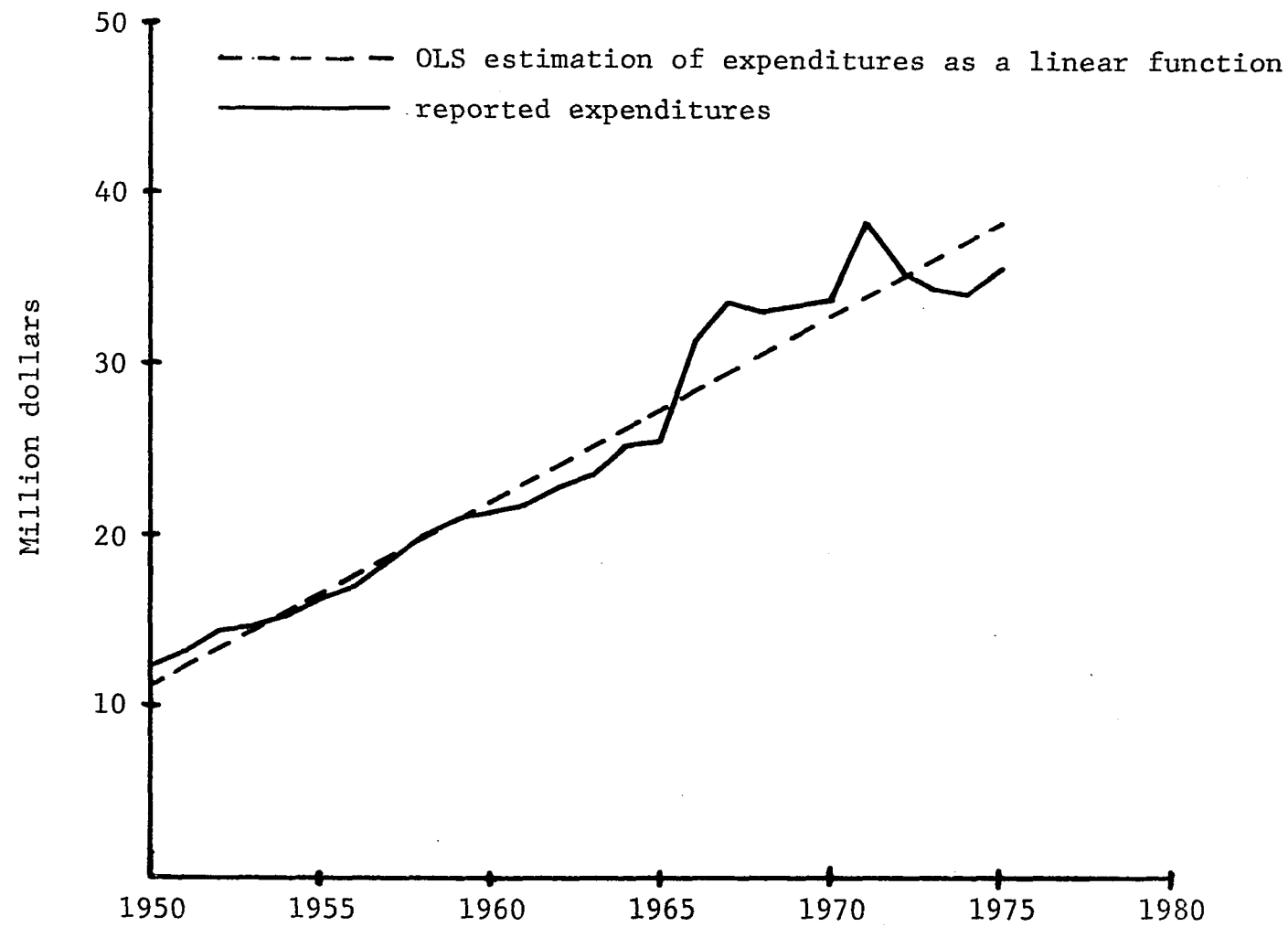
Figure A.2. Real (1967 dollars) public expenditures on agricultural R&D in the
Corn Belt, 1950-1975 (USDA, 1950-1975)
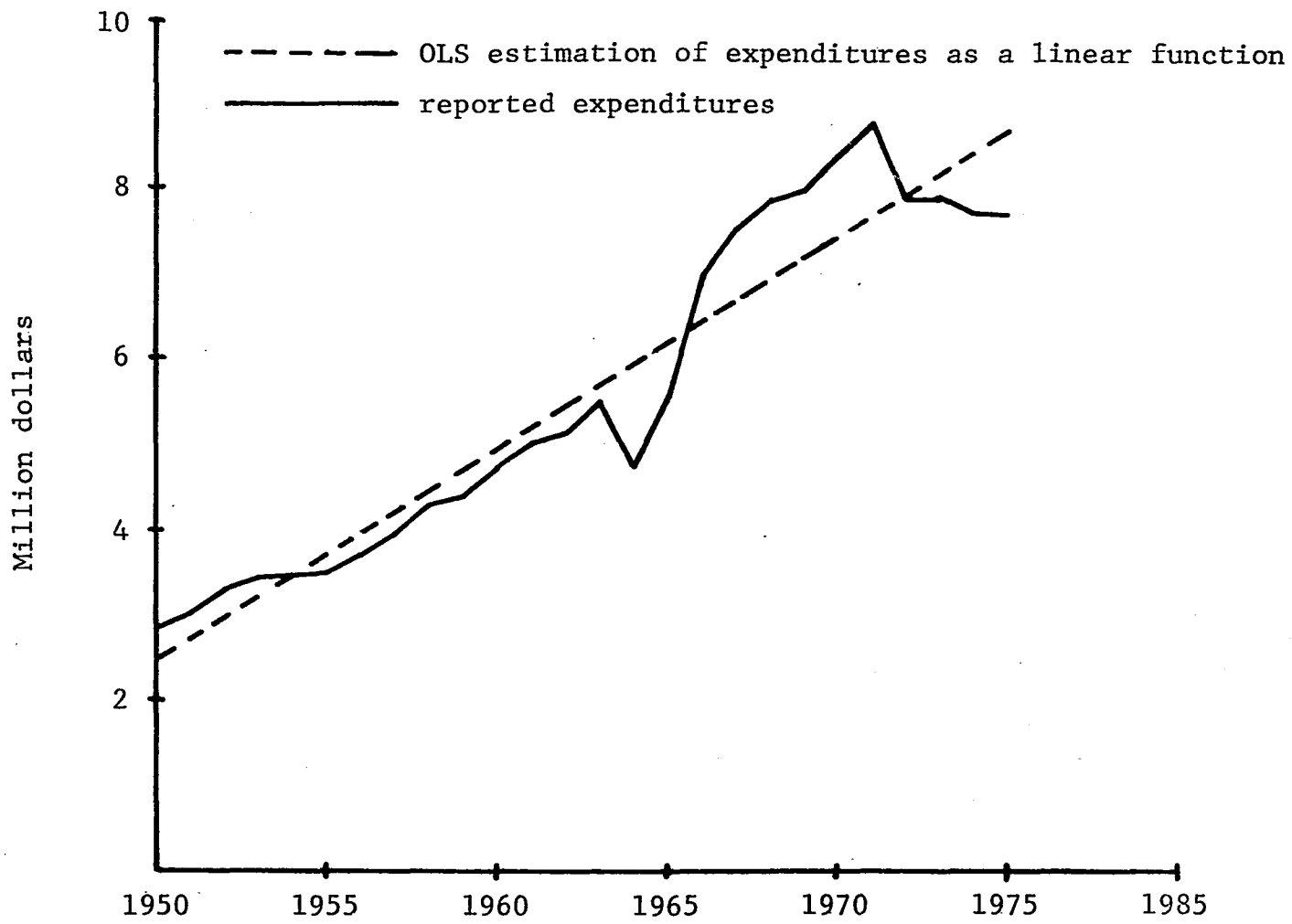
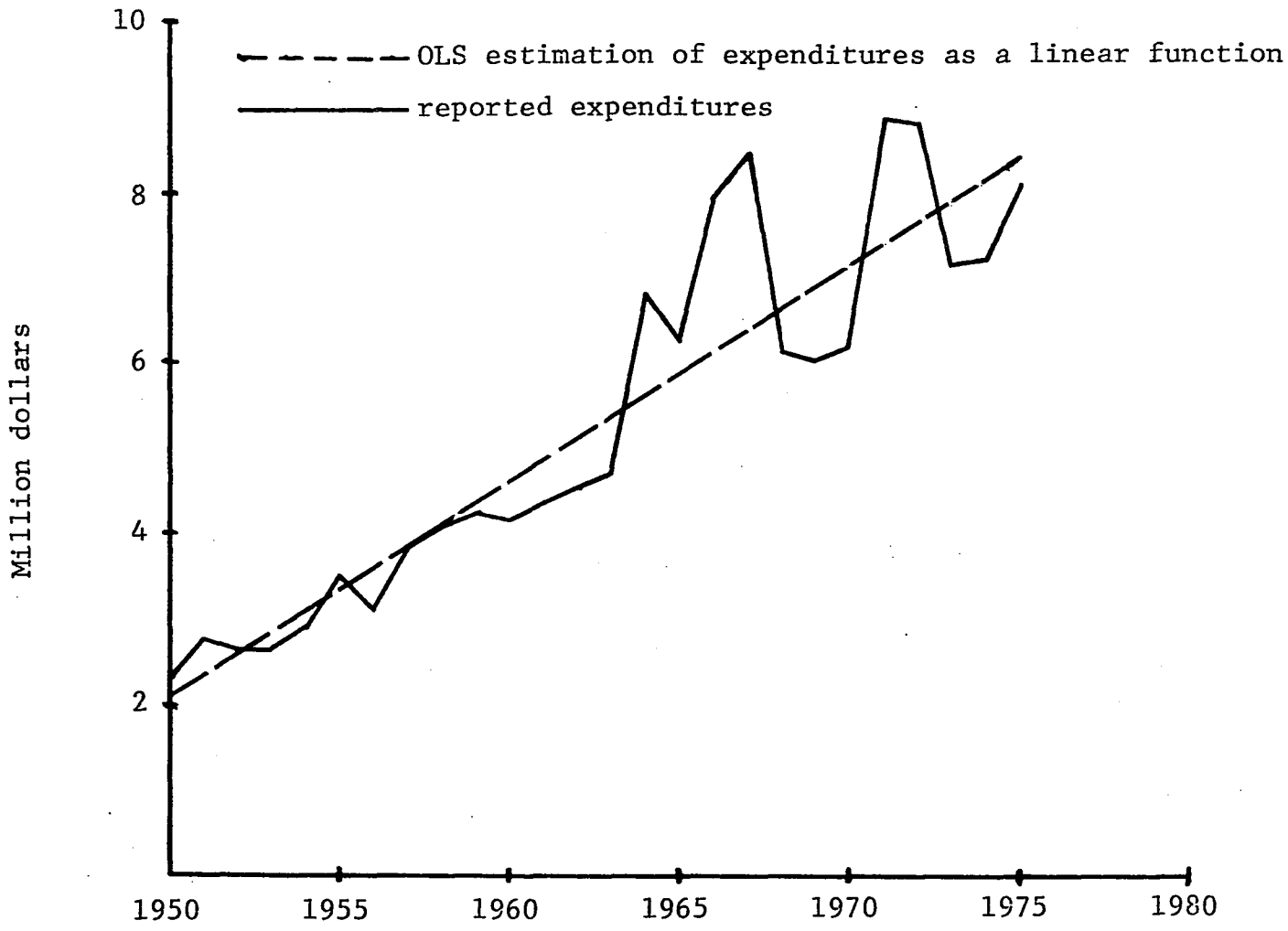Figure A.3.   Real (1967 dollars) public expenditures on agricultural R&D in Illinois, 1950-1975 (USDA, 1950-1975)
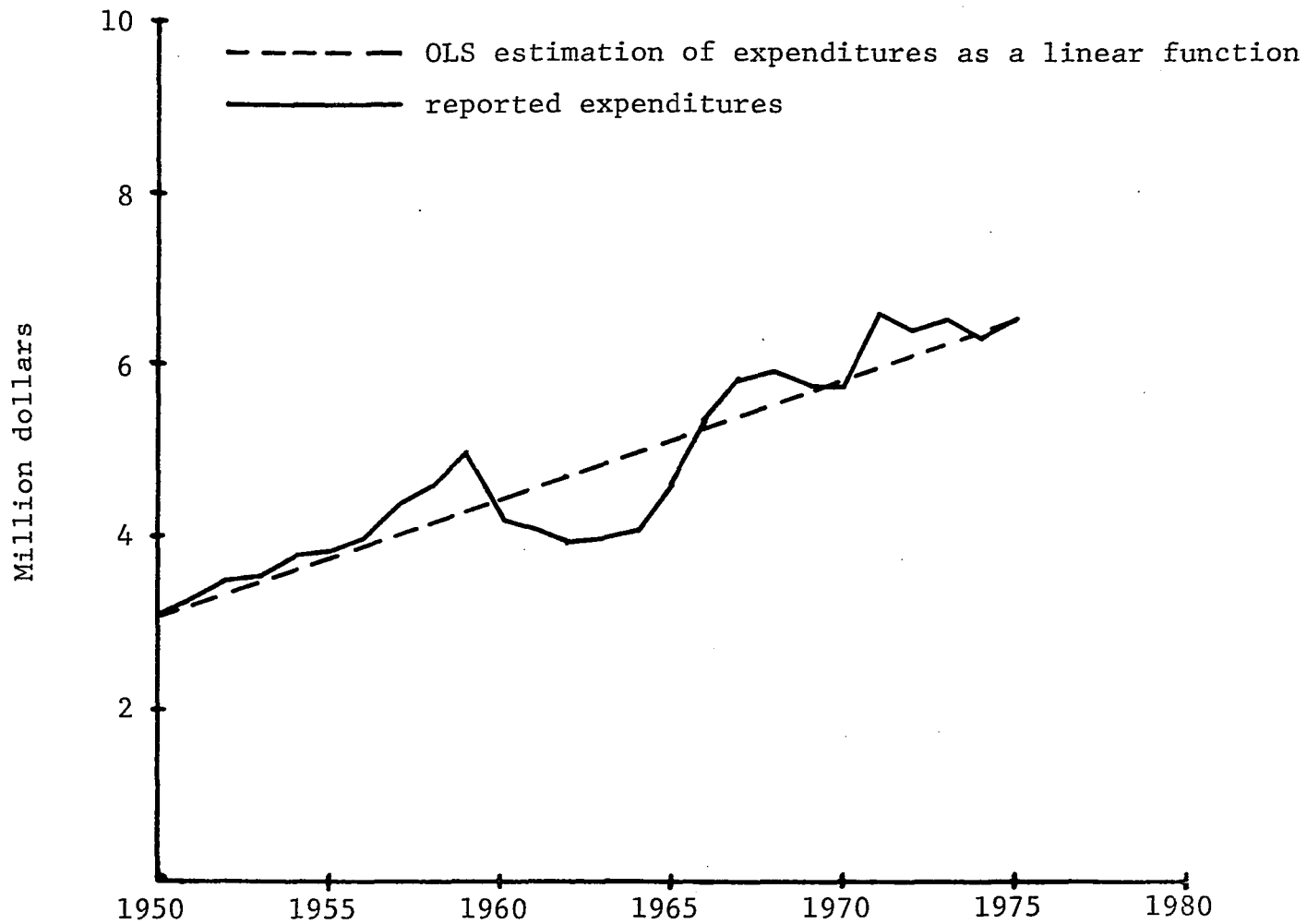
Figure A.4. Real (1967 dollars) public expenditures on agricultural R&D in Indiana, 1950-1975 (USDA, 1950-1975) ¦
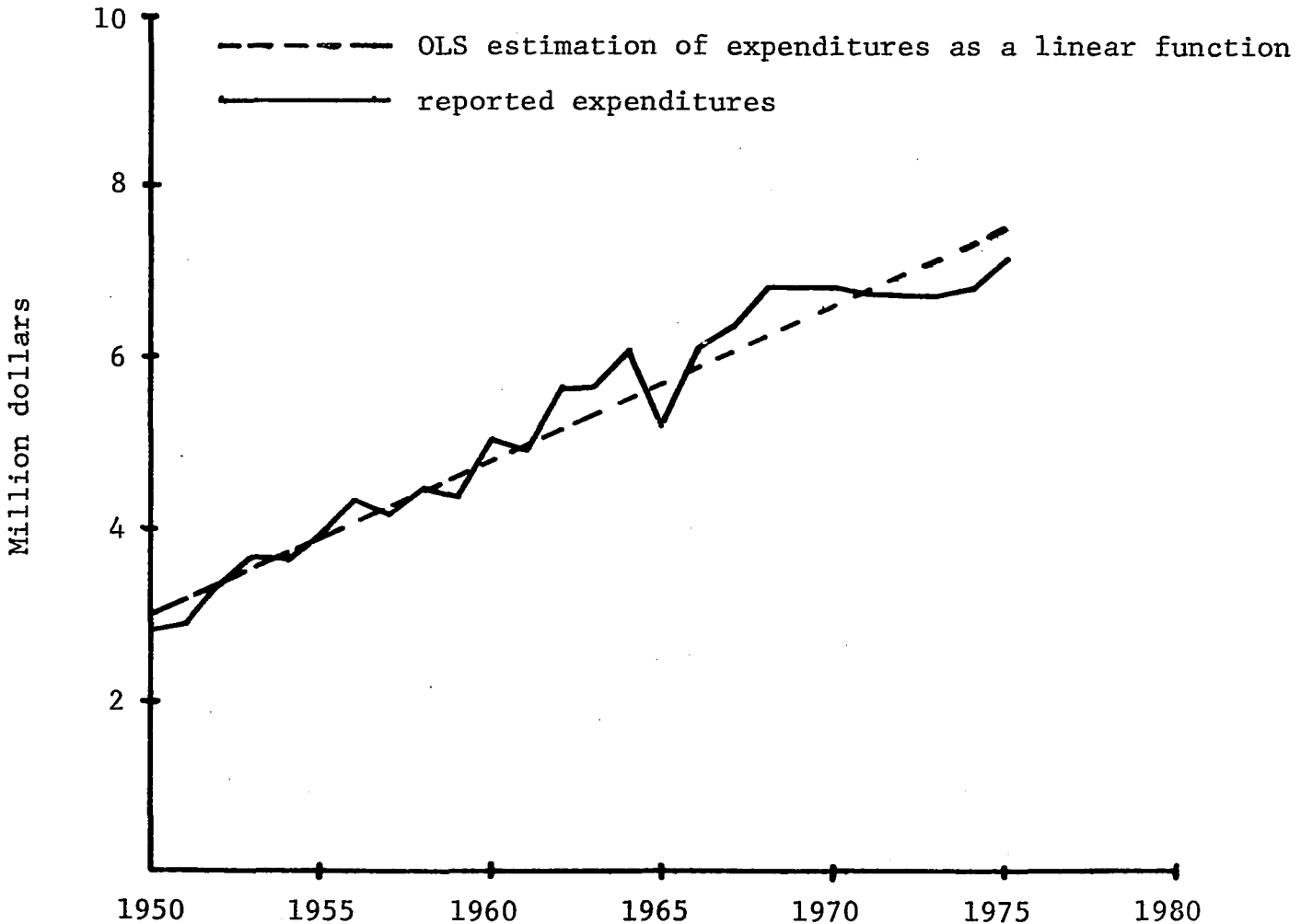
Figure A.5. Real (1967 dollars) public expenditures on agricultural R&D in Iowa, 1950-1975 (USDA, 1950-1975)

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Figure A.6. Real (1967 dollars) public expenditures on agricultural R&D in Missouri, 1950-1975 (USDA, 1950-1975)

Figure A.7. Real (1967 dollars) public expenditures on agricultural R&D in Ohio, 1950-1975 (USDA, 1950-1975)

APPENDIX B: ESTIMATED CORN YIELDS IN

IOWA WITH 1980 TECHNOLOGY
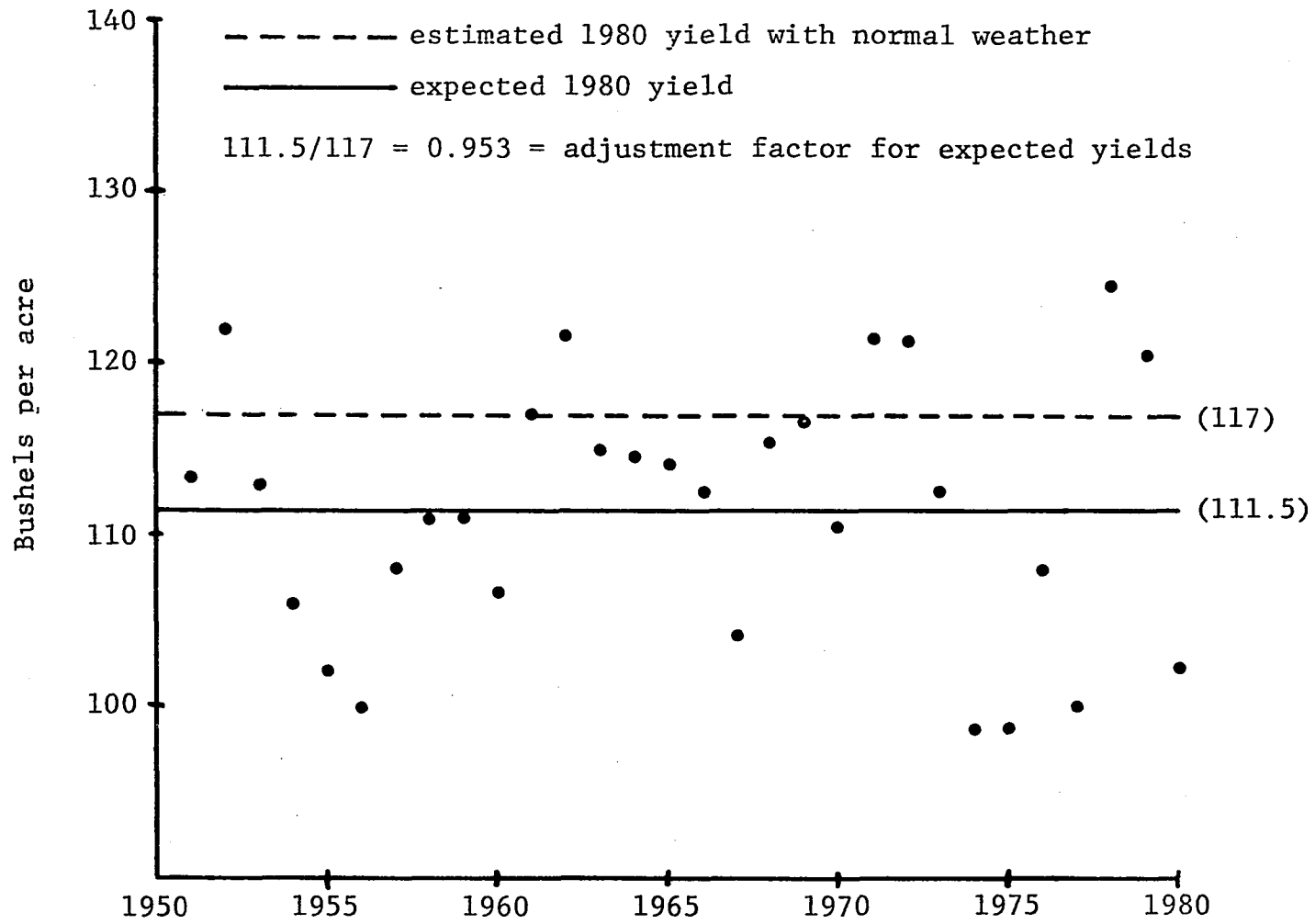
Figure B.1.   Estimated corn yields in Iowa with 1980 technology, 1950-1980

APPENDIX C: HARVESTED ACRES FOR CORN
BELT STATES
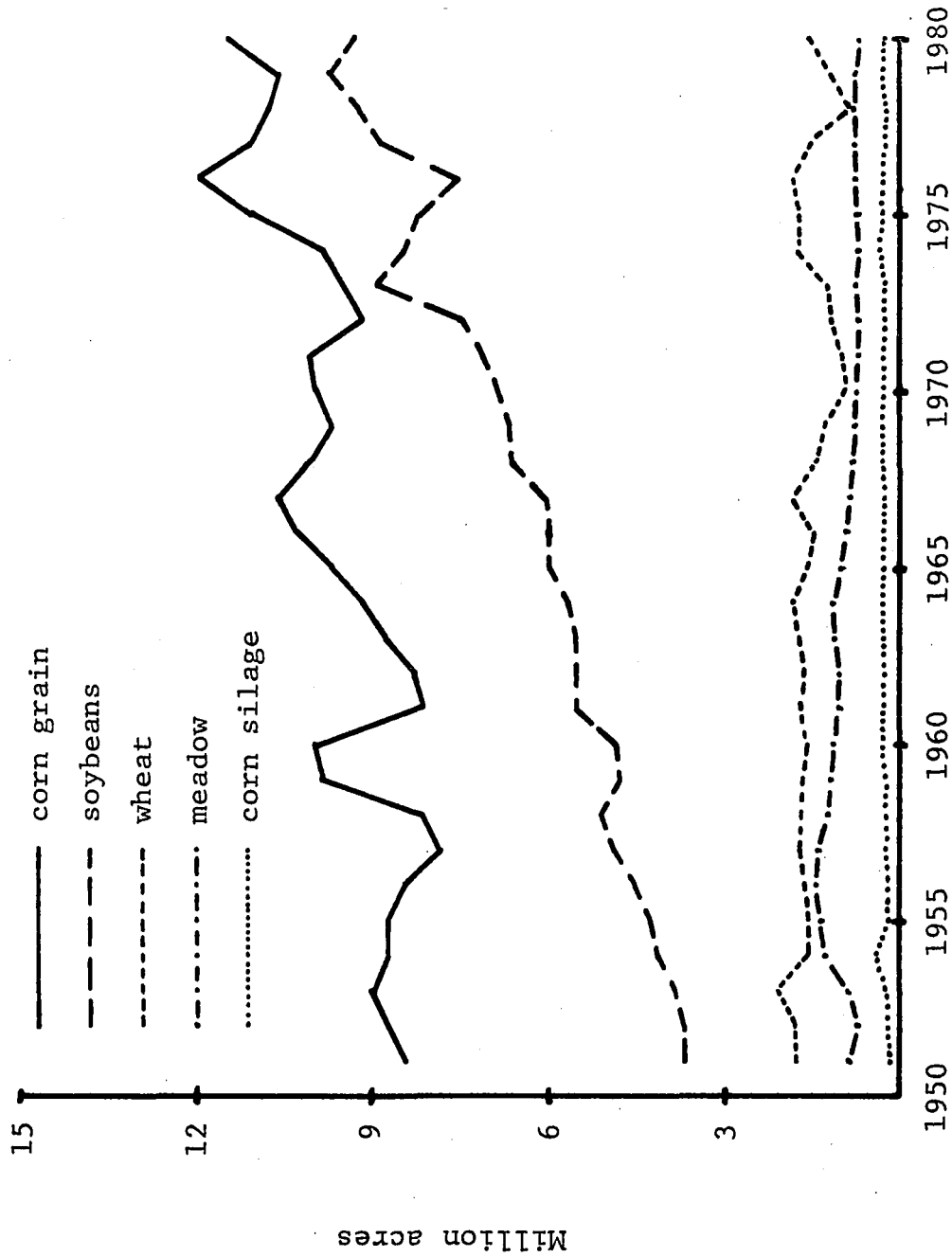
Figure C.1. Harvested acres for Illinois, 1951-1980 (USDA, Agric. Stats. 1952-1980)
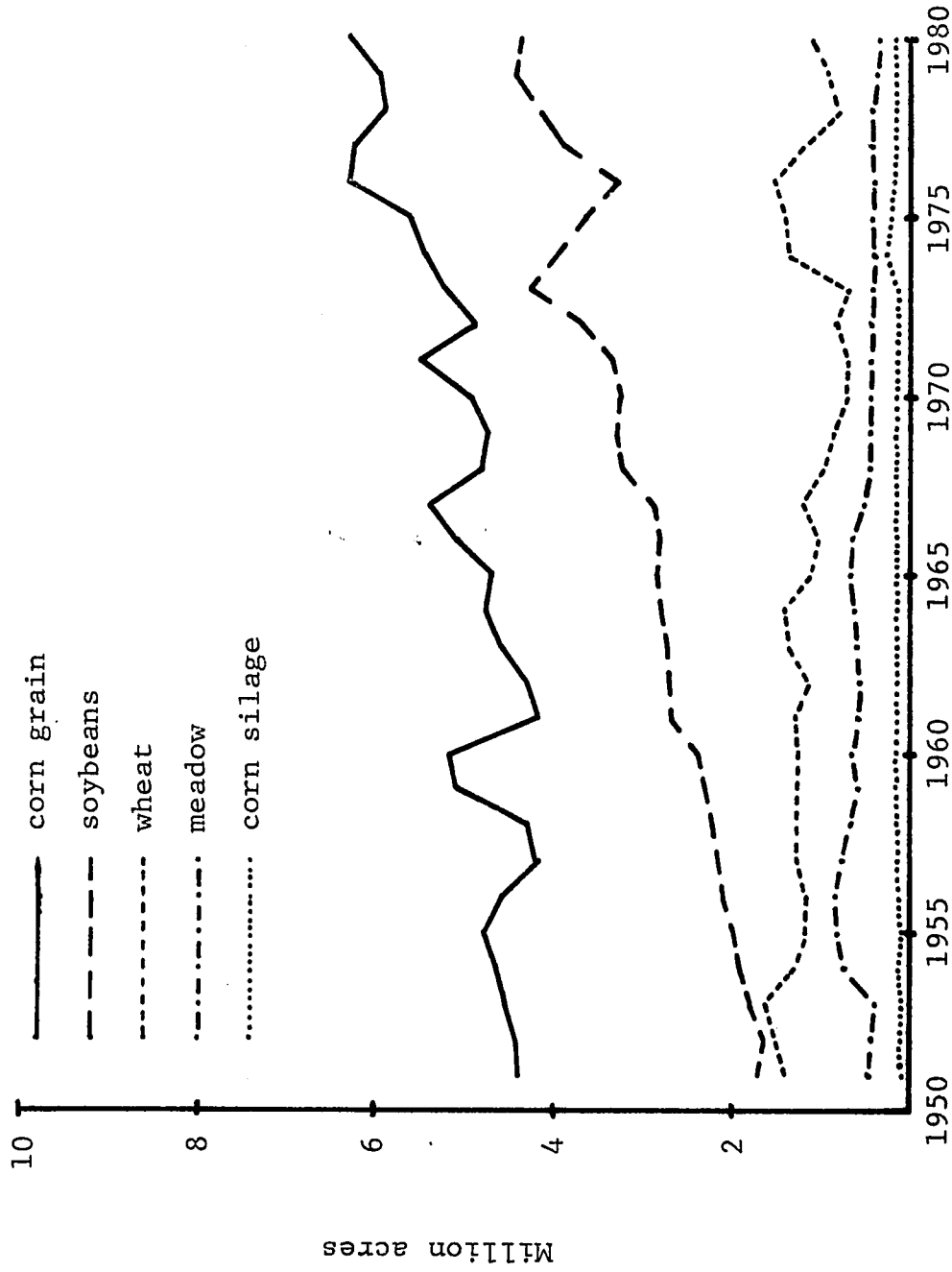
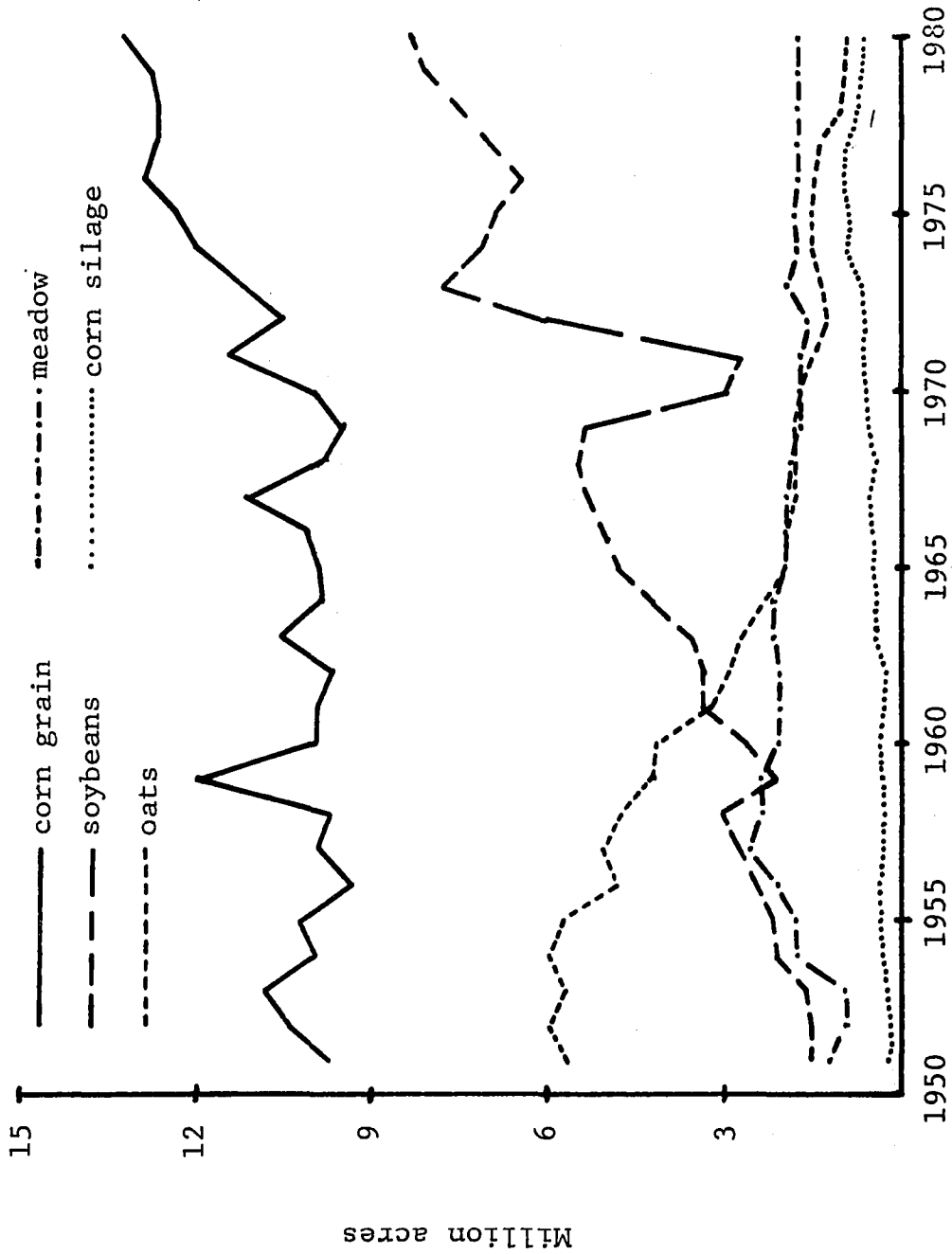Figure C.2. Harvested acres for Indiana, 1951-1980 (USDA, Agric. Stats., 1952-1980)

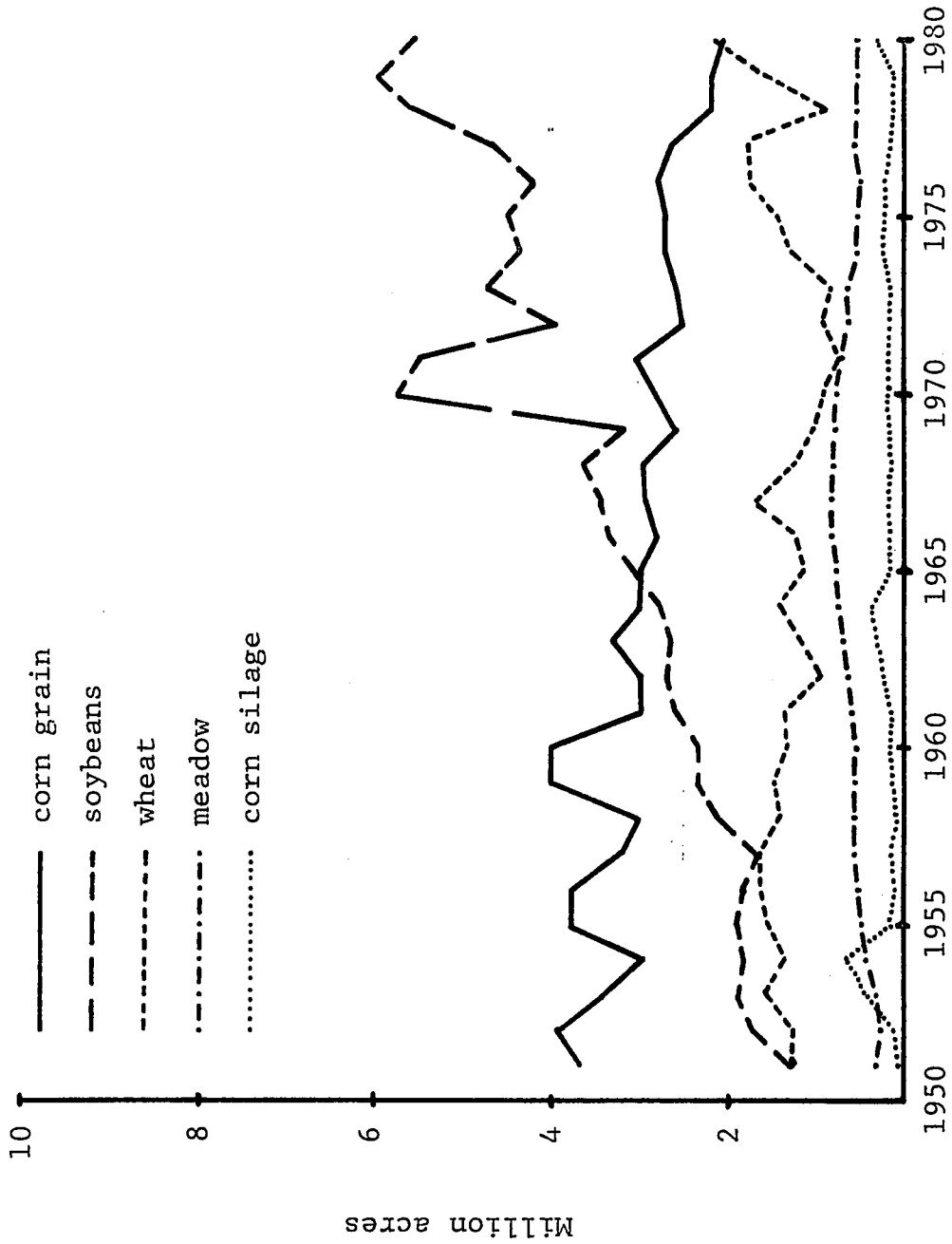Figure C.3. Harvested acres for Iowa, 1951-1980 (USDA, Agric. Stats., 1952-1980)

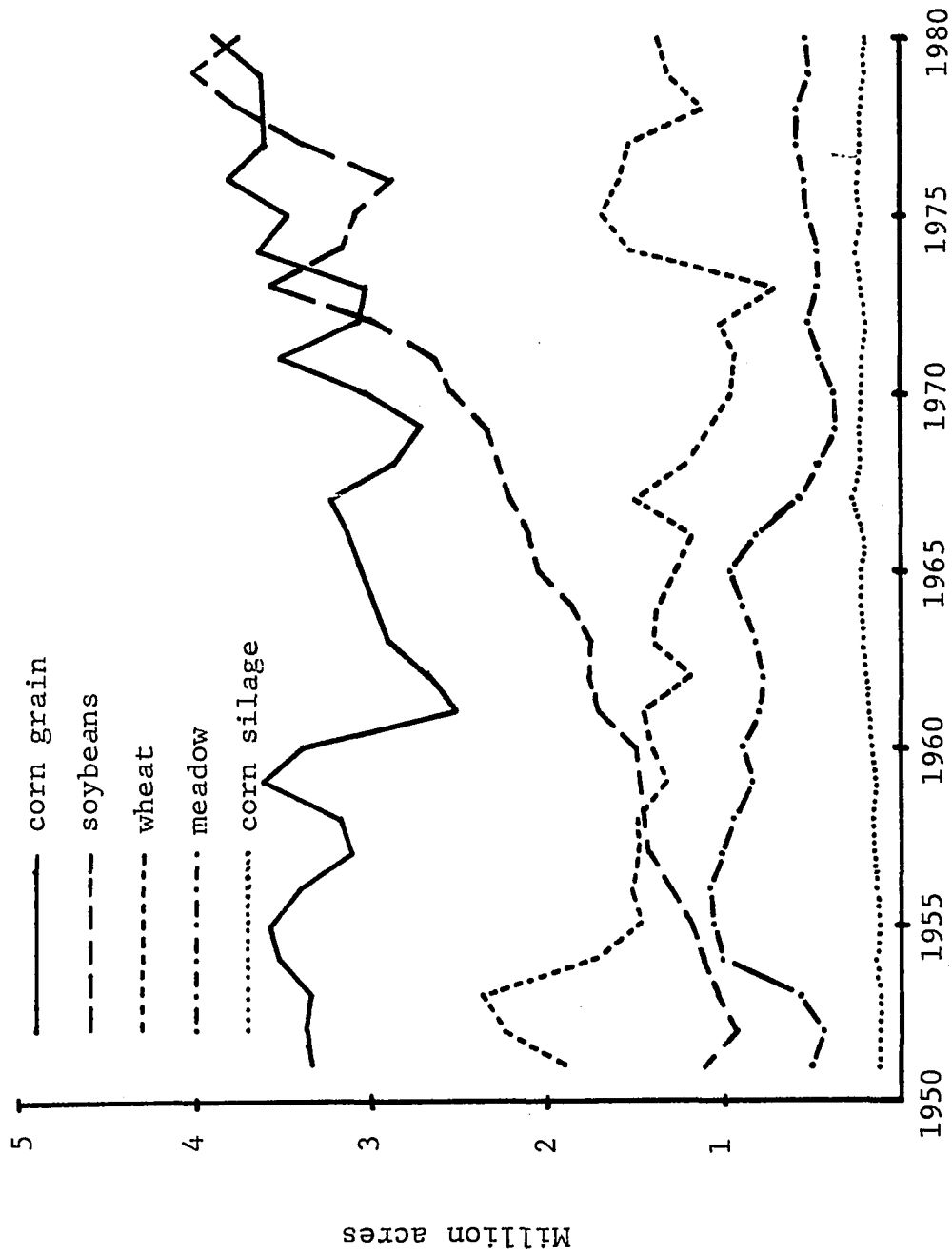Figure C.4. Harvested acres for Missouri, 1951-1980 (USDA, Agric. Stats., 1952-1980)

Figure C.5. Harvested acres in Ohio, 1951-1980 (USDA, Agric. Stats., 1952-1980)