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THE CONTRIBUTION OF TECHNOLOGY TO SOYBEAN YIELDS IN MINNESOTA

by

Alan G. Miner

Department of Agricultural and Applied Economics

University of Minnesota
Institute of Agriculture, Forestry and Home Economics
St. Paul, Minnesota 55108

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I am solely responsible for any errors that may remain in this report.

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INTRODUCTION

There is growing uncertainty about the future course of productivity growth in U.S. agriculture. In a widely publicized report issued in 1975 a committee of the National Academy of Sciences pointed out that productivity indicators such as output per acre, output per worker, and output per unit of total input appeared to be declining (13).

Soybean yield trends in Minnesota had appeared to conform to the pessimistic expectations expressed in the National Academy of Sciences report. There was very little gain in soybean yields in Minnesota between the mid 1950s and the late 1960s. Since the late 1960s, however, Minnesota soybean yields have improved rapidly (Figure 1).

In this paper an attempt is made to measure the sources of change in Minnesota soybean yields. The factors affecting yield include the year to year variations in environmental factors such as weather. Yields are also affected by the input levels used in soybean production. Input levels are affected by economic factors such as the prices of soybeans relative to the prices of inputs used in soybean production. Input levels are also affected by advances in technology -- by

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**Alan G. Miner is a Research Assistant in the Department of Agricultural and Applied Economics, University of Minnesota, St. Paul.

improvements in the quality of inputs and in production practices.

The major concern in this analysis is to separate the effects of technology on long term yield trends from the short run fluctuations due to weather and prices. An attempt has been made to measure and compare sources of yield change at the experiment station level and at the farm level in counties in which the experiment stations are located. The experiment stations are at Waseca (in Waseca County) in south-central Minnesota; at Morris (in Stevens County) in west-central Minnesota; and at Crookston (in Polk County) in north-west Minnesota. The yield trends at the stations and in the counties are shown in Figures 1-4.

RESULTS

The results are summarized here, and a more detailed analysis is presented later.

The analysis involved the estimation and interpretation of experiment station and county yield functions. The functions include weather variables, input and product prices, and technology indicators. The estimated yield functions are presented in Table 1. A brief interpretation of the results is presented in this section. A more detailed analysis of the results is presented on pages 11 to 29. A discussion of the methodology is presented in Appendix A (p 32 to 36). And a survey of the literature on yield ceilings is presented in Appendix B (p 37 to 39).

Weather

Weather variations had a significant and important impact on year to year changes in soybean yields both in the counties and at the experiment stations.

Higher than average July precipitation and temperature tend to boost county average yields. A longer bean fill period, from August 15 to the first frost, also tends to increase farm yields. Variations in precipitation and temperature in June and August were not statistically significant sources of variation in county average yields. Nor was the length of the frost free period (from first to last frost).

At the experiment stations, above average July precipitation was also associated with higher yields -- but only up to a point. Both too much and too little July precipitation tended to have an adverse effect on yield. In contrast to the county results, higher June rather than July temperatures tended to increase experiment station yields. Season length, bean fill period, June and August precipitation and July and August temperatures were not statistically significant nor important.

Under similar weather and price conditions yields tend to be higher on the average (a) at the Waseca and Morris stations than at the Crookston station, and (b) in Waseca County than in Stevens and Polk Counties. With average weather at each location yields would be highest in Waseca, intermediate in Stevens, and lowest in Polk County. The same order holds for the experiment stations.

Prices

County average yields increase when farmers expect the price of soybeans to increase relative to the price of corn. This relationship is both statistically significant and important. County average yields also tend to rise when the expected price of soybeans increases relative to fertilizer prices. Although this relationship is significant, it is not very important. Large increases in the price of soybeans relative to fertilizer are associated with only small increases in yield.

At the experiment stations yields were not significantly influenced by either the soybean-corn price ratio or the soybean-fertilizer price ratio. This is because the design of yield tests at the experiment stations is normally not modified in response to short run economic fluctuations.

Technical Change

Three variables were used to capture the effect of technical change on yield -- time trend, row spacing, and research expenditures. The time trend and research expenditures represent aspects of technical change which could not otherwise be specifically identified and measured. One important component is genetic/varietal change.

The time trend is effective in capturing part of the effect of technical change at the experiment stations. The coefficient for time is significant and important at all three experiment stations. The time trend is less effective at capturing the effects of technology on county average yields. It was a significant variable in Waseca, but not in Polk and Stevens counties.

Row spacing was an effective indicator of the effect of technical change on average county yields. Many of the cultural practices that have contributed to higher yields, particularly weed control, have been associated with narrower row width. At the experiment stations row spacing was a less effective indicator of the effect of technical change.

Narrower rows were associated with higher yields only at the Morris experiment station.

Lagged expenditures for applied and basic research also turned out to be significantly and importantly related to yield increases at the experiment stations. The results are, however, somewhat puzzling. A comparison of the coefficients for basic and applied research suggests that, at the margin, expenditures on basic research have had a much larger impact on soybean yields than expenditures on applied research.

There is also a second puzzle that emerges from the yield function analysis. There is a distinct break in the relationships between soybean yields and several independent variables before and after 1960. When all other factors are held equal estimated county yields are higher in the pre-1960s than in the post 1960 period.

There have been several suggested reasons for this which could not be rejected: 1) favorable weather during the earlier period which was not captured by the weather variables, 2) an increase in land quality from land diverted out of corn production by acreage set-asides, 3) the introduction of group 0 and 1 varieties in the early period which were significantly better than the older soybean varieties, coupled with disease emergence in the late 1950s, and 4) this may suggest it has become somewhat more difficult or more expensive, to generate the new technology needed to increase soybean yields since 1960 than before.

Figure 1. Minnesota average yield and acres harvested—soybeans, 1941-1979

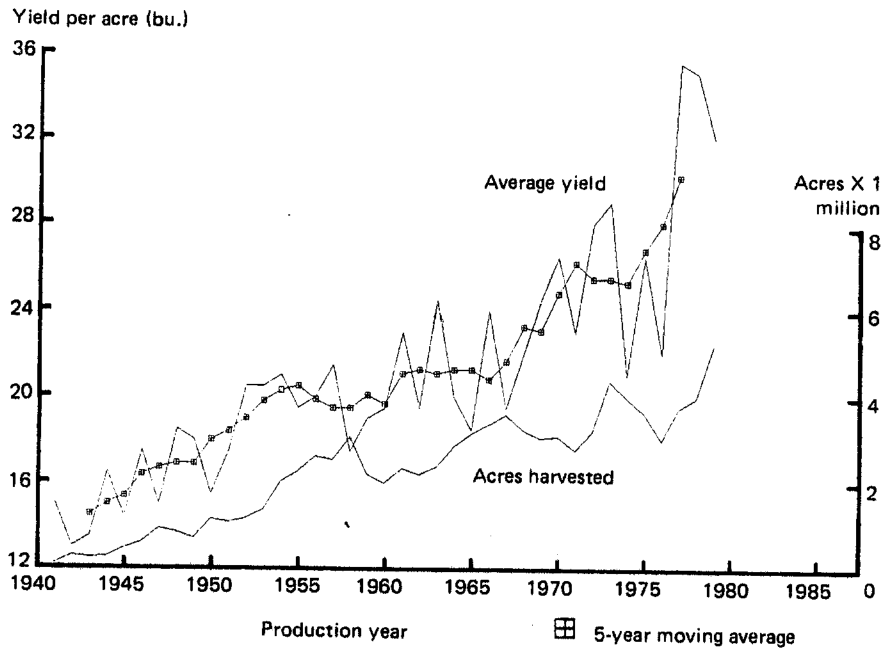


Figure 2. Relationship between Southern experiment station, Waseca, and Waseca County farm yield of soybeans—1943-1979

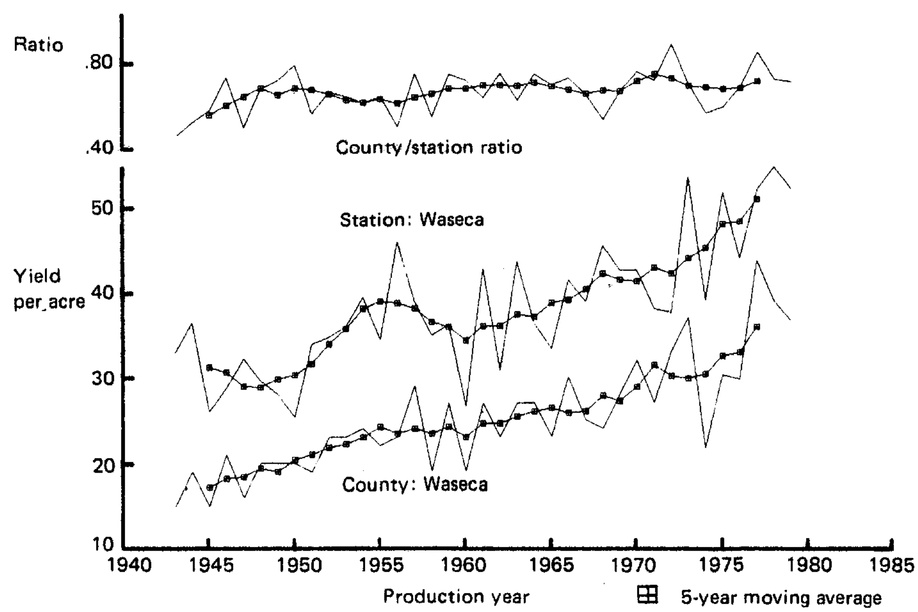


Figure 3. Relationship between West Central experiment station, Morris, and Stevens County farm yield of soybeans—1944-1979

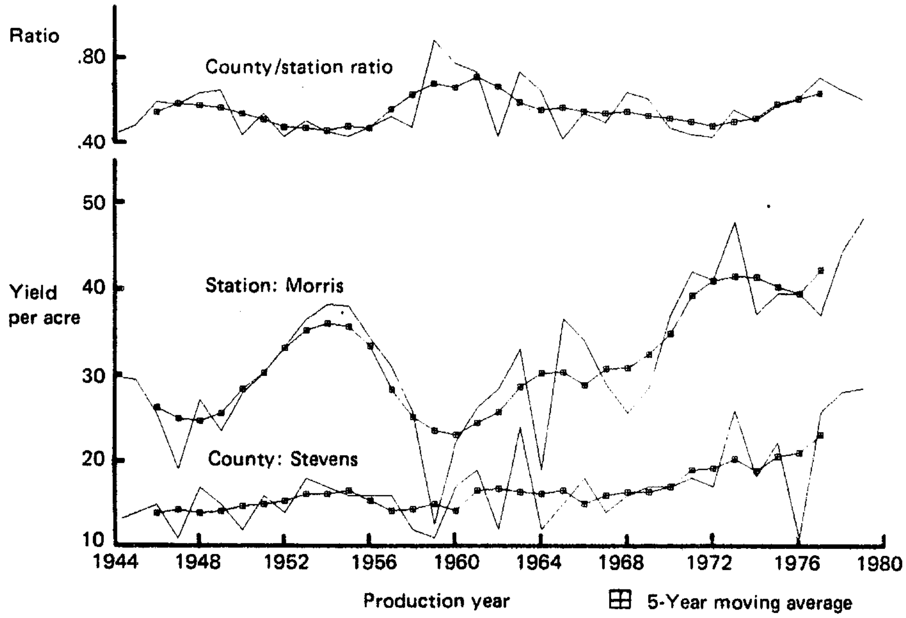
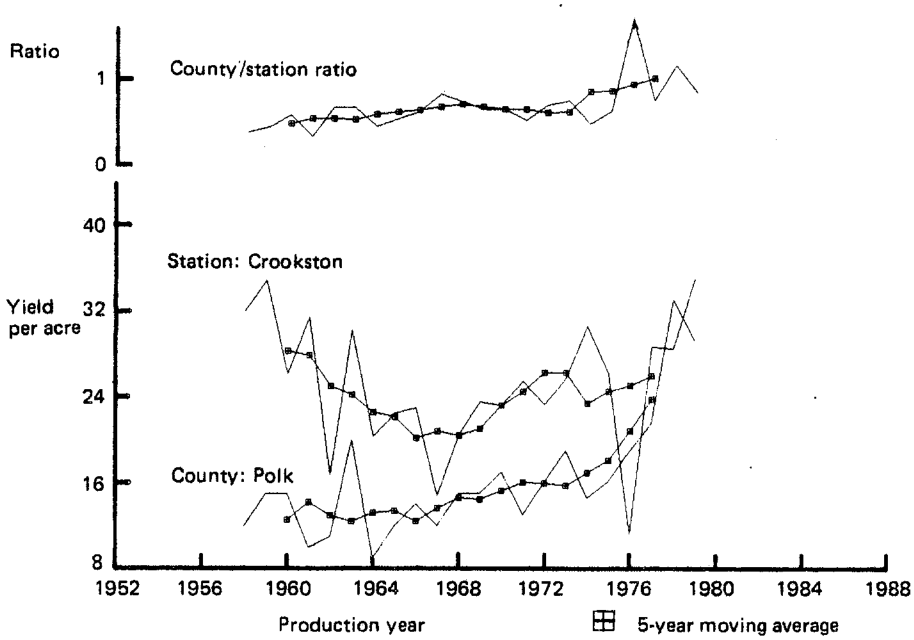


Figure 4. Relationship between Northwest experiment station, Crookston, and Polk County farm yield of soybeans—1958-1979



Source for figures 1-4: (1) County data are from *Minnesota Agricultural Statistics* (USDA-Minnesota Department of Agriculture, St. Paul, annual issues). (2) Station data are from *Results of Cooperative Uniform Soybean Tests,* Northern States (USDA Regional Soybean Laboratory, Urbana, Illinois, annual issues). Yield data are averages for five varieties with highest yield in specific group trials.

TABLE 1
ESTIMATED YIELD FUNCTIONS

	County	Experiment Station
Constant	14.2380 (13.66)	-73.28 (24.03)***
First Frost	0.8749 (0.2017)***	
June Temperature		0.7397 (0.2315)***
July Temperature	0.3328 (0.1320)***	
July Precipitation	0.4138 (0.1668)**	3.3521 (1.1193)**
July Precipitation^2		-0.2603 (0.1195)*
Soy/Corn Futures Price Ratio	5.146 (1.3044)***	
Fertilizer/Soy Futures Price Ratio	0.7557 (0.2370)***	
Time dummy 1961-78=1 1940-60=0	-2.6028 (0.9506)**	
Waseca Location Dummy		13.5322 (1.6598)***
Morris Location Dummy		25.1687 (6.7242)***
Time	0.1486 (0.0109)*** (Waseca county only)	0.7351 (0.2845)**
Row Spacing	-0.9672 (.1994)***	-0.5173 (0.1908)** (Morris station only)
Applied Research$_{t-i}$		$\sum_{i=6}^{12}$ (-0.0379 + .0076i) (0.0022)***
Basic Research$_{t-i}$		$\sum_{i=6}^{12}$ (0.1958 - 0.3590i + 0.0418i^2) (.0872)***(0.0104)***
Research Interaction$_{t-i}$		$\sum_{i=6}^{12}$ (0.0065 - 0.00026i^2) (0.00007)***
$\bar{R}^2$	0.82	0.62

(TABLE 1 Continued)

One, two and three asterisks refer to 0.05,0.01, and 0.001 levels of significance, respectively.

Environmental Variables

First Frost is the number of weeks from August 15th to the first frost. It is meant to represent the amount of time available for the bean pods to fill out before cold curtails growth.

June and July Temperatures are the means of daily mean temperatures for June and July, respectively. The daily mean is the average of the 24-hour high and low. June Temperature is meant to reflect the effect of June temperature variation on yields, and July Temperature to reflect the effect of July temperature variation on yields.

July Precipitation is the total amount of precipitation in inches for July. It is an imprecise measure of the amount of soil moisture available to the plants. July Precipitation^2 is the square of July precipitation. July Precipitation^2 is meant to reflect the adverse effects of either too much or too little rain.

Time Dummy is a dummy variable for time, dividing the series into an early period, pre-1961, and a late period, post-1960. It is meant to allow for the possibility of a structural change over time. Waseca and Morris Location Dummies are intercept dummies. They represent differences between locations.

Economic Variables

Soy/Corn Futures Price Ratio is the ratio of the Chicago mid-April futures prices for soybeans and corn for delivery in September and December, respectively. This variable is meant to reflect the farmers' expected price ratio of soybeans to its closest competitive crop, corn, at harvest time.

Fertilizer/Soy Futures Price Ratio is the ratio of the U.S. fertilizer price index (cost of production, 1967 basis) to the futures price of soybeans (discussed above). It is meant to capture the effect of the farmers' fertilizer allocation decision.

Technical Change Variables

The time trend is meant to represent (unidentified) technical change other than that specifically identified by other variables such as row spacing and research expenditures.

Row Spacing is the estimated state average row spacing of soybeans, for the counties. Row Spacing is the actual recorded row spacing at planting for the experiment stations. At both the experiment stations and in the counties this variable is meant to reflect the effect of changing the row spacing made possible by herbicide and related technical developments.

The last three terms, Applied Research, Basic Research, and Research Interaction, are real research expenditures for Minnesota. Applied Research is the amount of research funds devoted to applied research on soybeans. It is meant to capture the yield effect of own-state applied research investment. Spill-ins from other states were not available. Applied research is defined to be that for which results are meant to be directly applicable on the farm, e.g. new varieties. Basic Research is the amount of research funds devoted to theoretical or fundamental research on soybeans. Fundamental research is defined to be that for which the results would not be expected to be useful on the farm without further work, e.g. plant physiology. The interaction is intended to reflect the complementarity of basic and applied research.

ANALYSIS

COUNTY MODEL

A Weather

1) Temperature and Precipitation

Plant moisture stress may arise from two sources. Low soil moisture may directly stress the plant. High ambient temperatures may cause the water requirement to exceed the rate of translocation and uptake, thereby introducing stress. One well recorded datum that may serve as a proxy for soil moisture is precipitation.

The monthly temperature is a monthly average of daily averages. The daily average is the mean of the high and low of the twenty-four hour period at one location. Use of such an average may tend to wash out the effect of, for example, one week of 95 degree temperatures. The implicit equal weighting of daily average temperatures and even the extremes within the daily average may not be an accurate reflection of the effect of those extremes. However, daily or weekly oservations would have been unmanageable.

Each degree F rise in the average July temperature is associated with a 0.33 bushel increase. At some point one would expect the marginal effect of temperature to become negative as soil moisture or atmospheric stress increase. However, the quadratic term which would have allowed the marginal effect to become negative is not significant. It seems that the observed range of average July temperature is not wide enough to permit this phenomenon to emerge.

Each inch of rainfall in July adds about four-tenths of a bushel to yields, without a significant diminishing effect. Here, also, it seems that the range of the data is not wide enough to show an adverse effect of too much or too little rainfall.

The other June and August precipitation and temperature weather variables were not significant.

2) Other Weather Variables

Early frosts affect yields. If the weather is favorable, the beans will fill out and then rapidly dry down in the field. If early frosts occur, then the beans will not fill out completely, resulting in reduced yields. The number of weeks from mid-August until the first frost represents the amount of time for the beans to fill out. Since a number of varieties is used within a county, one would suspect a positive, but diminishing effect on county average yields. Early frosts reduce county yields by about 0.9 bushels per week. There is no evidence of a diminishing marginal effect on county yields from this factor.

Soil moisture depletion might carry over into the next year unless sufficient precipitation were received to replenish the soil moisture. Inadequate soil moisture in the Spring could lead to delayed germination, poor emergence, and worse. This effect is represented by the sum of the previous ten months' precipitation, and is not significant in either model.

Other weather variables which were not tested are hail distribution and incidence, flooding, wind, and other catastrophies.

Measures of these were not available. However, this may not be important since the yield measure is only for harvested acreage, and many acres would not be harvested after such catastrophies.

The significance of the time dummy means that, all other things equal, yields were about 2.5 bushels higher in the earlier period (1948-60), than in the recent period (1960-1978). A number of possibilities were suggested, but could not be eliminated. 1) One possibility is a favorable weather effect for the early period which is not captured elsewhere. 2) Another possibility is in institutional incentives. The diversion of acreage out of corn production in the early period may have tended to boost the average quality of land in soybeans. 3) Group 0 and 1 new varieties were released in the early period, with yields substantially higher than the original Chinese introductions which were used prior to 1948. In the later period soybean diseases became more prevalent. 4) This difference suggests that it may have become more difficult to generate the new technology needed to increase soybean yields since 1960 than before.

The location dummies were not significant for any of the counties. In addition, other weather, price and technology variables were not significantly different between counties. These results do not refute the hypothesis that the model is essentially the same for each county. This is interesting in light of the differences in location of the counties and the differences in importance of soybeans between those counties.

B Prices

Using economic theory, it can be shown that all factor prices and expected output prices (of substitutes) should be included in the yield equation. Under expected profit maximizing conditions one can derive factor damands in terms of input and expected output prices. The production function can be seperated into a yield and an acreage function. Substituting derived factor demands into the yield function delivers the yield function in terms of input and expected output prices (7), (22). Since the factor demands are homogeneous of degree zero, the yield equation must be also. This restriction can be imposed by estimating the model using price ratios rather than prices.

The Spring soybean and corn futures prices represent farmers' expected output prices. The soybean to corn futures price ratio is highly significant and important. Each increase of one unit in the price ratio is associated with a five bushel yield increase. For example, each $2 increase in the price of soybeans would be expected to increase soybean yields by five bushels with a $2 corn price. This means that farmers not only allocate their land according to expected crop prices, but they also allocate their time and other resources, within the growing season, according to those prices.

The price index of fertilizer deflated by the soybean futures price is highly significant, and the sign of the coefficient is as expected, negative. However, each 100 point rise in the U.S. fertilizer prices paid index (1967 base) decreases yields by only .75 bushels, with constant expected soybean futures prices. So fertilizer prices, although significant, do not appear to be important to

Minnesota farm soybean yields.

Other factor prices should be included in the estimation, but were not available. In real terms it seems unlikely that the correlations of these omitted variables to the included variables would be large enough to substantially bias the estimates.

The technical situation for herbicides suggests inelasticity of demand for herbicide use on soybeans, and consequently a small price coefficient. The combination of a small coefficient and correlation suggests there is no significant bias to other variables by not including herbicides in the model.

For example, yield loss may be as great as 50-60% of the yields of clean rows (16). Effective weed control (clean rows) is a combination of proper cultivation (80-85%), and proper herbicide application (14-19%) (27). Using a 50% yield loss figure, a 15% contribution from herbicides, and a forty bushel "clean" yield, results in a 3 bu per acre contribution from herbicides over and above mechanical cultivation. At $5.00 per bushel that is $15 per acre due to herbicides alone. This is a very conservative estimate. At the experiment stations, herbicide treatments consist of perhaps 1 pound of Treflan and 2 pounds of Amiben per acre. Treflan costs about $1 per pound, so the cost of the herbicides with application is probably less than half the value of its contribution to yield. In other words, herbicide prices would have to increase dramatically for them not to pay off. This suggests that herbicide use is very unresponsive to price and that therefore the herbicide price coefficient would be small.

C Technology

There are several dimensions of technical change in soybean production. One of these is weed control. Although herbicide prices are an economic variable, the improvement in herbicide quality is a technical change variable. One of the effects of this change has been to enable farmers to plant rows closer together without suffering increased weed competition.

Row spacing is an important and significant explanatory variable. Each inch rows are narrowed adds, on average, one bushel to yields. However, this must be taken with a grain of salt. The lack of an explicit measure for genetic change provides the potential for specification bias. Time might be used as a surrogate for varietal improvement, and row spacing is highly correlated with time. Thus

$$\hat{B}_{row} = B_{row} + R_{rg}B_{genetics},$$

in specification bias terms. R_{rg} is the correlation between genetics and row spacing (<0), B's are true parameters and $\hat{B}$ is the estimated row width parameter. B_{row} should be negative and $B_{genetics}$ should be positive, leading to a $\hat{B}_{row}$ which is probably too large in absolute value. This means that row spacing may represent factors in addition to row spacing. Yields may be increased by narrower rows alone, at the same population, but perhaps not by as much as one bushel per inch.

An attempt was made to include genetic change. A variable was constructed called the potential yield difference (PYD). The PYD is intended to measure the average yield difference of newer varieties relative to a base variety, and is derived from the Uniform Regional

Soybean Trial (URST) results.

The PYD_{tk} can be expressed as:

$$\frac{\left(\sum_{i=1}^{L} \sum_{t}^{N} (Y_i - Y_j)_t \; T_t\right) A_{itk}}{\left(\sum_{t=0}^{N} T_t\right) \sum_{i=1}^{L} A_{itk}}$$

Where Y_j is the reference variety yield, T is the number of test locations, A is the acreage sown to variety i, t is time, k is location, and i is variety.

In essence, one designates a reference variety, one that was popular in the early period. Then one computes the average of the differences between other varieties and the reference variety over time from the URST results. Uniform treatment on all varieties at any one location in any given year make this a valid comparison. The differences are then weighted by the percentage of acreage sown to the newer variety and summed for each year. Each sum represents the increase in yield to be expected over the reference variety due to genetic improvement and the distribution of that improvement through different varieties.

However, this variable was not significant. Apparently the variable failed to represent genetic improvement. There are several possible reasons for this.

First not all varieties were grown in every year, nor was the reference variety grown in every year in the URST. Thus the yield differences were "pieced" together relative to the reference variety which was popular in the early 1940s. I do not expect that this problem is significant since many years, test locations, and replications were used in the computation of each difference.

Second, and most important, estimates of acreages planted to each variety were not available. Certified acreage for each variety was used as a proxy. Unlike hybrid corn, next year's soybean seed can be taken from this year's harvest without foregoing high yields, since soybeans selfpollinate. Using 1978 figures optimistically, just over one-third of the total harvested acreage could have been planted using all the available certified seed. Misrepresentation of planted varieties by certified varieties is probably substantial.

PYD and row spacing do not represent the entirety of technical change on the farm. Other factors which were not explicitly identified and measured perhaps can be represented by a time trend. This would capture the regular or gradual change attributable to those unidentified factors. Some of those factors might be varietal change, machinery improvements, herbicide improvements and interactions between those effects.

A yield trend (Time), of 0.15 bushels per year, appears only for Waseca County. This means there has been technical change not associated with row spacing or other factors included in the farm model, but only for Waseca County. However, there was no significant difference between the trend for the early period and that of the later period. This suggests there has not been a yield plateau for Waseca County, but that there has been a plateau for Stevens and Polk counties.

IMPLICATIONS

The prospect for continually increasing soybean yields in Polk and Stevens counties is not good according to an initial reading of the county model. Row spacing (with the associated and enabling technology) seems to be the only way to systematically increase yields. However, there is a limit to how narrowly rows can be placed. Solid seeding, equivalent to about seven inch rows, is as narrow as can be had and still obtain satisfactory germination and growth characteristics. Anything narrower would involve compaction of the seed bed, leading to sporadic germination and emergence.

In Waseca County there is a significant time trend of about .15 bushels per year. That trend appears to be stable, indicating no yield plateau. In addition there is the potential to increase yields by narrowing the row spacing in Waseca County.

EXPERIMENT STATION MODEL

A Weather

The experiment station model is hypothesized to be different from the farm model. Although both types of yields are expected to be similarly affected by weather, economic portions of the models are different. The county model follows from economic optimization. The experiment station model is essentially a meta-production function including research as a cause of yield change. In the absence of profit maximization, short run prices are not relevant to experiment stations yield changes.

The stations differ somewhat since their intercepts (Location Dummies) are significantly different. This means that given the same circumstances, yields would be higher at the Morris and Waseca experiment stations than at the Crookston station. This is not surprising since Crookston is on the extreme northern fringe of the soybean belt.

June temperature increases experiment station yields by 0.74 bushels per degree F. At some point one would expect increasing temperatures to adversely affect yields. However, this is not born out by the data.

July precipitation does have a positive, but diminishing effect. About 6.4 inches of rain in July seems to be optimal for soybean yields at the experiment stations. This is consistent with Thompson's (24) formulation of precipitation parameters.

Early frost does not affect experiment station yields. Perhaps this is because varieties are closely matched to the length of the season.

Soil moisture depletion carried over from the previous year is not a significant factor. June precipitation, July temperature, and August precipitation and temperature are not significant in the station model.

B Technology

Row spacing seems to have a pronounced effect on yields, with a one-half bushel yield increase per inch decrease in row spacing, but only at the Morris station. This is surprising since the row spacing effect is so strong in the county equation. Since many of the varieties were the same on the farm and at the station over the time series, and row spacing was narrower at the experiment station, the individual effect of narrow rows may be overstated for the counties. This again suggests that the row spacing measure on the farm should be viewed as representing an index of technical change rather than as a single element of technical change.

Time has a large, significant coefficient. There has been a three-quarters of a bushel per year trend in experiment station top yields in Minnesota on average. This is taken to be technical change not associated with any of the other identified factors. In addition to that part of technical change, there is an effect attributable to expenditures on research.

Technical breakthroughs can be viewed as successful experiments that are drawn from some distribution of experiments. Applied scientific research may be thought of as a systematic combing of that distribution for successful experiments. Fundamental scientific research may be thought of as shifting, or creating new distributions of experiments (5). If basic research stops, then technical breakthroughs will tend to decrease over time as untried successful experiments are found and are exhausted. Similarly, if research effort per unit of time changes, this will lead to lower or higher expected rates of technical breakthroughs. Thus the rate of technical change at the experiment station depends on the rate of change of basic knowledge and the level of applied research effort.

Research effort may be represented by the constant dollar levels of expenditures. Until very recently virtually all soybean research has been at public experiment stations. Thus station expenditures on soybean research should be a good measure of research effort on soybeans.

Research effort can be classified a la Evenson (4) into two categories: applied research and general research. The distinction lies in the objective of the research, e.g. whether it is a direct improvement in the crop or its method of production (applied research); or enhanced knowledge of a plant's structure and environmental interaction (fundamental research). In reality a project may contain elements of both types.

As an example of the classification, in fiscal year 1944 costs of selected projects from the Agricultural Engineering, Agronomy, Entomology, Plant Pathology, Soils and Biochemistry Departments were classified into four mutually exclusive groups. One division was 1) Applied vs 2) Fundamental research. The second division was 1) Directly and primarily involved with soybeans vs 2) Partially or indirectly involved with soybeans. Thus Class I was Applied-Directly involved, II was Applied-Partially involved, III was Fundamental-Directly involved, and IV was Fundamental-Partially involved. The allocation of projects to these categories is summarized in Table 3 at the end of the ANALYSIS section.

Evenson's hypothesis about these types of research is that the applied effort and the interaction of applied and fundamental research effort are responsible for technical innovations. That is, fundamental research would not have a significant independent effect, but would work through applied research. Thus one would expect positive coefficients for applied research and the interaction of applied and fundamental research, but an insignificant coefficient for fundamental research alone.

An example of the interaction of applied and fundamental research is the recent and continuing stream of new herbicides predicated on the fundamental biochemical research carried out in the '40's and '50's. The basic research created a stock of knowledge which could be used to create and discover particular technical innovations: new herbicides.

Research investments do not usually pay off immediately. In the URST case it takes from 6 to 9 years for the initial crosses to be tested and purified to the point where they can be entered in the tests. For this reason lagged expenditures should affect current yields. Current expenditures should not affect current yields. In addition, the contribution to yields may not occur all at once, but may be distributed over several years. It also seems reasonable for the contribution to start, accelerate, and decelerate as the innovation is absorbed into the productivity base.

The last three terms in Table 1 represent Minnnesota real research expenditures, lagged 6 through 12 years. The Applied Research coefficients are positive and increasing with the lag, and the same is true for Basic Research. However, the coefficients on the Research Interaction are negative and declining. This means that both applied and fundamental research may contribute to experiment station soybean yields, but that these types of research appear to be competitive rather than complementary.

It is interesting to note that the sum of the coefficients is larger for theoretical research than for applied research. This suggests a higher payoff to theoretical research. When real expenditures get large and are approximately equally split between applied and theoretical research, the total effect can be dominated by the interaction, i.e. gains can be very small. This suggests there is an optimal level and distribution of real research expenditures. Taking the equation at face value, by shifting funds into theoretical research, the contribution to yields would be enhanced.

Considering the possibility of spillover effects, both from other states and from research not directed particularly at soybeans, there is a good chance that the research coefficients are biased. This may account, in part, for the disparity between the results and the hypotheses.

The spillover of fundamental research from other states may be captured by the in-state fundamental research variable, while the applied research may not, leading to the higher coefficients for fundamental research. Fundamental research results are likely to be valuable regardless of origination, while applied research results in soybeans may be oriented highly towards the local microclimate. If this is so, then the estimated coefficients for fundamental research have the potential of being biased upwards more than the applied coefficients. There is another possible reason for the apparent imbalance as well.

Applied research is likely to have a smaller probability of failure than fundamental research. If investing agencies are risk averse, then funds will be allocated on the basis of expected results and the degree of risk. The result is there may seem to be, in retrospect, an underinvestment in the more risky fundamental research. Capital rationing may reinforce the tendency to invest in research that is less likely to fail, i.e. the "success" image of the institution may be important for the directors of the institution to maintain.

It is slightly disturbing to have both a strong time trend and strong research effects in the same model. The time trend implies there is an unidentified source of technical change in addition to that of research investment. However, it is possible that the time variable and the research variable are picking up different parts of the technology effect.

IMPLICATIONS

The results are mixed. The time trend appears to be stable. However, the marginal contribution of current levels of research expenditures indicate a diminishing rate of productivity growth.

COMPARISON OF THE COUNTY AND STATION MODELS

1) Weather

Several differences between the models are expected, based on economic theory, and are "built in". These include using factor and output prices in the county model only, and using research expenditures in the experiment station model only. Other differences emerged from the data.

July precipitation is important to both models, but only for the experiment station model did there appear to be an optimum level. In the farm model the effect was linear. At the experiment station June temperature seemed to be important while on farms the July temperature took precedence.

The bean fill period until the first frost is important in the farm model, but not in the station model. This may be the result of the nature of the experiments. In the URST, maturity groups are closely matched with test locations so that the full cycle will be completed within a growing season. Farmers, on the other hand, may plant several varieties of different maturities to maximize yields given the variability of the first frost date. Since later maturing varieties also tend to yield more, this may account for the difference between equations. More nearly optimal growing conditions at the experiment stations may hasten seed set and development too, leading to rare frost effects.

The county yield model seems to explain more of the variation than does the experiment station equation. A word of caution: aggregating data for an area even as small as a county may have washed out some of the weather variations and yield variability, giving rise to a higher R^2. In any case the weather variables are only proxies for the real weather effects.

2) Technical Change

Row spacing, confounded with trend and perhaps other factors, seems to be important on farms, but row spacing is important only for the Morris station. Over this time series the changes in row width have been comparable for both farm and experiment stations. Neither is exceptionally narrow. Varieties have also generally been the same. However, row spacing at the experiment stations is not highly correlated with time, and is not very important in explaining experimental yields. This suggests row spacing may have contributed some to increases in farm yields, but that a substantial amount of the effect is due to other factors.

Contrasting the county and station models suggests that since there is a substantial difference between county and experiment station yields as well as a substantial difference in their rates of change, there exists an unused technical stock. That technical stock does not comprise the entire yield gap, but a large portion of it. The other part is largely attributable to physical differences of land quality.

If farmers treated crops the same as at the station, and if the high and low spots in the fields could be evened out, 85-90% of the station yield could be achieved in Waseca and Stevens counties (28). An estimate was not available for Polk County. If the farm yield potential is 90% of experiment station yields, then there is still a substantial technical stock in Stevens and Waseca counties.

In Stevens county there appears to be no trend in the ratio of county to station yields. Farm yields are not catching up to experiment station yields. The average of that ratio is 0.56, meaning the Stevens county farm yield is only, on average, 56% of the Morris experiment station yield. That leaves about 30% of the experiment station yield as an unused technical stock in Stevens county. In Waseca there is evidence that the county yield is catching up to the station yield, i.e. there is a positive trend in the county to station yield ratio. Even so, the 1980 estimated ratio is only .74 leaving some unused technical stock (10%) in Waseca.

Polk county showed a definite trend in the yield ratio, and the predicted 1980 ratio of county to station yields is 1.0. That prediction was based on a much shorter data series and strongly reflects a bad crop yield at the Crookston station in 1976 and an excellent county yield in 1978. With this in mind the ratio prediction must be discounted.

In short, there appears to be a substantial unused technical stock in Waseca and Stevens counties, but the picture for Polk county is not clear. The lower rates of yield increase at the Polk station may be attributable to growing soybeans on the fringe of the soybean belt.

SUMMARY

There is no indication that Minnesota soybean yields will reach a plateau in the near future. In Waseca and Stevens counties there exists a substantial unused technical stock. If the real price of soybeans increases, that stock can be expected to be used. There is a strong, stable yield trend for all three experiment stations, while county yield trends and yields are lower, indicating a growing technical stock.

If no new technology were discovered, what would it take for the county yields to catch up to the station yields? The predicted yields for 1981 are in the following table.

	WASECA	STEVENS	POLK
station	55	50	39
county	38	26	24

Table 2: predicted yields for 1981 based on research expenditures identical to those for 1978, average weather, and 1979 row spacing and prices.

The station yields are predicted by the county model with values of 6.0, 7.5, and 5.5 (Waseca, Stevens and Polk, respectively) for the futures prices ratio of soybeans to corn. With two dollar corn, a soybean futures price at planting in excess of ten dollars would be necessary to achieve equal station and county yields, if that were possible.

If the trend in Waseca county could be kept up without further technological change, it would take nearly forty years for farm yields on average to catch up to experiment station yields. This assumes normal weather, a three to one soybean to corn futures price ratio, row spacing of 22 inches on average (with a one bushel per inch increase), and a constant relative price of fertilizer to beans.

The effect of a large increase in the price of fertilizer would have a small effect on county average yields. A 50% price increase (a rise in the index from 200 to 300) would suggest an decrease in yields of only four-tenths of a bushel.

The potential for farm yield increases from narrower rows seems to be dramatic - one bushel per inch. However, row spacing seems to capture other effects as well.

Table 3

An Example of Classification of Research Projects into Fundamental and Applied Research Groups for FY1944

Group I -- Applied Research Primarily Involved with Soybeans
Agronomy and Plant Genetics Department
project 114: "Soybean Testing and Improvement"

Group II -- Applied Research Partially Involved with Soybeans
Agricultural Engineering Department
project 107: "Investigations Relating to the Design and Rehabilitation of Farm Drainage Systems"
project 119: "Combine Harvesting of Grain and Seed Crops"
project 133: "Determination of the Optimum Soil Moisture Conditions for Growth and Development of Major Crops and Methods of Establishing and Adaptation of Known Subdrainage Principles"
Agronomy and Plant Genetics Department
project 8: "Characteristics, Growth Habits and Control Methods of Weedy Plants"
project 121: "Crop Rotation Investigations"
project 122: "Cooperative Seed Production and Distribution"
Plant Pathology Department
project 8: "Characteristics, Growth Habits and Control Methods of Weedy Plants"
project 104: "The Development of Disease-resistant Varieties of Farm Crops"
project 110: "Plant Disease Survey"
project 302: "Weeds"
Soils Department
project 109: "Soil Survey"
project 116: "Rapid Soil Tests"

Group III -- Fundamental Research Directly Related to Soybeans
No Entries

Group IV -- Fundamental Research Partially Related to Soybeans
Agronomy and Plant Genetics Department
project 108: "Cytology in Relation to Genetics"
Entomology Department
project 139: "The Relation of Insects to the Spread, Transmission and Development of Plant Diseases"

(Table 3 Continued)

Plant Pathology Department
project 117: "The Relation of Insects to the Dissemination and Development of Plant Diseases"
project 120: "The Nature and Variability of Plant Disease Resistance"
project 121: "Aerial Dissemination of Allergens and Pathogens"
project 201: "Effect of Low Temperatures on Plants"
project 203: "Investigation of Respiratory Enzymes"
project 207: "Physiology of Seed Germination"
project 208: "Studies in Plant Metabolism and Growth"
project 301: "Seed Studies"
Soils Department
project 16: "A Comprehensive Study of the Sulfur Metabolism of Plants"
project 102: "Fertilizer Experiments"
project 117: "Exchangeable Bases and Base Exchange Relationships"

APPENDIX A

Data and Methodology

I DATA

A Weather Variables

Weather variables were collected for the experiment station locations and used also for the counties. These variables came from the annual summaries of the Climatological Data for the United States, U.S. Environmental Data Service: Dept. of Commerce. In addition to temperature and precipitation for the growing season months, several other weather variables were collected. Precipitation for the prededing September to June period was collected. The number of weeks from August 15 to the first frost was calculated. The number of weeks between last and first frosts was calculated to represent the length of the growing season. Other weather variables which could have affected yields, such as hail, were not available.

B Economic Variables

The fertilizer price variable is actually the U.S. fertilizer prices paid index (1967) reported in U.S. Agricultural Statistics. This was deflated by the futures price of soybeans to reflect the real price of fertilizer. Fertilizer prices may have differed in Minnesota, but previous work of mine (13) has shown the Minnesota price to be a linear transformation of prices at other locations; i.e. the U.S. index should be a good proxy.

April futures prices for September soybeans and December corn were taken from the Chicago Board of Trade Annual Statistical Summaries. These are the closing prices on either the 15th, 16th, or 17th.

County yields and harvested acreage figures came from the Minnesota Agricultural Statistics.

A price series for herbicides or a quantity series was not available.

C Technological Variables

Experiment station data were obtained from various editions of the Uniform Regional Soybean Trials. The yields were computed as the average of the top five varieties for each year, location and maturity group. The URST is an on-going program to compare recently developed varieties to established varieties under different conditions at different locations. At each location, however, the best agronomic and management practices are employed. The "Uniform" refers to the use of the same overall set of varieties at each station. Northern stations use groups of the 00 to IV maturity classes and the southern stations use groups of the IV to VIII classes, with those of appropriate maturity grown at each station.

Expenditure data was collected directly from budget books at the experiment station administrative offices. These figures diverge from total research expenditures for several reasons. The reported figures generally exclude nonspecific overhead such as secretarial, materials and office costs. Project leaders' salaries are not included in these figures unless allocation for their time was explicitly made. The administration of the experiment station itself is not included in any of these figures. USDA employees' salaries which are paid outside the experiment station are not included in the figures. In fact, no USDA funds are included in these figures. The full support of the branch stations is not included here. Private research expenditures are not included. Thus the estimated coefficients represent a maximum effect of research since the dollar amounts are consistently understated.

The selection of the projects to be included in the applied soybean research figure keyed on the inclusion of the word soybean in the project title, or a description which made it particular and nearly unique to soybeans. Obviously this eliminated a large portion of funds that were devoted to no single crop, but which included soybeans. Such projects might be weed, insect, or pest control, which impinge directly and significantly on soybeans, but the monies for which were not allocated by commodities in the budget books. These projects were further classified into applied and fundamental research groups (see Table 3).

Farm row spacing figures are from surveys of selected states reported in "Crop Production," Crop Reporting Board, SRS, USDA. Survey data only goes back to 1967, but before about 1963 rows were spaced an average of 40 inches. The values between 1967 and 1963 were interpolated. Experiment station row spacing data was directly available from the URST reports.

II METHODOLOGY

Ordinary least squares were used to estimate the models. One variable was added at a time, automatically, until no excluded variable would enter the equation at a 10% significance level. The economic variables were forced into the equations from the outset. Interactions between variables were calculated to test for location differences, interaction of weather variables, interaction of economic variables, and interactions of technological variables.

Some of the variables were not statistically significant at any level or did not meet the minimum requirements to enter the regression. Those variables were discarded.

Harvested acreage was not significant for inclusion after other variables. The significance level was so poor that harvested acreage was dropped from the regression. The estimated acreage coefficient would have been indistinguishable from zero, and would have added virtually nothing to the yield explanation. Apparently the acreage and yield functions are strongly seperable.

The potential yield difference (PYD) also fared poorly. The significance level was so poor that the PYD was also dropped from the regression.

Season length, preseason precipitation, and pod fill period[2] are other variables which were dropped due to lack of significance.

An Almon lag structure was used. The Almon lag structure (12, p. 356) estimates the lag coefficients after imposing a polynomial functional form, as a function of time, on those coefficients. That is, by imposing a polynomial form, only a very few parameters are estimated (typically two or three) rather than the full complement of lagged coefficients.

Since there should be some delay between spending the money and seeing the results in these particular experiments, it was hypothesized that there would be a five year delay for applied experiments and an eight year delay for theoretical experiments. Although the statistical test rejected that hypothesis, I could not discard that formulation since to expect immediate or even quick results would be unreasonable. It is not clear that meaningful results will be forthcoming in the first years, and once significant results are forthcoming, it takes time to analyse them, communicate them, and adjust to their implications.

The question of whether in fact there is a lag is not testable with the Almon lag structure. There is also no explicit test for lag length. In this case, however, I am confident there is a significant lag structure.

Other functional forms, Cobb-Douglas, Trans-Log, etc, were not used since this was a preliminary analysis.

APPENDIX B

Survey of Literature

Deaton's study (2) of grain production found no evidence of inordinately favorable weather and found it a rather ordinary period in terms of drought for the period 1954-73. "Climatologists generally accept, however, that the climate of the past half century has been milder than any previous half century of the preceeding 900 years (3)."

Thompson (23) suggests that "unusually favorable weather" has been a major factor in the corn production technology explosion of the 1960's.

Oury (14) suggested the use of the de Martonne or Angstrom aridity indexes as proxies for available soil moisture.

Stallings (19) and Shaw (18) extoll the advantages of the weather index in which a time-series of yields of plots with constant practices is used to compute the weather index as the ratio of the actual yield to the detrended yield. Such a measure captures the net effect of weather, and avoids the problems of selecting which variables to use and guessing at their relationship. It is also limited in its use to normal weather predictions. The index is highly location-specific, making it only useful for a small geographic area, perhaps several counties.

Individual temperature and precipitation variables may allow insight into the yield response function itself if yields are not from a wide geographic area. The weather index does not. Predictions using deviations from normal can be made as well as using normal weather. In addition, temperature and precipitation data is usually published for many locations, greatly simplifying data collection. This helps in estimating a geographically narrow response function, which is desirable in that several aggregation problems are avoided.

Aggregation to even the state level may wash out opposite weather effects and otherwise distort yields. Average state yields place too much emphasis on low production areas relative to higher production areas.

Swanson and Nyankori (20) suggest weather factors significantly depressed yield increases of corn and soybeans for the period 1950-76 on the Allerton Trust Farms, Piatt County, Ill. The importance of accounting for weather is demonstrated in this paper. When weather is accounted for, the linear trend coefficient for both corn and soybeans increases significantly. However, the results seem slightly muddled. Their comparison of the linear trends both with and without weather variables resulted in the statement that weather depressed the yield growth rate over the period 1950-76 on those farms. There may be some problem with that interpretation. I will look at it in a specification error context.

If a variable is left out that should not have been left out, specification bias may arise. In particular; $E(\hat{B}_t) = B_t + R_{tw}B_w$; where the B's are the true parameters, t is time and w is weather. Now it becomes obvious that the accuracy of the estimate will depend on R_{tw}, the correlation of time and weather. It is not clear that time and weather are correlated. Be that as it may, there are only two possibilities: either $R_{tw} = 0$ or $R_{tw} \neq 0$.

If $R_{tw} = 0$, leaving weather out of the model does not make a difference in estimating the yield trend. Both regressions (with and without weather) estimate the same thing. In this instance without more information it is very difficult to interpret weather as having depressed the rate of yield change. However, it may have depressed yields within that period.

On the other hand it may be that $R_{tw} \neq 0$. Then $E(\hat{B}_{t1}) = B_t + R_{tw}B_w < \hat{B}_{t2}$ (with weather), and B_t is only unbiasedly estimated in their second regression. $\hat{B}_{t1}$ has no particular importance because it is biased and the bias results from the misspecification of the model.

In either case it is very difficult to make the interpretation that weather depressed the yield trend over that period. Perhaps with more information such an interpretation would be warranted. What that would require could be expressed as $dY/dt = f(w) > 0$ (a positive yield trend where the weather variable enters) and $d^2Y/dtdw > 0$ with $\bar{w}_{1950-76} - \bar{w} < 0$ or $d^2Y/dtdw < 0$ with $\bar{w}_{1950-76} - \bar{w} > 0$. (The second case would be strange in that above normal weather would depress the yield trend.) This would be direct confirmation that weather depressed the yield trend. I suspect that $d^2Y/dtdw = 0$ by specification; i.e. time by weather interactions were not included in the model.

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