AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

Soybeans

25444

UNIVERSITY OF CALIFORNIA
DAVIS
SEP 10 1981
Agricultural Economics Library

THE CONTRIBUTION OF HERBICIDES AND OTHER TECHNOLOGIES TO SOYBEAN PRODUCTION IN THE CORN BELT REGION, 1965 TO 1979

by

David Schroder
Research Analyst
Department of Agricultural Economics
University of Missouri-Columbia

and

J. Charles Headley
Professor
Department of Agricultural Economics
University of Missouri-Columbia

and

Robert M. Finley
Professor
Department of Agricultural Economics
University of Missouri-Columbia

ABSTRACT

This report attempts to identify the contributions of technology and weather to soybean yield variation for the period 1965 to 1979 in the Corn Belt Region. Technology variables included were genetic improvement, herbicides, and row-width. A pooled cross-sectional time-series data base was used to estimate regression parameters for herbicides and other variables. A marginal private benefit/cost return of $2.3 per dollar of herbicide cost was estimated for additional land treated with herbicides.

1981

Soybeans

AAEA 1981

The Contribution of Herbicides and Other Technologies to Soybean Production In The Corn Belt Region, 1965 to 1979*

Introduction

The use of pesticides in the U.S. agricultural production systems has resulted in intensified production by controlling pest that would otherwise cause serious damage. Increasing use of chemicals in controlling weeds in soybeans is one of the important changes that has taken place in soybean production. Herbicides or weed control chemicals are used primarily as a substitute for labor and equipment in mechanical cultivation. In 1966, about 30 percent of soybean acres planted (27 percent for U.S.) in the Corn Belt were treated (USDA, 78).[1/] Alachor and Trifluralin were the two major herbicide compounds used in 1976. Regionally, the Corn Belt accounts for a substantial share of the herbicides used, which is more than 40 percent of the U.S. total.

Recently, increased attention and controversy, by governmental agencies and private companies, have been directed at the risk and benefits of chemical weed control in crop production. This controversy surrounding the use of agricultural pesticides in crop production was summarized by Headley.

> "The controversy surrounding the use of agricultural pesticides has resulted in the examination of pest control technology and a need for estimates of the cost and benefits of pesticides... Use of values determined through the market system to estimate benefits are a necessary part of evaluating chemical pest control... Considerably more analysis and information are required to evaluate pesticide technology and to form good national policy in this area," (Headley, 68).

---

*Submitted for Presentation as a Selected Paper at the American Agricultural Economics Association Meetings, (Pest Management Session), July 26-29, 1981, Clemson University, Clemson, South Carolina. This research is funded by EPA Cooperative Agreement (CR807130020) with the University of Missouri, Columbia.

The objectives of this paper are to evaluate the role of herbicides in soybean production within the Corn Belt Region since 1965 and to assess the productivity of output with respect to herbicides.

Recent Studies

Past studies addressing the contribution of pesticides to crop production are few. Most of the past studies have looked at all farm crops in general with respect to pesticide use. The most common method used to evaluate the value of productivity of pesticides to an added dollar spent on pesticide chemicals is the use of marginal analysis.

The most quoted study concerning the value of pesticides to agricultural production is that of Headley (1968, 1970), using a Cobb-Douglas function, estimated the marginal productivity of pesticides and other farm inputs including labor, land and buildings, machinery, fertilizer, and other expenses. The value of marginal product (VMP) ranged from $3.90 to $5.66 for pesticide expense. Headley considered his best equation estimate of marginal productivity of pesticides to be $4.16 in gross income for an additional dollar spent on pesticides.

Heady and Auer (1966), estimated the portion of increased predicted yields due to weather and technology for several major U.S. crops for the time period 1939 to 1960. Time-series production functions were employed as the basis for imputations. An approximated first-term Taylor expansion was used to estimate the annual changes in expected state crop yields. Their research indicated that the 4.1 bushel increase in soybean yields were due to weather, fertilizer, variety, location and other nonspecified variables. Fertilizer application was estimated to have increased soybean yields by 1.3 bushels. The location effect, (land effect) indicated a negative influence of 1.4 bushels, while other nonspecified technologies represented by trend indicated a .8 bushel effect.

Hawkins *et al.* (1977) estimated the returns to range from \$3.30 to \$4.89 per dollar of herbicide cost. Their analysis was conducted on ten years of experimental data of herbicide treatment on crop rotation systems. Their results were similar to what Headley found using aggregate expenditure data on pesticides with a production function approach.

Janke (1978) estimated the value of pesticides on crop farms in Northeast Kansas using several types of production functions; which consisted of linear, Cobb-Douglas, and quadratic forms. He found the linear and quadratic forms appeared to have the best fit. The results from the linear functional form indicated that on the average, Kansas farmers earned \$2.78 gross income per dollar expended on pesticides, whereas the quadratic functional form revealed a return of \$3.26 per dollar of pesticides expended. Returns were calculated at the mean of the pesticide expenditure sample.

Cashman *et al.* (1980) estimated the farm-level impact of selected soybean insecticides with respect to EPA bans. A mathematical programming model was used to simulate the operation of a 600-acre Indiana corn-soybean farm. Their research indicated that the benefit/cost ratio for each of the three soybean insecticides was greater than two, based on 1979 cost and price data. Also they found yield gains of 2.5, 2.9, and 3.4 bushels per acre for insecticides carbaryl, methomyl and malathium, repsectively, using regression analysis as experimental plot data.

The Method and Model

A pooled cross-sectional time-series analysis was made on soybean yields in the Corn Belt for the period 1965 to 1979. State average monthly temperatures (F) and total monthly rainfall (inches) for the following variables were considered: (1) Pre-season rainfall (September-May inclusive), (2) June rainfall and mean temperature, (3) July rainfall and mean temperature, and (4) August rainfall and mean temperature. The weather variables were expressed as deviations from the mean for the time period 1965 to 1979.[2/] The technology variables in the model include acres treated with herbicides, percent acres planted to row-widths less than 28.5 inches, and a genetic improvement index. State dummy variables were included in the model to estimate the state effects, and soybean harvested acres was used to measure the quality of land brought into production.

Ordinary least squares multiple regression was used to explain the variation in soybean yields when regressed on weather and applied technology variables.[3/]

In matrix notation the statistical model of interest reduces to the form,

$$\underline{y} = x\underline{\beta}+\underline{\varepsilon} \qquad (1)$$

where $\underline{y}$ is a (η x 1) vector of observations on the dependent variable, x is a (η x κ) matrix of nonstochastic observations on the explanatory variable, $\underline{\beta}$ is a (κ x 1) vector of unknown parameters, and ε is a η x 1 vector of normally independent disturbances with mean zero variance σ^2. In addition, the x matrix is assumed to be of full rank, κ. The usual procedure for estimating $\underline{\beta}$ is to use ordinary least squares regression, which will yield the best linear unbiased estimators, with minimum variance. The estimator is expressed in matrix notation as:

$$\hat{\underline{\beta}} = (x'x)^{-1}x'\underline{y},$$

The error term was tested for normality using Proc Univariate under the Statistical Analysis System 1979. The stem-leaf and box test indicated the error term was normally distributed, for the model specified in equation 1. The error term was also tested for heteroscedasticity across geographical units (states) and through time. The F-test was used to test the assumption of $E(\varepsilon_i)^2 = \sigma^2$. [4/]

A scatter plot of the residuals against time and other independent variables of the pooled data was used to determine if the error variance increased over time. The scatter plots showed no evidence that the error variance was increasing.

Variables for Soybean Model and Their Measurment

Annual observations for variables representing weather, acreage, variety improvement, acres treated with herbicides and inter-row spacing were collected for each state.

Monthly weather variables were obtained from USDA Oasis data bank. Each state is divided into various climatic divisions which are similar, in most cases, to the crop reporting districts designated by the Crop Reporting Service. State weather indices were aggregated by weighting each climatic divisions' monthly weather variables by the percent land area of the state's total land area for the respective climatic divisions.[5/]

Weather Variables

The pre-season moisture variable for each state measures the amount of rainfall (inches) from September of the past year, to May (inclusive) of the current year. This variable is assumed to reflect subsoil moisture conditions prior to planting. An above normal level of subsoil moisture and cool temperatures could be detrimental to seedling establishment, thus, affecting yield negatively.

June average temperatures (above normal) should have a positive effect on soybean development during seedling establishment and vegetative growth. Normal July and August temperature should have a positive relationship to soybean yields. However, consistent high temperatures above 86 F should have a negative effect on yield. This is due to the structural and physiological nature of the soybean plant. Soybeans are classified as C-3 plants which carry on photorespiration during the light period as well as normal respiration during the dark period.[6/]

Rainfall in July and August appear to be very important in soybean production. Runge and Odell (1960) in Illinois, indicated soybeans have two severe periods of moisture requirements. One in mid-July when the vegetative growth is extremely active and the other in mid to late August when the pods are filling-out. They found that above normal precipitation during blooming and pod-filling periods increased yields, whereas abundant rainfall during early vegetative growth periods was detrimental to yield. Thompson (1970) reports essentially the same results in his time-series cross-sectional pooled data for the five Corn Belt States for the period 1930 to 1968. Shaw and Laing (1965) further substantiate the importance of moisture stress during the bean filling stage and the last week of pod development. Their results indicated greater decreases in yield when stressed during pod-development than during the vegetative stage or the first part of the flowering period which may prevent luxuriant vegetative growth and reduce lodging.

Land and Applied Technology Variables

The acreage variable; soybean harvested acres, expressed as millions of acres, reflects the land quality brought into soybean production. Historically as new land was acquired, it was planted to soybeans with very little production inputs applied. Since the 1950's, soybeans have become a major income crop in the Corn Belt Region. Much of the land is in crop rotation, thus shifting from corn to soybeans. Additional land brought into soybean production from government set-aside programs or pasture-wheat programs would be marginal and, therefore, have a negative influence on soybean yields. Since 1964, soybean acreage in the Corn Belt increased 84 percent, whereas corn acreage increased only 13 percent.

Acres treated with herbicides is a proxy variable to measure the average contribution of herbicides on soybeans in the Corn Belt States since 1965. Chemical herbicides are being used increasingly in soybean weed control, and are hypothesized to increase yields. The herbicide variable, in the model, is thus expected to be positively related to yields. The USDA (1965) estimated average annual losses of about 17 percent of the potential value of the crop due to weeds. Yields in experiments with natural infestations of annual weeds confined to the row were reduced 6 to 27 percent. Staniforth (1965) showed that a stand of 80 giant foxtail plants or 10 velvet leaf plants per meter of row, reduced yields by 25 percent. Knake and Slife (1962) reported that giant foxtail reduce soybean yields by up to 30 percent. In experiments in Iowa over several years, annual weeds such as foxtail, pigweed, smartweed and velvet leaf, reduced soybean yields 10 percent on the average, despite use of good cultural practices for control.

In 1960, several herbicides were made in granular formulation and the herbicide chloramben was evaluated as a pre-emergence treatment. Chloramben showed considerable potential for selective control of both broadleaf and grassy annual weeds. In 1963, trifluralin became available for use as a pre-planting incorporated treatment for control of annual grasses in soybeans. This new herbicide required farmers to incorporate it into the soil before it volatilized. The herbicide alachor was registered for use on soybeans in 1969. It was chemically similar to propachlor, which controls many annual grasses and some broadleaf weeds. However, alachor controlled weeds for a longer period of time.

Herbicides such as trifluralin, nitralin, chloramben, alachor, and linuron, together with good cultural practices gave producers the means to control annual grasses and some broadleaf weeds in soybeans.

Surveys to estimate herbicide usage in crops show a marked increase in use of herbicides in soybeans from 1959 to 1979 (USDA; 1968, 1975, 1978). The estimated percentages of the total soybean acreage in the United States treated with herbicides were 2, 10, 23, 55, 77 and 92 in 1959, 1962, 1965, 1968, 1971, 1976, respectively.

In the 1970's, more than 30 herbicides were being used on soybeans in the United States. Those herbicides have allowed for improved weed control and encouraged the development of new cultural practices, such as narrow-rows and increased plant population. These two practices have a tremendous impact on reducing soil erosion during the growing season by giving additional soil coverage and reducing tillage operations.

Row-width has decreased on the average for the Corn Belt Region. The percent acres planted to row-widths less than 28 inches was collected for each state per year. Surveys conducted by USDA (1971) measured row-widths in categories from 1965 to 1976, then added two additional categories since 1976. Row-widths were measured as rows less than 28.5 inches, 28.6 to 34.5 and greater than 34.6 inches. This variable in equation 1 is hypothesized to be positively associated with yields.

Soybeans are usually grown in rows of 20 to 40 inches apart in the Corn Belt. In 1965, less than 6 percent of the acres planted to soybeans in Illinois, Indiana, Iowa, and Missouri were in rows less than 28 inches while Ohio planted approximately 22 percent of its soybean acres to row-widths less than 28 inches. Average row-width for the Corn Belt States excluding Ohio was around 36 inches for 1965 (USDA, 1971). In 1980, soybeans planted to rows less than 28 inches increased in Illinois, Indiana, Iowa, and Missouri by 15 percent, whereas in Ohio it increased 10 percent. Average row-width for the Corn Belt was 33 inches in 1980.

The movement to narrow rows has been encouraged by effective weed control by the use of herbicides. Herbicides have reduced the need for cultivation, if not eliminated it totally. Studies have demonstrated that maximum yields result from increased plant population. Donovan *et al.* (1962) evaluated the performance of Mandarin soybeans planted at intervals of 2.5, 5 and 7.5 cm (1", 2", and 3") within the row. Maximum yield was obtained from the combination of narrowest row-width and widest within-row plant spacing variables. Inter-row spacing varied from 13 cm to 102 cm (5 to 40 inches) and plant populations ranged from 13,000 to 929,000 plants/ha (5,000 to 272,000 plants/acre). Other research has indicated that yields tended to be highest at populations between 170,000 to 400,000 plants/ha (Cooper, 1971; Fontes and Ohlrogge, 1972; Hicks, *et al.*, 1966; Hinson, *et al.*, 1962; Lehman and Lambert, 1960; Weber, *et al.*, 1966).

<u>Genetic improvement</u> has been an important technology in yield improvement in soybeans. The variety index was developed by dividing current mean variety plots yield data by each state's base year. The base year, which does not include the year 1965, represents a five year average. This approach has limitations in measuring relative genetic gain. The variety index equal to 1 says the base year varieties are performing as well as the early developed varieties. A value greater than 1 indicates genetic improvement.

The variety index was developed from the USDA uniform variety test plots for the North Central States. The overall plot mean in group maturity

IV was used since the maturity group captures the major area of the Corn Belt.

During the early 1900's soybean producers in the midwest grew either plant introductions from the Orient or pure line selections from these introductions. The hybridization programs started by 1930 selected progeny that were superior to their parents. The first cultivars of hybrid origin were released in the 1940's for production in the midwest. Luedders (1977) and Wilcox, *et al.* (1979) measured genetic improvements in yield of soybeans for maturity groups II, III and IV.[7/] Their results showed that breeding contributed substantially to the yield and lodging resistance of present commercial cultivars in maturity groups II, III and IV. Since 1965, U.S. soybean yields have increased 44 percent. Wilcox showed that plant breeders have increased yield potential of soybean cultivars by 25 percent.

Binary variables were used to measure geographical difference as well as environmental difference between states. Missouri and Ohio together represented the base for which the other states were measured, this procedure allows one to save degrees of freedom. Also both states had very similar intercept values. The difficulty with the OLS procedure is that the assumption of constant state intercept may be unreasonable in pooled model.[8/] Also the dummy variables helped to improve the R-square. In addition, it is expected that different states may have different intercept values due to environmental differences.

There are several important problems associated with the use of covariance model for the purpose of pooling. The use of dummies may not directly identify the variables which might cause the regression line to shift over geographical areas. Another problem is a substantial portion of the error variation may be explained, without obtaining specific information about the model.

Results and Discussion

The results from OLS estimation procedures are summarized in Tables 1 and 2. Table 1 represents a linear model with weather variables expressed as deviations from normal and incorporates the applied technology variables discussed earlier, while Model II uses the conventional trend variable as a proxy for technology.

The weather variables in Models I and II are highly significant. A one unit change in June and August temperature from normal would change area soybean yield by .34 and .47 bushels per acre, respecitvely. A per unit change in July and August precipitation would affect soybean yields by .93 and .51 bushels per acre, respectively. Estimated parameter values for the weather values were smaller than those estimated with trend as a proxy for technology. This points out that models that use trend as a proxy for technology would tend to over estimate the values for weather variables. Since there is variation in both weather and applied technology variables, year to year variation in yield is not solely due to weather variation but also changes with levels of physical production inputs.

During this time period, predicted area soybean yields increased by 7.3 bushels per acre. The total effect of weather can be portioned out by multiplying the estimated regression coefficients, in model I, by the change in the weather input variables from 1965 to 1979. The portion of the change in predicted soybean yeilds since 1965, due to total weather is summarized in Table 3, for each state and the average effect. The slope parameters estimated in the cross-sectional time-series model were assumed to be constant for each state. Weather variation, for the average, accounted for approximately 2.6 bushels per acre of the 7.3 bushels per acre change in predicted yields.

Table 1 - Linear Covariance Multiple Regression Model for Soybean Yield Using Pooled Cross-Sectional Time-Series Data for the Corn Belt 1965-1979

Variables	Model I Parameter	Model I T-Ratio	Model II Parameter	Model II T-Ratio
Intercept	17.626	6.85	28.3092	25.90
Pre-season Moisture 1/	-0.163	-2.93	-0.1518	-2.38
June Temperature	0.3489	3.32	0.3799	3.07
July Precipitation	0.9323	5.52	1.3116	7.10
August Precipitation	0.5148	3.24	0.5343	2.95
August Temperature	0.4764	3.45	0.5626	3.62
Harvested Acres	-0.000000424	-0.56	-0.00000165	-3.97
Herbicides	0.000000783	1.99	--	--
Variety Index	6.1857	4.19	--	--
Narrow-Row	0.1535	4.69	--	--
Trend	--	--	0.6617	7.3
D17 (Illinois) 2/	6.5847 2/	3.55	11.340	6.23
D18 (Indiana)	4.747	7.34	3.303	5.31
D19 (Iowa)	6.207	5.15	9.243	6.95
R^2	87		81	
$\bar{R}^2$ 3/	84		79	

(1) Weather variables are measured as deviations from normal.

(2) State effects, base variable includes Missouri and Ohio.

(3) R-square adjusted for degrees of freedom.

Table 2 - Second Degree Polynomial Covariance Multiple Regression Model for Soybean Yield Using Pooled Cross-Sectional Time-Series Data for the Corn Belt, 1965-1979

Variables	Model			
	III		IV	
	Parameters	T-Ratio	Parameters	T-Ratio
Intercept	18.656	6.83	28.4204	25.68
Pre-season Moisture 1/	-0.1867	-3.26	-0.1692	-2.65
June Temperature	0.2675	2.38	0.2746	2.14
June Temperature Squared	-0.0076	-0.212	-0.0127	-0.32
July Precipitation	1.1112	6.35	1.484	7.93
July Precipitation Squared	-0.1026	-1.14	-0.2392	-2.39
August Temperature	0.5175	3.52	0.5965	3.69
August Temperature Squared	0.1666	2.435	0.1373	1.75
August Precipitation	0.6526	3.68	0.7146	3.70
August Precipitation Squared	-0.1028	-1.25	-0.1725	-1.83
Harvested Acres	-0.000000908	-1.14	-0.0000017	-4.03
Herbicides	0.00000111	2.65	--	--
Narrow-Row	0.1339	4.022	--	--
Variety Index	6.3077	4.44	--	--
Trend	--	--	0.7126	8.24
D17 (Illinois) 2/	7.4110	3.92	11.63	6.74
D18 (Indiana)	4.6466	7.42	3.584	6.06
D19 (Iowa)	6.7162	5.43	9.7060	7.62
R^2	88		84	
$\bar{R}^2$ 3/	84		80	

(1) Weather variables are measured as deviations from normal.

(2) State effect, base variable includes Missouri and Ohio.

(3) R-squared adjusted for degrees of freedom.

Table 3 - Predicted Soybean Yield Portions Attributed to Weather, Land, and Technology Effects for the Corn Belt States, 1965 to 1979[1]

State	Change in State Yield		Sources of Yield Change and Amount Per Acre				
	Actual	Predicted	Weather[2]	Land	Herbicides	Narrow Row	Variety
Illinois	9.00	7.20	2.34	-2.14	6.19	1.26	0.45
Indiana	8.00	8.50	5.07	-0.66	2.74	1.24	0.06
Iowa	12.0	9.30	2.82	-1.41	5.32	0.45	2.05
Missouri	5.50	2.00	0.18	-1.22	3.78	0.92	0.01
Ohio	11.50	9.40	2.59	-0.84	2.6	3.42	2.15
AVERAGE	9.20	7.28	2.60	-1.30	4.12	1.46	0.94

(1) The regression coefficients estimated in the cross-sectional, time-series model were assumed to be constant for each state.

(2) The weather contribution reflects the total sum of the effects of the individual parameters variable estimated in Model 1.

The values estimated for the weather values differed from those in the Thompson study (1970). These differences can be attributed to the different time period investigated, genetic differences, changes in management practices, functional form, and model specification. Thompson used a second degree polynomial model with trend for the time period 1938 to 1968. Estimated parameter values for similar months reported by Thompson were larger than those reported in this study. Thompson found the pre-season moisture variable to be positively associated with soybean yield in the linear term. The signs on August temperature for Thompson's quadratic model indicated that both the linear and squared terms were negatively associated with soybean yields, whereas, in this study, Models III and IV indicated they are positively associated with soybean yields. He further points out that cooler than normal temperatures favor soybean development. However, work concluded by Van Schaik and Probst found that flowering is poor below 68 F (20 C) and increased up to about 90 F (32 C). Cooler than normal temperatures in August tend to delay physiology maturity and the short day lengths are necessary to offset the delaying effects of cool temperatures. This would support that above average temperatures in August would have a positive affect on physiological maturity up to a critical level.

Land and Technology Variables

The amount of acres planted to soybeans since 1965 has increased 84 percent. The parameter estimated to measure land quality indicated a negative response to soybean yields. A million acre increase in additional marginal land would decrease area yields by .7 bu per acre, Model 1. When trend is used in place of the applied technology and cultural practice, then the harvested acre parameter increased from -.7 to -1.6 bushel per acre, per million acre increase.

The additional land brought into production is estimated to have lowered normal yields by 1.30 bushels per acre. This development results from expanding soybean acreage into areas where land was less fertile. Heady and Auer estimated land quality to have lowered normal yields by 1.4 bushels which is comparable to our findings.

The technology variables were positively associated with soybean yields. Acres treated with herbicides were significant at the .01 level. The herbicide parameter indicated that an additional million acres treated with herbicides would increase area yields by .78 bushels per acre. This would mean, on the additional land treated, the yield increase would be 5 bushels per acre. An economic analysis of the yield increase for the additional treated acres indicated a private cost/benefit return of $2.3 per dollar of herbicide cost. This assumes a $7.00 price for soybeans and a $15.00 cost for chemical treatment. This return is smaller than the returns estimated by Headley, Hawkins, *et al.*, and Janke.

Interaction effects between herbicide acres and narrow row-width indicated a non-significant relationship. Other interaction affects were tested between weather variables, but found to be significant at the 30 percent alpha level or higher.

Table 3 summarizes the sources of yield change and amount per acre for the technology variables indicated in Model 1. Most of the change in predicted soybean yield, from 1965 to 1979 was attributed to herbicides. Herbicides accounted for 62 percent of the yield change or approximately 4.12 bushels of the 7.3 bushels predicted, using Model 1 equation. This amount is larger than Heady and Auer estimated the contribution of pesticides and other effects for the period 1943 to 1960. Their estimates indicated a .8 bushel increase in predicted yields due to pesticides and other effects.

Narrow Rows

The effect of narrow rows (plant population) is positively associated with soybean yields. In 1980, over 6 million acres were planted to narrow rows in soybeans. Model I indicated that a per unit increase in percent acres planted to narrow-row soybeans, would increase area yields by .15 bushels per acre. Increased acres planted to rows less than 28 inches is estimated to have increased yields by 1.47 bushels since 1965. This represents 20 percent of the 7.3 bushel increase in predicted yields. Most of the change in predicted soybean yield in Ohio was attributed to narrow-rows. In addition, Ohio has the largest percent of acres planted to narrow-rows than any of the other four states in the Corn Belt.

The availability of new varieties with improved lodging resistance and the increased use of herbicides with greater selectivity has lead to an accelerated acceptance of narrow-row soybean production systems in the Corn Belt. As more acres are planted to narrow-rows, the use of herbicides in weed control, becomes very important since mechanical cultivation techniques are not applicable. Interaction affects between narrow-row width and weather variables were not significant at the 20 percent alpha level.

Genetic Index

The variety index reflects the improvement in genetics since 1965. The gradual increase in soybean yields in the Corn Belt has been due to a combination of improved varieties as well as other technology contributions. The magnitude of the contribution of improved varieties relative to the contribution of all other technological inputs into soybean production is difficult to ascertain. This difficulty resides in that variety improvements are reflected in genetic yield potential, whereas improvements in production are reflected in a gain in environmental yield potential. These two factors are not independent of each other.

The regression results indicated that a one unit change in the genetic index would increase soybean area yields by 6.2 bushels per acre. This would mean the index would have to increase from 1.0 to 2.0. The variety index indicated a 30 percent improvement since 1965 which is an average yield increase of 12 percent. Variety improvement since 1965 has attributed .94 bushels of the 7.3 bushel average change in predicted soybean yields, Table 3. However, Heady and Auer estimated variety improvement contributed 3.8 bushels of the 4.3 bushel change in soybean yields from 1943 to 1960.

Table 2 represents a second degree polynomial function for the weather variables and first degree for the technology variables. The linear deviation weather variables gave similar results as Model III. The quadratic term, or squared deviation term was negative for June temperature and August precipitation. However, for August temperature, the squared deviation term remained positive, when it was expected to be negative. The positive sign for the squared August temperature variable could be a problem due to model specification and/or the uniqueness of the time period. The use of a Cobb-Douglas functional form does not affect the signs found on the linear model.

Adjusted R-square was not much higher for the second degree polynomial model than the linear model specified in Table 1.

Conclusion

The objective of this study was to measure the contributions of herbicides and other applied technology variables to soybean yields in the Corn Belt Region for the period 1965 to 1979. Since 1965, data on technology variables, such as herbicides, fertilizer use, row-width, and variety improvement can be obtained from USDA surveys or estimated from experimental data.

A pooled cross-section time-series data base was used for the Corn Belt Region. Dummy variables were used to measure the state effect, due to major soil differences as well as environmental differences. Ordinary least squares regression was used to regress soybean yields on weather and technology variables collected for each state since 1965.

Results indicated that acres treated by herbicides would increase area yields on the average, by 0.8 bushels per million acre increase in acres treated. The percent of acres planted to row-widths less than 28 inches has increased 15 percent since 1965 for the Corn Belt. A per unit increase in the narrow-row coefficient would increase area yields by .2 bushel per acre. Of the variables quantified for soybean production herbicides and narrow-row variables had a large positive effect on soybean yields during 1965 to 1979. An increase of 4.12 bushels was imputed to herbicides. Narrow-row technology and genetic improvement contributed 1.46 and .94 bushels, respectively. Land quality had a negative effect of 1.30 bushels during this time period.

The technology variables used in this study are not the sole factors that have increased soybean yields by 44 percent since 1965. Improved timeliness of planting and harvesting, fertilizer carryover, and better management are also important factors not easily measured. In addition, interaction affects between weather and technologies are also important but were found not be significant at the 20 percent alpha level.

The marginal private benefit/cost ratio estimated for the additional land treated suggest that while there may be pests, the average effect of an increase or decrease in the mix of herbicides used by farmers would result in a 2.3 unit change in the unit input in value terms.

Limitations

The estimates have several limitations:

(1) We have not been able to cover 100 percent of production since the analysis was performed on samples collected from different areas within the states.

(2) The use of an aggregate production function assumes homogeniety throughout the region. Therefore, the use of the estimated function parameters for individual decisions is not valid.

(3) Interpretation of the estimated coefficients and the true partial effects of the variables is hampered by strong complementarities between technology variables, weather, and cultural practices.

(4) Because of the variable measuring herbicides input is acres treated, it is assumed to be a good proxy for the input of the particular chemicals used. Obviously, the productivity of a particular herbicide will vary widely and will depend on the crop and variety grown, the particular weed problem, and the timing of application. Better estimates will be available for measuring pesticide inputs when quantity data become available.

Other limitations could be mentioned including form of the function used. However, from available data and the corresponding restraints on estimating procedures, we believe our analysis provides some improved insight into the sources of crop-yield and production changes since 1965.

Footnotes

1. In this study the Corn Belt States include Illinois, Indiana, Iowa, Missouri, and Ohio.

2. The representation of weather data in deviation form is done primarily to simplify interpretation of the weather data. The use of deviation does not involve any loss of generality.

3. In deriving the estimator $\hat{b}$ we adopted the least square procedures since this is a well accepted method of estimation. However, other methods such as generalized least squares, and maximum liklihood methods could have been used.

   These methods of estimation all lead to the same estimator under certain frequently used assumptions. The generalized least squares assumes that the variance-covariance matrix of c is var(c) = V. This method involves minimizing $(y-Xb)'V^{-1}(y-Xb)$ with respect to b. This leads to $\tilde{b} = (X'V^{-1}X)^{-1}X'V^{-1}Y$. When $V = \sigma^2 I$ then the generalized and the ordinary least squares estimators are the same $\tilde{b} = \hat{b}$.

   The maximum liklihood has no assumptions made about the form of the distribution of the random error terms in the model but some assumption is made about this distribution, often that it is normal, and the liklihood of the sample of observations represented by the data is then maximized. On assuming that the c's are normally distributed with zero mean and variance - covariance matrix V, the liklihood is:

$$L - (2\pi)^{-1/2N}|V|^{-1/2}\exp\{-1/2(y-Xb)'V^{-1}(y-Xb)\}$$

   Maximizing this with respect to b is equivalent to solving, $\partial(\log L)/\partial b=0$. The solution is the maximum liklihood estimator of b and turns out to be:

$$\tilde{b} = (X'V^{-1}X)^{-1}X'V^{-1}y,$$

   As before when $V = \sigma^2 I$, $\tilde{b}$ simplifies to $\hat{b}$.

   The least squares estimation does not pre-suppose any distributional properties of the c's other than finite means and variances. Under the normality assumptions leads to the same estimator, $\hat{b}$, as generalized least squares, and this reduced to the ordinary least squares estimator $\hat{b}$ when $V = \sigma^2 I$.

4. To test for increased variance across geographical units, soybean yields were regressed on three independent variables; average July-August mean temperature; July-August precipitation; and trend. The sum of square error (SSE) values for each state model was tested against the other states to determine if the error variance was equal and if pooling across the five states was appropriate. The F-test was as follows:

$$F^*_{11,\,11} = \frac{\frac{SSE_i}{n-1}}{\frac{SSE_j}{n-\kappa}}$$

Where:

SSE_i = the sum of square error for the i state, $i \neq j$,

SSE_j = the sum of square error for the j state, $j \neq i$,

n = the number of observation

κ = number of parameters estimated.

Specifying the level of significance at .10, we required F(.05, 11, 11) = .340 and F(.95, 11, 11) = 2.86.

The F* fell between the two limits, thus the conclusion was that the five states regressions had equal error variances.

5. The percent land area of the states total land area is constant over time. This method of weighting is appropriate for a particular time period. But over a large time period this method may not be appropriate due to the changes in production patterns of a particular area. The use of variable weights, such as the percent acres planted or harvested of the total state planted or harvested acres, for each climatic or crop reporting district would be more appropriate. This would pick up the influence of production changes and emphasize the weather in these areas where crop production is most intense. This would also reduce the level of "noise" or additional variance brought in by human error.

6. The first stable product of CO_2 assimilation in the Calvin Cycle is a 3-carbon compound, 3-phosphoglyceric acid (PGA). C_3 plants carry on photorespiration which is inefficient in CO_2 assimilation when compared to C_4 plants such as corn. Photorespiration, a degradation process, is very sensitive to temperature changes above 86 F.

7. Luedders evaluated genetic improvement using 21 cultivars determined in 3 years. Most of the cultivars were involved in essentially two cycles of recurrent selection. The mean was computed for each selection cycle or year. Then genetic improvement was evaluated as a percent increase in yield. Also two other variables were measured as percent increases above the first selection cycle or year; Lodging and Height. Wilcox measured genetic improvement by use of regressing yield of each cultivar for each environment on the mean yield of all cultivars at those environments to determine whether difference in stability existed among cultivars. If so, the mean yield of all cultivars for each location and each year provided a gradation of the environments across which he could evaluate yield stability of the various cultivars.

8. The choice of whether to pool data using OLS or sacrifice degrees of freedom by using OLS with dummy variables is one which can be statistically tested. The test involves a comparison of the residual sum of squares associated with two estimation techniques. The OLS model includes more parameter restrictions than the covariance model (those using dummy variables) where the intercepts are restricted over states. The residual sum of square would be expected to be larger for the OLS model, without dummy variables, than the OLS covariance model. If the residual sum of squares change significantly, then one adopts the covariance model.

   The appropriate test statistic

$$F(\eta-\kappa,\ \eta-\kappa) = \frac{(SSE_1 - SSE_2)/\eta-\kappa}{(SSE_2)/\eta_1 + \eta_2 - \kappa}$$

   Where SSE_1 and SSE_2 are the sum of square residuals using OLS without the dummy variables and with the dummy variables, respectively. η_1 and η_2 are the number of observations.

Literature Cited

Brady, R.A., L.R. Stone, C.D. Nickell, and W.L. Powers, 1974. Water Conservation Through Proper Timing of Soybean Irrigation. J. Soil Water Conservation 29:266-268.

Carlson, Gerald A., 1970, "Long Run Productivity of Insecticides." American Journal of Agricultural Economics, Vol, 59:543-548.

Cashman, C., Marshall A. Martin, and Bruce A. McCarl, 1980. Indiana Farm-Level Impacts of Possible Environmental Protection Agency Bans on Selected Soybean Insecticides. SJAE, Vol 12, pp 147-152.

Caviness, C.E., and P.E. Smith, 1959. Effects of Different Dates Rates of Planting Soybeans. Ark. Agr, Exp. Sta. Rep. Ser. 8.

Cooper, R.L., 1971. Influence of Soybean Production Practices on Lodging and Seed Yield in Highly Productivity Environments. Agron. J. 63:490-493.

Donovan, L.S., F. Dimmok, and R.B. Carson, 1962. Some Effects of Planting Patterns on Yield, Percent Oil, Percent Protein in Mandarin (Ottawa) Soybeans. Can J. Plant. Sci. 43:131-140.

Fontis, L.A.N., and A.J. Ohlrogge, 1972. Influence of Seed Size and Population on Yield and Other Characteristics of Soybeans. Agron. J. 64:833-836.

Hanway, D.G., 1954. Growing Soybeans in Nebraska. Soybean Dig. 14:19-20.

Hartwig, E.E., 1973. Varietal Development in B.E. Caldwell (ed) Soybeans: Improvement, Production, and Uses. Agron. J. 16:187-210. Am. Soc. Agron., Madison, Wis.

Hawkins, D.E., F.W. Slife, and E.R. Swanson, 1977. Economic Analysis of Herbicide Use in Various Crop Sequences. Illinois Agricultural Economics, pp 8-13, January.

Heady, E. and L. Auer, 1966. Imputation of Production to Technologies. American Journal of Agricultural Economics, Vol 48, pp 309-322.

Headley, J.C., 1968, Estimating the Productivity of Agricultural Pesticides, American Journal of Agricultural Economics, Vol 50:13-25.

Headley, J.C., 1970. Productivity of Agricultural Pesticides for Policy Decision Making. Washington, D.C., U.S. Department of Agriculture. Proceedings of a Symposium, pp 80-88.

Hicks, D.R., J.W. Pendleton, R.L. Bernard, and T.J. Johnston, 1969. Response of Soybeans Plant Types to Planting Patterns. Agron. J. 61:290-293.

Hinson, Kuell, and W.D. Hanson, 1962. Competition Studies in Soybeans. Crop Sci. 2:117-123.

Janke, H.W., 1978. Estimating the Marginal Productivity of Pesticides on Predominantly Crop Farms in Northeast Kansas. Non-published Masters thesis, Department of Economics, KSU, Manhatton, KS.

Johnston, J., 1972. Econometric Methods, 2 ed. (New York: McGraw-Hill) p. 163.

Knake, E.L., and F.W. Slife, 1962. Competition of (Setario Faberie) with Corn and Soybeans. Weeds 10:26-29.

Lehman, W.F. and J.W. Lanbert, 1960. Effects of Spacing of Soybean Plants Between and Within Rows on Yield and its Components. Agron. J. 52:84-86.

Luedders, V.D., 1977. Genetic Improvement in Yields of Soybeans. Crop Sci. 17:971-972.

Lumin, J., and M.H. Gallatin, 1960. Narrow-Row Soybeans Produce Top Yields. Crops Soil 12:10.

Probst, A.H., 1945. Influence of Spacing on Yield and Other Characters in Soybeans. J. Amer. Soc. Agron. 37:549-554.

Runge, E.C.A. and R.T. Odell, 1960. The Relation Between Precipitation, Temperature and the Yield of Soybeans on the Agronomy South Farm, Urbana, Illinois. Agron. J. 52:245-47.

Shaw, R.H., and D.R. Laing, 1965. Moisture Stress and Plant Response. Ch. 5. Plant Environment and Efficient Water Use. Amer. Soc. Agron. Spec. Pub. Madison, Wisconsin.

Staniforth, D.W., 1965. Competitive Effects of Three Foxtail Species on Soybeans. Weeds 13:191-192.

Thompson, Louis, 1970. Weather and Technology in the Production of Soybeans in the Central U.S. Agron. J. 62:232-236.

U.S.D.A., 1965. Losses in Agriculture. Agriculture Handbook No. 291ds. 120 p.

________, 1968. Extent and Cost of Weed Control with Herbicides and an Evaluation of Important Weeds, 1965. ARS 34-102, 85 p.

________, 1971. Cropping Practices 1965-1970. SRS-17.

________, 1972. Extent and Cost of Weed Control with Herbicides and an Evaluation of Important Weeds, 1968. ARS-H-1, 227 p.

________, 1975. Farmers' Use of Pesticides in 1971. Extent of Crop Use. ESCS-AER, Report No. 268.

________, 1978. Farmers' Use of Pesticides in 1976. ESCS-AER 418.

Weber, C.R., R.M. Shibles, and D.E. Byth, 1966. Effect of Plant Population and Row Spacing on Soybean Development and Production. Agron. J. 58:99-102.

Wiggins, R.G., 1939. The Influence of Space and Arrangement on the Production of Soybean Plants. J. Amer. Soc. Agron. 31:314-321.

Wilcox, J.R., W.T. Schapaugh, Jr., R.L. Bernard, R.L. Cooper, W.R. Fehr, and M.H. Nichaus, 1979. Genetic Improvement of Soybeans in the Midwest. Crop Sci. 19:803-805.