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Production Economics Paper No. 6209
Purdue University
June 26, 1962

CONSTRUCTION AND APPLICATIONS OF WEATHER INDEXES WITH COMPARISONS TO ACTUAL YIELD DATA

by

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The adage, "Everyone talks about the weather but no one does anything about it," is as applicable to agricultural economists as it is to many others who are concerned with the effects of the weather. While all in our profession recognize that variable incomes are a problem for farmers, much of our economic analysis has proceeded along static lines, as though every year will be an "average" year. To a certain extent we can excuse our reluctance to depart from this "average" concept because of the lack of measurements for the factors contributing to variability. The development of such measurements could make a substantial contribution toward explaining the causes of income instability.

Recent literature contains a number of approaches to the variability measurement problem. One approach to the measurement of factors associated with variability is the "Weather Indexes" constructed by Stallings.[1/] Working with experimental plot data, Stallings computed the weather index as the ratio of the actual yield to the predicted trend yield. By combining data from several sources, and weighting individual indexes, he was able to construct several series of weather indexes covering the period 1900-1957.

1/ Stallings, James L., "Weather Indexes," Journal of Farm Economics, XLII, 1 February 1960, and "A Measure of the Influence of Weather on Crop Production," Journal of Farm Economics, XLIII, 5 December 1961, 1153-62.

Greve, Plaxico, and Lagrone have published work related to management strategies in the high-risk areas of Oklahoma in which they compare the variability of production, price, gross income, and income above specified costs for selected farm enterprises.[2/] The Oklahoma yield data showed no evidence of a yield trend which is obvious in data series for most other parts of the country. Inter-crop relationships have been left for consideration in a later stage of this overall study.

Carter and Dean have studied yield, price, and income variability for California agriculture.[3/] For removing trend these authors preferred a statistical method that did not require the a priori specification of a rigid function. To meet this objection they used the variate difference method to separate the systematic and random components of the time series data. However, use of a simple regression to remove trend has an advantage of simplicity and economy of calculation.[4/]

The Stallings indexes, as published, are applicable only to regional or national data. For study of individual farms an index representative of conditions nearer to the farm level is desirable. The Oklahoma and California studies cannot be extended beyond the localized areas of study.

The objectives of this paper are to show the feasibility of calculating a relatively simple index applicable to local situations, to compare statistics calculated from an index with those calculated from actual yield data, and to illustrate some possible uses of this index.

2/ Greve, Robert W., James, S. Plaxico, and William F. Lagrone, Production and Income Variability of Alternative Farm Enterprises in Northwest Oklahoma, Oklahoma State University Experiment Station, Bulletin B-563, August 1960.

3/ Carter, H. O., and G. W. Dean, "Income, Price, and Yield Variability for Principal California Crops and Cropping Systems," Hilgardia, Vol. 30, No. 6 October 1960, University of California, Berkeley, California.

4/ Two independent research projects now in progress by L. M. Eisgruber at Purdue University and J. C. Headley at University of Illinois may make possible a comparison of the regression trend and variate difference methods in the near future.

DATA, PROCEDURE, AND ASSUMPTIONS

The methodology used to calculate the weather indexes was basically the same as that used by Stallings. Time series yields were obtained for corn, wheat, oats, soybeans, and hay. A trend was calculated by linear, least squares regression and a trend yield prediction made for each year. The ratio of the actual yield to the predicted trend yield was the crop yield index for the particular crop for the year. The individual crop indexes were combined, weighted by value production, to form an aggregate crop yield index.

The method for calculating the individual indexes is illustrated in Figure I. The chart shows the average county corn yield for Tipton County plotted against time. The solid line is the yield trend as calculated by least squares regression, using a pooled regression coefficient and the Tipton County mean. The corn yield index, the actual yield divided by the predicted yield, for 1945 is 69.6 divided by 61.6 = 1.12.

The basic data were the county crop yields, as published by the State Statistician's Office,5/ for 20 counties in Central Indiana from which farm data were available for a Farm Finance study. Trends were calculated for the years 1939-1960, trend yields predicted, and indexes calculated for those years.

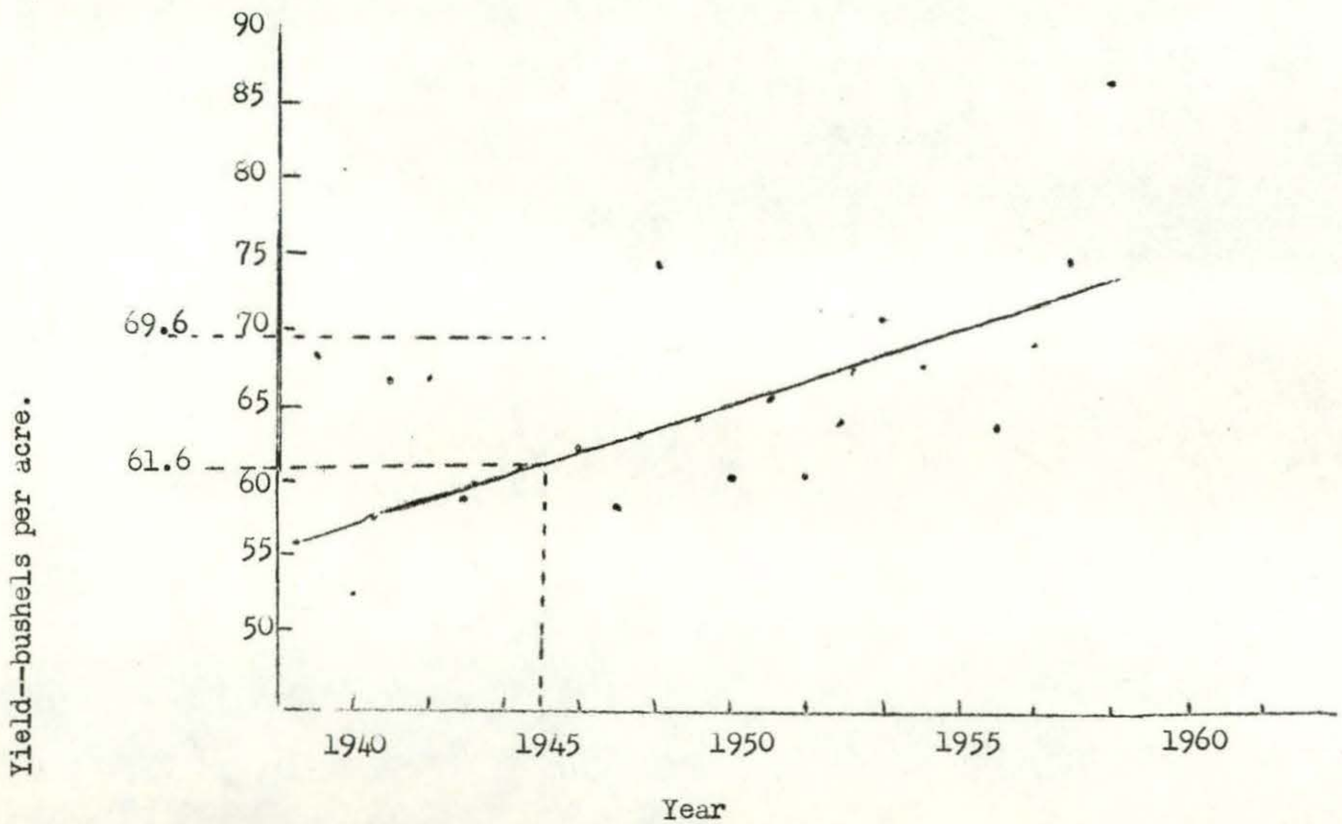
It was assumed that for each county the number of individual observations was large enough that the factors other than weather "averagedout", or remained constant, except for those accounted for by trend. It was also assumed that the trends are linear.

The term weather, as used herein, refers to a broad aggregate of all natural factors affecting crop yields. It should also be noted that the attempt was to measure the effects of weather with no attempt to measure weather as a causal factor directly.

5/ United States Department of Agriculture, Agricultural Estimates Division, cooperating with Purdue University, Department of Agricultural Statistics, Indiana Crops and Livestock, "Annual Crop Summary," Issues 1940 through 1960.

Figure 1. Method of Calculating Corn Yield Index

(Tipton County)



EMPIRICAL RESULTS

Separate yield trend equations were calculated for each of the 20 counties for corn, wheat, oats, soybeans, and hay. A separate trend equation was calculated for each crop on the weighted mean yield of all counties.

The hypothesis that one regression line could be used to represent all counties was tested using the "F" test. The hypothesis was rejected for all crops except oats.

The regression line is determined by the "b" value and the mean. Tests were run on these to determine which of these statistics prevented using a single regression line to represent all counties. The "F" test failed to reject the hypothesis: $b_1 = b_2 = ... = b_{20}$, but rejected the hypothesis that the county mean yields were equal for each of the five crops. The "Chi-square" test failed to reject the hypothesis of homogeneous variance within the counties. Therefore, it was concluded that the regression line to use for each county should be determined by a pooled estimate of the "b" value, and the individual county mean. The "b" values used were the values for the regressions of the weighted mean yields. These regression coefficients are summarized in Table I.

Table I. Summary of Regression Coefficients of Weighted Mean Yields of 20 Counties, 1939-60.

Crop	Units	Regression Coefficient b	Standard Deviation s_b
Corn	Bushels	.8143	.1941
Wheat	Bushels	.6752	.1368
Oats	Bushels	.8302	.2872
Soybeans	Bushels	.5021	.0692
Hay	Tons	.0185	.0039

To compute weighting factors to combine the separate crop indexes into a total county index, a value product was computed for each crop for each county by multiplying the average production of the crop in the county for the period 1949-58 times the average Indiana price for that period. The value products of the five crops were totaled for a total value product for the county. The ratio of each crop's value product to the total value product for the county was the weighting factor used to compute the total index.

The completed indexes for two counties are presented in Tables II and III. These counties were arbitrarily selected as representative of the extremes in productivity in the sample, with Tipton County illustrating a "high-yield" county and Jay County representative of the "low-yield" counties. The average corn yield for Tipton County for the 22 years was 65.3 bushels per acre, compared with 47.4 for Jay County.

COMPARISON OF INDEX STATISTICS AND ACTUAL YIELD STATISTICS

In many applications of crop yield data, particularly those which utilize individual crop variance or the correlation between two crops, either the statistics calculated from an index of the type described above or those calculated from actual yield data might be used. A priori we might expect the following:

1. Relatively larger variance when actual yield data are used.
2. Higher correlation coefficients between crops when actual yield data are used.
3. A problem of aggregation when variances of two or more crops are involved using actual yield data.

Table II. Weather Indexes for Crop Yields in Tipton County

Year	Total Index	Individual Crop Yield Indexes				
		Corn	Wheat	Oats	Soybeans	Hay
1939	1.1345	1.2046	1.0667	.7444	1.1142	1.1250
1940	.9134	.9130	1.1152	1.4701	.6786	.9928
1941	1.0470	1.0617	1.1480	1.2149	.9432	1.0144
1942	.9794	1.0491	.365[illegible]	1.0390	.9786	1.1277
1943	.9422	.9867	.7932	.6183	.9749	.9930
1944	.7968	.7632	.9465	.7338	.7951	.9310
1945	1.1211	1.1299	1.2200	1.2268	1.0683	.9932
1946	.9961	1.0016	1.0664	1.0311	.9606	.9463
1947	.9351	.9240	1.1749	.7799	.9382	.8013
1948	1.1122	1.1672	.8550	1.1356	1.1136	1.0000
1949	1.0133	.9938	.9312	.9436	1.1264	.9091
1950	.9353	.9193	.7350	.9735	1.0474	.8782
1951	.9892	.9910	.7474	1.0500	1.0609	.9873
1952	.9570	.8990	.9493	.9252	1.1092	.8688
1953	.9621	.9457	1.0960	.8782	.9827	.8951
1954	1.0379	1.0305	1.1359	1.0742	1.0272	.9509
1955	1.0258	.9770	1.1968	1.2738	.9498	1.2424
1956	1.0144	.9943	1.1149	1.1437	.9638	1.1078
1957	.9249	.8978	.97[illegible]	.5686	1.0291	1.0237
1958	.9743	.9612	1.0896	1.1004	.9459	.8889
1959	1.0210	1.0260	.9386	.8897	1.0282	1.2197
1960	1.1530	1.1775	1.1954	1.1850	1.0957	1.0743

Table III. Weather Indexes for Crop Yields in Jay County

Year	Total Index	Individual Crop Yield Indexes				
		Corn	Wheat	Oats	Soybeans	Hay
1939	1.1818	1.2294	.9742	.7931	1.3453	1.1000
1940	1.0104	.8838	1.4938	1.6208	.7917	1.1250
1941	1.2111	1.1753	1.4083	1.2374	1.2617	1.0526
1942	1.2289	1.2688	.7429	1.1224	1.3052	1.3793
1943	1.0321	1.0950	..7033	.4626	1.2453	1.0169
1944	.8398	.7366	1.1277	.7921	.8963	.9083
1945	1.1009	1.0984	1.4103	1.4244	.9408	.9752
1946	.9559	.8854	1.1045	1.1661	.8908	1.0894
1947	.8774	.8962	1.1346	.5793	.8883	.8080
1948	1.0684	1.1515	.9302	1.1429	1.0598	.8268
1949	1.0023	.9213	.8869	.9099	1.2275	.9612
1950	.9896	.9456	.7763	.9405	1.1804	.9313
1951	.9998	1.1193	.5940	.8670	1.0000	.9774
1952	.9740	.9271	.9751	.8293	1.1324	.9030
1953	.9389	.9940	.9717	.9098	.8517	.9265
1954	1.0238	1.0686	1.0157	1.0257	.9813	.9565
1955	1.1018	1.1329	1.1264	1.3071	.9817	1.0786
1956	.9610	.8918	1.2322	1.1219	.8438	1.1479
1957	.8547	.9028	.7190	.5815	.8559	.9931
1958	.9207	.8508	1.0393	1.1432	.9145	.9315
1959	.8440	.8838	.7875	.6581	.8201	.9388
1960	1.0510	1.0501	1.0956	1.4289	.9098	1.0470

All of the crop yields had an upward yield trend in the period studied. In the weather indexes the variation "explained by trend" has been removed. For the data used to calculate the above indexes the amounts of variation "explained by trend" were 36 per cent, 55 per cent, 25 per cent, 73 per cent, and 41 per cent, respectively, for corn, wheat, oats, soybeans, and hay in Tipton County. The corresponding figures for Jay County are 23 per cent, 29 per cent, 19 per cent, 27 per cent, and 24 per cent.

The variances, coefficients of variation, and simple correlation coefficients for the two counties as calculated from the index data and the actual yield data may be compared in Table IV. Comparisons of variance cannot be made directly, but a comparison of the coefficients of variation partially confirms the a priori expectations of the relative size of the variances calculated by the two methods. For Tipton County the differences between the two measures is correlated with the percentage of variation "explained by trend". For Jay County the results do not confirm the expected relationship. The pooled estimate of trend used was not entirely accurate for any county. However, the discrepancies between the pooled trend estimates and the estimated trends for Jay County were much greater than those for Tipton County. For Jay County the errors introduced by incorrect regression coefficients produced as much or more variation than was "explained by trend".

The comparisons of the simple correlation coefficients confirm the a priori expectations about the effects of removing trend. The coefficients from actual yield data are numerically larger than those from the index data in all cases for Tipton County, and in nine out of ten cases for Jay County.

The problem of aggregation arises from the use of different units to measure output. Corn is measured in 56 pound bushels, oats in 32 pound bushels, and hay in tons. The difficulties of aggregating variances are dramatically

Table IV. Comparison of Variation and Correlation Statistics from Weather Indexes and Actual Yield Data, Tipton and Jay Counties.

Statistic	Tipton County Index Data	Tipton County Actual Yield Data	Jay County Index Data	Jay County Actual Yield Data
s_C^2	.0109	68.64	.0197	46.00
s_W^2	.0411	57.49	.0579	33.18
s_O^2	.0495	123.35	.0909	131.09
s_S^2	.0113	22.82	.0304	8.97
s_H^2	.0129	.0544	.0152	.0283
CV_C	.1042	.1270	.1404	.1431
CV_W	.2027	.2715	.2405	.2567
CV_O	.2226	.2474	.3015	.3287
CV_S	.1064	.1758	.1745	.1563
CV_H	.1135	.1503	.1231	.1295
r_{CW}	.0976	.5291	-.1434	.1298
r_{CO}	.2286	.5512	.1841	.4181
r_{CS}	.5668	.7622	.6366	.6212
r_{CH}	.4291	.6439	.4115	.4794
r_{WO}	.2790	.5546	.6717	.7553
r_{WS}	-.1460	.5438	-.3010	-.0306
r_{WH}	-.0498	.4612	.0719	.3168
r_{OS}	-.2365	.3402	-.1764	.1323
r_{OH}	.2092	.4517	.3783	.5168
r_{SH}	.0522	.5388	.2662	.3087

illustrated by the differences between the variance of corn and the variance of hay as calculated from the actual yield data, while these variances calculated from the index data and the coefficients of variation are approximately equal.

The use of an index basically converts the variation to a percentage figure. While the concept has some limitations it does give a basis for aggregation, much as converting units of output to value product. However, if the aggregation problem is the only objectionable feature of the actual yield data statistics, the problem can be handled by converting the yields to a per cent of the mean.

DIVERSIFICATION

Diversification is one possible method of dealing with the income variability problem arising from variations in crop yields. Diversification will be effective only in cases where the correlation coefficients between enterprises are significantly less than one, and most effective when these values approach negative one.[6/]

When a given bundle of resources is used to produce multiple products the variance of total production, in the two product case, is:

$$S_T^2 = a^2 S_A^2 + b^2 S_B^2 + 2r\ ab\ S_A S_B$$

where:

S_T^2 = the variance of total production

S_A^2 = the variance of production of product A

S_B^2 = the variance of production of product B

a = the proportion of total production represented by A

b = the proportion of total production represented by B

r = the correlation coefficient for the two enterprises.

6/ For a discussion of diversification concepts see: Heady, Earl O., Economics of Agricultural Production and Resource Use, Prentiss Hall, 1952, 510 ff.

For computational simplicity, the formula may be rewritten:

$$S_T^2 = \frac{a^2 m_{AA} + b^2 m_{BB} + 2ab m_{AB}}{N-1}$$

where the m_{ij} are the second order moments about the mean, and N is the number of sample observations.

Using this formula the Tipton County data was applied to a group of highly intensive rotations and the Jay County data was applied to a group of rotations more suitable to less productive, more rolling land. These variances are summarized in Table V.

Calculating the effects of diversification from this data is an application of county-wide data to an individual farm. To a certain extent this will understate the true variation. Random fluctuations on individual farms will be partially averaged out eliminating part of the variability. Conversely, variability measures based on individual farm data may overestimate the variability due to "weather". An individual farmer's capital position, tenure arrangements, managerial ability, and other factors may be confused with random fluctuations due to weather.[8/]

Furthermore, the interest here is in the development of a simple, relatively inexpensive measure of variability. Collection of individual historical yield records, if they are available at all, would involve a major expenditure. County yield data hve been used because (1) of all readily available data series, county data are the closest to the individual farm, and (2) the variation due to factors which are, or might be, under the control of the individual operator tend to be "averaged out" in the county-wide data.

8/ See Carter and Dean, op. cit., p. 178.

Table V. Effects of Diversification on Crop Yield Variance

Rotation	Variance		Coefficient of Variation	
	Index Data	Actual Yield Data	Index Data	Actual Yield Data
Tipton County				
Con't C	.0109	68.64	.1042	.1270
CCS	.0089	46.43	.0942	.1301
CCSW	.0077	40.48	.0876	.1371
CCS $\frac{W}{O}$	.0073	43.25	.0857	.1189
CCSWH	.0050	26.22	.0731	.1368
CCS $\frac{W}{O}$ H	.0062	28.01	.0791	.1353
Jay County				
Con't H	.0152	.0283	.1231	.1295
COHHHH	.0149	7.0839	.1221	.1827
CCOHHH	.0141	12.7182	.1187	.1603
CSOHHH	.0130	8.2214	.1139	.1634
CSWHHH	.0092	3.5784	.0958	.1222
CCSWHH	.0093	8.3915	.0963	.1251
COHH	.0170	15.5204	.1303	.1858
CCOH	.0170	28.0753	.1305	.1619

The probelm of aggregation using the actual yield data is illustrated in Table V. It may be noted that the variances calculated from actual yield data vary directly with the proportion of corn in the rotation and inversely with the proportion of hay in the rotation. No such pattern exists in the variances calculated from index data.

None of the rotation variances within a county, as calculated from the index data, are significantly different at the five per cent level. Although the differences are significant between some of the variances as calculated from actual yield data, no conclusions can be drawn because of the differences in basic units. The coefficients of variation suggest that few, if any, of these differences are significant.

The aggregation problem is evident in the calculation of the coefficients of variation also. The mean yield used in this calculation was a weighted arithmetic mean of the mean yields of the individual crops. As an arithmetic mean it was influenced by extreme values. Hence, a high proportion of corn in a rotation tended to bias the coefficient of variation downward and a high proportion of hay biased it upward. The problem did not exist when the index data were used since all means were equal to one.

For all rotations the coefficient of variation was greater when calculated from actual yield data than when calculated from index data. This reflects the greater variance and higher correlation from leaving in the trend effects.

The effects of diversification on income are summarized in Table VI. The expected incomes over "out-of-pocket" costs were taken from farm management data.[7/] The deviations from these figures were based on expected gross income.

7/ Suter, Robert C., Farm Planning Props, Developed for purpose of advanced Farm Management Class, Purdue University, February 1961.

Table VI. Effects of Diversification on per acre crop income.

Tipton County

Rotation	Expected Income Over "out-of-pocket" costs	95% Confidence Range of Income Over "out-of-pocket" costs. Index Data		Actual Yield Data	
		Lower Limit	Upper Limit	Lower Limit	Upper Limit
1. Con't C	$58.03	$38.96	$77.10	$34.78	$81.28
2. CCS	54.82	42.90	73.94	33.38	76.24
3. CCSW	56.93	42.89	70.97	34.96	78.90
4. CCS $\frac{W}{O}$	53.04	40.00	66.08	34.95	71.13
5. CCSWH	52.94	41.50	64.38	31.54	74.34
6. CCS $\frac{W}{O}$ H	49.83	37.97	61.69	29.54	70.12

Jay County

Rotation	Expected Income	Index Lower Limit	Index Upper Limit	Actual Lower Limit	Actual Upper Limit
1. Con't H	$13.40	$ 0.55	$26.55	$ 0.30	$26.50
2. COHHHH	20.15	8.43	31.87	2.62	37.68
3. CCOHHH	25.45	12.93	37.97	8.54	42.36
4. CSOHHH	22.79	11.70	33.88	6.88	38.70
5. CSWHHH	26.60	16.51	36.69	13.73	39.47
6. CCSWHH	31.90	20.84	42.96	17.53	46.27
7. COHH	22.38	9.59	35.17	6.49	38.27
8. CCOH	30.32	15.65	44.99	11.31	49.33

In choosing a rotation, within technical and institutional limits imposed by soil capabilities and acreage restrictions, a farmer may rationally choose either of two criteria: (1) maximize expected income, or (2) maximize the minimum income, a survival consideration.

For Jay County, the choice criteria would make little difference in the relative desirability of the rotations listed, and the method of calculation (index vs. actual yield) would make no difference.

For Tipton County, continuous corn would maximize expected income on land suited to that kind of cropping. However, the farmer with small reserves can make a substantial improvement in the minimum income limit at a small cost in expected income by adding soybeans and wheat, if the variances calculated from index data are accepted. Using the results of the actual yield data, there is no advantage to diversification for income stabilization (neglecting price variation effects). There is no crop income value in adding either oats or hay to the rotation regardless of which choice criterion or method of calculation is used.

Application of these indexes to income range and probabilities assumes a normal distribution. The "Chi-square" test for "goodness of fit" was not significant for corn, oats, hay, or the total index; was inconclusive for soybeans, and highly significant for wheat (see Table VII).

Table VII. Summary of "Goodness of Fit" Tests for Normal Distribution of Crop Yield Indexes

Crop Index	Chi-square	Degrees of Freedom	Approximate Significance Level
Corn	9.158	10	50%
Wheat	25.279	10	½%
Oats	24.411	16	9%
Soybeans	18.581	10	5%
Hay	14.447	10	15%
Total	8.452	9	50%

The wheat index plainly did not follow a normal distribution and there was some question about the soybean yield distribution. Since, in this context, the primary interest in the distribution was for survival implications, the lower end of the distribution should be examined in greater detail.

For wheat and soybeans, the number of observations in the lowest class was substantially in excess of the expected frequency. The corn yield index showed a moderate excess of observations over the expected frequency in the lowest class, while oats and hay indexes had fewer than the expected number of observations in the lowest class. Hence, the lower limit of the confidence interval estimate is high for rotations with a relatively large proportion of corn, wheat, and soybeans, and low for rotations heavy in hay and oats.

ESTIMATING MAGNITUDE AND FREQUENCY OF INCOME FLUCTUATIONS

Although it is impossible to predict any year's weather in advance, the weather indexes give us some indication of the expected magnitude and frequency of yield fluctuations.

The "goodness of fit" test indicated that the distributions of the total indexes for the 20 central Indiana counties, and similar indexes for nine northeastern Indiana counties, did not depart significantly from the normal distribution. The normal distributions for these indexes are tabulated in Table VIII.

If the expected return on the capital invested in a farm is 5 per cent at constant prices, the entrepreneur can expect a negative return 30 per cent of the years in central Indiana and 27 per cent of the years in northeastern Indiana from weather variations alone.

The expected per acre gross incomes in Table VIII were calculated for the 1960 predicted trend yields and 1949-58 average prices, assuming the farm division between crops to be proportional to the division for the area.

Table VIII. Expected Frequency of Weather Indexes

Class limits	Expected Number of Observations in 1000 years		Expected gross income per acre at class lower limit	
	Central Indiana	Northeastern Indiana	Central Indiana	Northeastern Indiana
79 and under	19	6		
80 - 84	39	26	$58.01	$56.48
85 - 89	89	76	61.63	60.01
90 - 94	154	161	65.26	63.54
95 - 99	199	231	68.88	67.07
100 - 104	199	231	72.51	70.60
105 - 109	154	161	76.14	74.13
110 - 114	89	76	79.76	77.66
115 - 119	39	26	83.39	81.19
120 and over	19	6	87.01	84.72

The expected gross income for the central Indiana area of $72.51 per acre compares very closely with the $72.12 expected gross income for the Tipton County CCS $\frac{W}{O}$ H rotation in Table VI. Using the same "out-of-pocket" costs the expected income over OCP costs drops below $50.22 nineteen years out of 1000. From Table VI the comparable expected income from the CCS $\frac{W}{O}$ H rotation falls below $49.83 twenty-five years out of 1000.

This type of analysis can be used to illustrate the differences in "risk" between areas. The data show that the probability of yields dropping below 80 per cent of the expected yeild is three times greater for central Indiana than for northeastern Indiana. However, the analysis shows Tipton County to be "low risk" county where yields would be expected to fall below the 80 per cent figure only four years per thousand. For Jay County yields below this level could be expected 72 years per thousand. While the latter figures probably overstate the differences between these two counties they do indicate that yield fluctuations do vary between locations.

SUMMARY

Weather indexes have been calculated as an attempt to measure one of the elements contributing to variability of farm income. For individual crops the index was the ratio of the actual yield to the yield predicted by a trend equation. Individual crop indexes were aggregated into a total crop yield index, weighted by value production.

Statistics of variation and correlation calculated from the weather indexes were compared to the same statistics calculated from the actual yield data. Generally, the variation and correlation were smaller when calculated from weather index data. This difference is attributed to the removal of variation and correlation caused by trend. When these statistics were applied to problems of diversification the weather index statistics showed more favorable results from diversification than the use of actual yield statistics.

The indexes were used to estimate the magnitude and frequency of yield fluctuations. This application can be used to estimate the frequency with which different levels of income can be expected at constant prices. It also provides a basis for evaluating the differences in yield variations between areas.

Limiting the discussion to "weather" variability obviously presents an incomplete picture of the total variability problem. The purpose has been to show the feasibility of calculating a measure of weather variability at a reasonable cost for application to local problems, and to demonstrate the usefulness of such an index. Indexes of this type, when combined with suitable price variability statistics, can serve a useful role in studying the problem of variable farm income.