WERE U.S. CROP YIELDS RANDOM IN RECENT YEARS?

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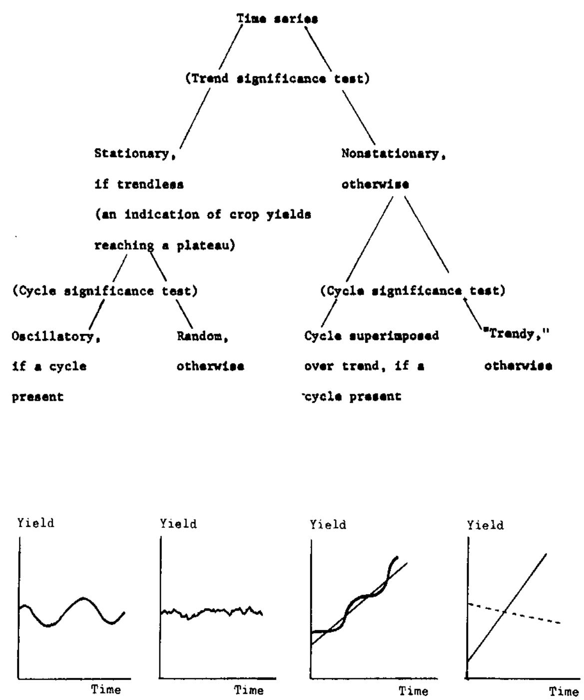
After three to four decades of substantial increase, yields per acre of major U.S. crops appear to have tapered off. The average annual rate of growth in crop yields[1] decreased markedly from 2.7 percent for the 1950s to 1.8 percent for the 1960s, and finally fell to 0.1 percent for the first half of the 1970s [2]. Scientists commissioned by the National Academy of Sciences to investigate agriculture production efficiency first discovered the problem [6]. Concern about the situation was expressed in the literature early this year by both a plant physiologist [11] and agricultural economists [1, 2]. If a crop yield series has reached and remains on a plateau, it would conform with what is expected in a stationary or trendless series.[2] Therefore, examination of the leveling of crop yields can be accomplished by testing for the presence or absence of a trend in the series.

Recently, Luttrell and Gilbert [5] investigated the influence of weather on crop yields.[3] They assumed that weather dominates the yearly variation of crop yields around the long-term trend and nonweather factors determine yield trend. Detrended yield series were used to test "whether year-to-year changes in weather have random effects on crop yields" [5, p. 522]. The trend-deviation approach implies that a series is additively composed of the trend and residual elements. The validity of the approach depends on the specification of the functional form for the trend. Model misspecification will generate a meaningless trend-deviation series.

This study has two objectives. As shown in Figure 1, the first is to examine (by trend significance test) whether crop yields were on a plateau in recent years. If a yield series has little evidence of a trend, it is considered to have plateaued. The second objective is to investigate whether a crop yield series, if trendless, is random or oscillatory and, if nonstationary, whether cycles are present. An oscillatory series is defined as a trendless series dominated by cycles; a random series is one lacking trend and cyclical elements. It is not the authors' intention to quantitatively evaluate factors underlying the level and changes in the level of individual crop yields.

FIGURE 1. CLASSIFICATION OF DATA SERIES



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[1]Computed from variable weights for individual crops produced each year.

[2]Fuller defines a stationary series as the residual portion of a series after the trend, cyclical, and seasonal components have been removed [3, p. 387]. In this study, the authors adopt Kendall's and Yamane's definition [4, p. 69; 12, p. 351].

[3]Previous work on testing of the random versus cyclical hypothesis about crop yields is reviewed by Luttrell and Gilbert [5] and is not discussed here.

THE METHODS

The Kendall tau statistic and the regression method can be used to test for trend in a series. The former method, being a nonparametric statistic, requires a larger value of Type I error to yield test results comparable with those of the more powerful tests using conventional levels [7, p. vi]. The authors discovered that, at the .1 significance level, the Kendall tau statistic would yield conclusions similar to those of the regression t-tests at the .05 level.[4] Because the Kendall tau method requires much less calculation than regression analysis and can be easily updated, it is used in this study. Another consideration is that the sample of the study may be too small to be analyzed by the regression method.

The value of the Kendall tau coefficient ranges between -1 and $+1$. A series is considered to be trendless if the test statistic value is not significantly different from zero at the selected .1 significance level. Kendall advocates using the tau coefficient to test for a "linear trend." However, a series with ever-increasing values, whether it approximates a linear or a nonlinear function, always has a tau value of unity. Therefore, it seems more appropriate to use the statistic to test for the presence of a trend, rather than specifically a linear trend.

A yearly series usually is assumed to be composed of the trend, cyclical, and residual elements. The result of a trend test, significant or not, does not preclude other components. All it indicates is the presence or absence of trend in the series. Therefore, a cyclical significance test also is conducted to examine the presence of cycles in the individual yield series.

Traditionally, a detrended series is used to test for cycles. Because the series studied are too short to allow trend fitting by the conventional moving-average or variate difference methods, a test statistic that does not require trend elimination is employed. Wallis and Moore indicated that the phase-length statistic is suitable for a cyclical test for both the original and a derived series (such as trend deviations), because the method is not sensitive to primary trend[5] [10, pp. 401, 406]. A .1 level of significance is acceptable in the test because the phase-length statistic is a nonparametric statistic. The value of the test statistic is always nonnegative. The cyclical hypothesis will be rejected if the value of the phase-length coefficient is not significantly different from zero.

The U.S. average yields per harvested acre of 19 crops for 1960-1977 are selected for study. The sources of data are *Agricultural Statistics, 1977* [8] and *Crop Production, 1977 Annual Summary* [9] of the U.S. Department of Agriculture.

RESULTS

The values of the Kendall tau (Table 1) for the yields of barley, corn, hay, peanuts, potatoes, rice, soybeans, sugarbeets, sweet potatoes, and wheat are significant at the .01 level. Those of oats, rye, sorghum, and tobacco are significant at the .05 level; that of sugar cane is significant at the .1 level and negative in value, an indication of declining trend. Therefore, the test results show little evidence of a trend for

TABLE 1. RESULTS OF TREND AND CYCLICAL TESTS FOR CROP YIELDS, 1960-77

Crop	Value of test statistic	
	Kendall-tau	Phase-length
Barley	.55***	8.09**
Corn for grain	.65***	1.07
Cotton, lint	.06	4.20
Dry edible beans	-.24	1.41
Dry edible peas	.06	.64
Flaxseed	.02	.11
Hay, all	.71***	2.76
Oats	.36**	.24
Peanuts for nuts	.88***	8.54**
Potatoes	.89***	2.61
Rice	.61***	7.88**
Rye	.44**	2.76
Sorghum for grain	.40**	3.96
Soybeans for beans	.57***	1.74
Sugar cane for sugar & seed	-.29*	.11
Sugarbeets	.62***	1.84
Sweet potatoes	.89***	4.20
Tobacco	.40**	1.47
Wheat	.56***	9.29**

*Significant at the .1 percent level. **Significant at the .05 percent level. ***Significant at the .01 percent level.

[4]The authors obtain the same conclusions from the two methods, for instance:

Crop	Kendall tau	Regression coefficient
Dry edible beans, 1960-77	Not significant at .1 level	Not significant at .05 level
Sugar cane, 1960-77	Significant at the .1 level	Significant at the .05 level
Tobacco, 1960-77	Significant at the .05 level	Significant at the .01 level
Tobacco, 1961-77	Significant at the .1 level	Significant at the .05 level
Tobacco, 1962-77	Not significant at the .1 level	Not significant at the .05 level

[5]The method was used by Luttrell and Gilbert [5] and many other authors to examine detrended series.

the period of 1960-1977 for cotton, dry edible beans, dry edible peas, and flaxseed.

Although the yields of many crops have begun to level off since the early 1960s, the patterns of crop yield variation from year to year are not identical. Peanuts, potatoes, and sweet potatoes show a rising trend, with little downward fluctuation. The rest of the series with a significant trend, except for sugar cane, show a marked upward trend in the early 1960s and then taper off. Selection of 1960 as the starting point is somewhat arbitrary. Therefore, the trend significance test is conducted to ascertain whether the series with a significant trend are stationary after removal of one year for five consecutive years. The results are reported in Table 2. The tau values for eight crop yield series (barley, corn, oats, rice, rye, sorghum, tobacco, and wheat) become nonsignificant. As a result, one can conclude that the yields of the 19 crops studied, except those of hay, peanuts, potatoes, soybeans, sugar cane, sugarbeets, and sweet potatoes, plateaued during 1965-1977.

Because the Kendall tau coefficient, a rank test, uses the relative position on a scale of the values of a series, important information about the absolute differences among the values is lost. Therefore, the average annual rate of growth for 1960-1977 and for 1940-1959 is calculated for the seven crops that have shown no leveling of yields (Table 3). Peanuts is the only crop that shows an exceptional increase from 1940-1959 to 1960-1977. In other words, although the yields of hay, potatoes, soybeans, sugarbeets, and sweet potatoes had a significant rising trend in recent years, the rate of growth has slowed considerably, and that of sugar cane has become negative.

The next question to be investigated is whether a stationary crop yield series is random or oscillatory, and whether a nonstationary series contains cycles. The phase-length test as reported in Table 1 shows that the value of the test statistic is significant, at the .05 level, for barley, peanuts, rice, and wheat. Because the trend test results reported in Table 2 indicate that the yields of barley, rice, and wheat became stationary after 1964, the phase-length test is conducted for these series. The values of the test statistic (Table 4) are significant for rice and wheat at the .1 and .05 level, respectively. From the results of cycle and trend significance tests reported in Table 1, 2, and 4, one can conclude that (1) peanuts appear to have a cyclical element superimposed over the yield trend for 1960-1977; (2) yields of hay, potatoes, soybeans, sugar cane, sugarbeets, and sweet potatoes are nonstationary and without a significant cyclical element for 1960-1977; (3) yields of rice and wheat are oscillatory for 1965-1977; and (4) the remaining 10 series are random for 1965-1977.

TABLE 2. VALUES OF KENDALL TAU STATISTIC FOR CROP YIELDS OF SELECTED SUB-PERIODS

Crop	1961-77	1962-77	1963-77	1964-77	1965-77
Barley	.50***	.44**	.37*	.28	.18
Corn	.60***	.55***	.50***	.45**	.35
Hay	.70***	.66***	.64***	.61***	.54**
Oats	.31*	.22	.14	.06	-.10
Peanuts	.90***	.88***	.87***	.85***	.82***
Potatoes	.87***	.89***	.89***	.90***	.88***
Rice	.58***	.52***	.45**	.36*	.26
Rye	.41**	.33*	.28	.16	-.05
Sorghum	.32*	.25	.18	.08	-.08
Soybeans	.55***	.59***	.57***	.54***	.47**
Sugar cane	-.35*	-.32*	-.35*	-.30	-.44**
Sugarbeets	.65***	.60***	.55***	.66***	.62***
Sweet potatoes	.87***	.86***	.86***	.83***	.80***
Tobacco	.33*	.24	.13	.10	.24
Wheat	.58***	.52***	.45**	.37*	.28

*Significant at the .1 percent level. **Significant at the .05 percent level. ***Significant at the .01 percent level.

TABLE 3. CROP YIELD AVERAGE ANNUAL RATE OF GROWTH[a]

Crop	1940-59	1960-77
	..........percent..........	
Hay	1.09	.98
Peanuts	1.73	4.06
Potatoes	4.18	1.63
Soybeans	1.43	.83
Sugarbeets	1.55	1.02
Sugar cane	1.46[b]	-.36
Sweet potatoes	2.28	1.87

[a]To reduce the effect from abnormal values, the means of the first three years' and the last three years' data are used as the "present" and "future values" in calculating the average rate of growth for each period.

[b]For 1950-59.

TABLE 4. VALUES OF PHASE-LENGTH STATISTIC FOR CROP YIELDS OF SELECTED SUB-PERIODS

Crop	Period	Phase-Length value
Barley	1964-77	4.40
Rice	1965-77	5.71*
Wheat	1965-77	6.98**

*Significant at the .1 level. **Significant at the .05 level.

IMPLICATIONS

U. S. average yields of 12 crops, including corn, cotton, rice, tobacco, and wheat, were stationary in recent years (rice and wheat being oscillatory and the rest random), an indication of a yield plateau. This finding may imply that since the 1960s prevailing technology in producing these crops has been adopted by farmers to the largest extent possible. If so, weather and other nontechnological factors will play an increasing role in the determination of the level and changes in the level of crop yields. Two possible developments could prevent continued plateauing. One is new technical breakthroughs such as high yield, pest- or drought-resistant varieties. The other is dramatic changes in the cost-price structure, such as a marked reduction in the cost of fertilizer, which would make it profitable for farmers to increase production investment.

An optimistic view of the problem is that leveling in crop yields is, in part, a result of stricter agriculture pollution controls and/or an increase in crude oil and natural gas prices. The farm sector may still be in the resource reallocation process resulting from pollution regulation and petroleum market disruptions. A few years may pass before the situation becomes clear. One reviewer pointed out that growing fixed costs in recent years (in particular higher real estate and farm machinery values) may have affected crop yields. In other words, because of increasing production costs (both fixed and variable) producers are becoming more concerned about net return per dollar investment than increased yield.

REFERENCES

[1] Breimyer, Harold F. "Agriculture's Three Economics in a Changing Resource Environment," *American Journal of Agricultural Economics,* Volume 60, 1978, pp. 37-47.

[2] Crosson, Pierre. "U. S. Agricultural Production Capacity: Comment," *American Journal of Agricultural Economics,* Volume 60, 1978, pp. 144-147.

[3] Fuller, Wayne A. *Introduction to Statistical Time Series.* New York: John Wiley & Sons, Inc., 1976.

[4] Kendall, Maurice. *Time-Series,* 2nd edition. New York: Hafner Press, 1976.

[5] Luttrell, Clifton B. and R. Alton Gilbert. "Crop Yields: Random, Cyclical, or Bunchy?" *American Journal of Agricultural Economics,* Volume 58, 1976, pp. 521-531.

[6] National Academy of Sciences. *Agricultural Production Efficiency.* Washington, D. C., 1975.

[7] Tate, Merle W. and Richard C. Clelland. *Nonparametric and Shortcut Statistics.* Danville, Illinois: Interstate Printers and Publishers, Inc., 1959.

[8] U. S. Department of Agriculture. *Agricultural Statistics, 1977.* Washington, D. C.

[9] U. S. Department of Agriculture. *Crop Production, 1977 Annual Summary,* Economics, Statistics, and Cooperative Service, January 16, 1978.

[10] Wallis, W. Allen and Geoffrey H. Moore. "A Significance Test for Time Series Analysis," *Journal of American Statistics Association,* Volume 36, 1941, pp. 401-409.

[11] Wittwer, S. H. "The Next Generation of Agricultural Research," *Science,* Volume 199, Number 4327, January 27, 1978.

[12] Yamane, Taro. *Statistics; An Introduction Analysis,* 2nd edition, 1967.