CROP ROTATION IMPACTS 'TEMPORAL SAMPLING' NEEDED FOR LANDSCAPE-DEFINED MANAGEMENT ZONES

E.M. Pena-Yewtukhiw

Division of Plant and Soil Sciences
West Virginia University
Morgantown, West Virginia

J.H. Grove

Plant and Soil Sciences Department
University of Kentucky
Lexington, Kentucky

ABSTRACT

Yield and landscape position are used to delineate management zones, but this approach is confounded by yield's weather dependence, causing yield to evidence temporal variability/lack of yield stability. Management options (e.g. crop rotation) also influence yield stability. Our objective was to define the influence of crop rotation on the temporal yield stability of landscape defined management zones, and then to predict future yields. Corn (*Zea mays* L.) yield data for two rotations, monoculture corn (C-C) and corn alternating yearly (W/S-C) with winter wheat (*Triticum aestivum* L.)/double-crop soybean (*Glycine max* L. Merr.), taken in four landscape (shoulder, upper backslope, lower backslope, footslope) zones, were obtained for 1987 to 2006 from a study established near Lexington, Kentucky. Spatial and temporal yield stability was evaluated by ANOVA, Spearman rank correlation, and time series analysis using Box-Jenkins methodology. Time series ARMA models were used to forecast 2007 and 2008 yields in each zone, for each rotation. The 20-year average yields were lower for C-C (8.3±2.6 Mg ha^{-1}) than for W/S-C (9.6±2.7 Mg ha^{-1}). Yield versus time plots for individual zones exhibited slightly positive linear trend (0.13 Mg ha^{-1} yr^{-1}) for both rotations. The rank correlations among landscape positions, for each rotation, were generally high and rotation determined which positions were most, and least, similar. After removing linear yield trend, Box-Jenkins time series analysis found that C-C yield exhibited greater temporal lag (less yield stability) than W/S-C yield for the whole field and two of the four zones. Upper backslope and footslope W/S-C yields exhibited maximal autocorrelation at lags of one to two years in length, while C-C yields in those same zones required lags of three to five years. Forecasted 2007 and 2008 yields were within 5 to 30% of observed, and zones with the least/most stability exhibited the greatest/smallest difference between predicted and observed yields.

Keywords: Temporal sampling, ARMA models, Spearman rank correlation, corn rotations

INTRODUCTION

Management zone establishment assumes that agronomic interpretation of yield, soil property, and landscape topography maps will improve, with greater profit to site-specific practices such as cultivar selection and rates of seed, fertilizer, and pesticides. The most popular criteria used to delineate management zones of “similarity” are soil properties (usually soil fertility), topographic properties, or those that otherwise define areas with similar yield/yield response. Yield is the characteristic most often used to define management zones, but yield’s dependence on seasonal weather, evidenced as temporal variability, can confound this approach. The term “yield stability” includes both spatial and temporal variation, though that definition can be operational. Areas of similar “yield potential’ (low, medium or high) might be found in the same geographic location, over a series of years, though this is not always observed. Lamb et al. (1997) reported that corn grain yield was not spatially consistent across time; areas of better grain yield were not the same, year to year, nor were those areas exhibiting poor production.

The importance of temporal variability is manifest in the oft-substantial interaction between management zones and stochastic factors, and may affect usefulness of those management zones. Via its stochastic nature, seasonal weather brings risk to production systems. Climate can explain 32 to 83% of yield variation in corn and soybean cropping systems (Yamoah et al., 1998), affecting yield’s year-to-year spatial structure (Jaynes and Colvin, 1997). The latter concluded that neither the deterministic nor the stochastic components to yield’s spatial structure were temporally stable. The studies noted above, as well as numerous others not cited, suggest that a field’s spatial variability is not well managed until something of its temporal variation is understood. In the absence of this knowledge, over-interpretation of one-year yield maps, using these to develop management strategies for next year’s crop (or the next season the same crop is grown) is likely. If yield stability is not observed, site-specific management recommendations based on yield maps is in jeopardy.

Spatial-temporal yield interactions are not only a consequence of landscape position-microclimate, but may also be due to other micro-environmental variables like diseases, insects and weeds. Additionally, agronomic management choices (genetics, irrigation, etc.) also influence yield stability (Raun et al., 1993). Crop rotation is an important management choice.

Many researchers have observed the benefits of rotation, the “rotation effect”, on individual crop species. The effect, increased crop yield, is due, at times, to improved nutrition (Varvel, 1994), better weed control (Liebman and Ohno, 1997), or reduced pest incidence (Koenning et al., 1995; Hendrix et al., 1992). The effect is apparent when nutrition is non-limiting and known weed, disease and insect pressures are non-existent, indicating that not all causes of the effect are understood (Crookston et al., 1991). The rotation length required for expression of the benefit to yield is important. Yamoah et al. (1998) reported that the effect was evident after 2 to 4 years of a corn/soybean rotation. Porter et al. (1997) concluded that the rotation benefit was lost after 2 years of continuous corn, though rotation benefited both crop components in a corn/soybean rotation (Crookston et al., 1991; Porter et al., 1997).

The spatial and temporal dynamics of rotation have been studied. Porter et al. (1997) observed that rotation was not as beneficial in higher yielding field areas. Rotation interacts with seasonal weather, and Peterson and Varvel (1989) reported that the rotation benefit was more evident with moisture stress. Raun et al. (1993), examining a long-term experiment with several rotation treatments, found differences in temporal yield stability (year by treatment interactions). Porter et al. (1998) observed that temporal and spatial variation in the rotation effect depended on crop species. Their 10-year study found temporal variability to be greater than spatial variability, and soybean to be relatively less temporally variable than corn. This observation suggests a possible crop by rotation by space by time interaction.

Analysis of data that extends over space and time has proven challenging, and has been the subject of a number of statistical approaches. Genotype yield stability, over time and/or space, has commonly been analyzed using rank correlation. The higher the correlation between years, the more stable the yield over time (Lamb et al., 1997). The limitations of analysis of variance (e.g. split plots in time) are often discussed when this approach has been used (Raun et al., 1993). Raun et al. (1993) noted that their wheat yield stability analysis, performed on an experiment with management treatments (including rotation) continuously applied to the same area of soil, was confounded by the presence of inter-annual autocorrelation.

This limitation is examined, though not always avoided, by using variography or fractal analysis (Jaynes and Colvin, 1997; Eghball and Powers, 1995). Jaynes and Colvin (1997) found that spatial-temporal models for describing the spatial distribution of crop yield potential over multiple years would need to reproduce both the spatial structure and temporal instability contained in the data. Using existing yield maps to design future management zones is a form of yield forecasting.

Forecasting is the product of another approach to modeling temporal yield behavior; time series analysis. Time series analysis derives the temporal distance (the temporal lag) at which the present is best related to previous measures of the same event, via a time series model. Yield stability has been evaluated using time series analysis (Hu and Buyanovsky, 2003; Linden et al., 2000). Hu and Buyanovsky (2003) related corn yield to precipitation and temperature, while Linden et al. (2000) related corn stover and grain yields to excessively wet and dry years.

The impact of management choice on yield stability in different field areas (different landscape positions), for the purposes of determining the number of years needed to properly design management zones, has not been reported. Given that each rotation and landscape position experiences the same annual weather, the hypothesis of this study was that the temporal behavior of corn yield is different for different rotation-landscape position combinations. Management zones and/or rotation options with higher temporal yield stability will require fewer years of information be acquired by the grower/consultant seeking to understand the temporal behavior of crop yield for a field, or for an area within a field. Consequently, yield is more predictable. As the lag increases, due to higher stochasticity, the number of previous measures of corn yield required to forecast a future corn yield (and delineate a management zone) also increases, because that yield is inherently less stable. The objective of this study was to describe the influence of crop rotation choice on the temporal stability of corn yield for landscape defined management zones using time series models.

MATERIALS AND METHODS

Twenty years (1987 to 2006) of corn (*Zea mays L.*) grain yields from two rotations; monoculture corn (C-C), and corn alternating yearly (W/S-C) with winter wheat (*Triticum aestivum* L.)/double-crop soybean (*Glycine max* L. Merr.); were used. The two rotations were part of a larger rotation study established near Lexington, Kentucky, USA. The rotation study was established in four replications across a hillslope, with each replication located on an individual landscape position (shoulder, upper backslope, lower backslope and footslope). The predominant soil series in the study area is a Maury silt loam (fine, mixed, semi-active, mesic Typic Paleudalf), developed in loess-capped limestone residuum, with an average slope of 6%. The main soil characteristics differentiating the landscape positions are topsoil depth and total profile depth, both due to differences in erosion and deposition processes in this landscape. Each landscape position defined a management zone (Fig. 1).

Corn was planted in late April-early May of each year, without prior tillage, and was harvested in late September-early October. Cultivars changed over the course of the study period, and were chosen for superior yield potential and disease resistance. Weeds were well controlled and crop nutrition did not affect yield in either rotation. Insecticides were used as needed.

Spearman rank correlation provided a comparative measure of temporal yield stability, among landscape position/management zones, by rotation (SAS, 1997). The time series analysis consisted of autoregressive-moving average (ARMA) model development, using the methods of Box and Jenkins (1976), to understand the temporal impact of rotation within each landscape position/management zone. The Box and Jenkins approach causes the data to be fit to the ARMA model in a way that most assures that residuals are both small and without pattern (residuals are “white noise”).

Autoregressive (AR) models are commonly used to model univariate time series. An AR model can be described as:

$$X_t = \delta + \phi_1 X_{t-1} + \phi_2 X_{t-2} + \dots\dots\dots + \phi_p X_{t-p} + A_t$$

where X_t is the time series, A_t is white noise, $\phi_1, \dots, \phi_p$ are the coefficients of the model, and δ is a parameter related to the mean of the process:

$$\delta = \left(1 - \sum_{i=1}^{p} \phi_i\right)\mu$$

with μ denoting the mean. An AR model is a linear regression of the current value in the series against one or more prior values in the series.

a)

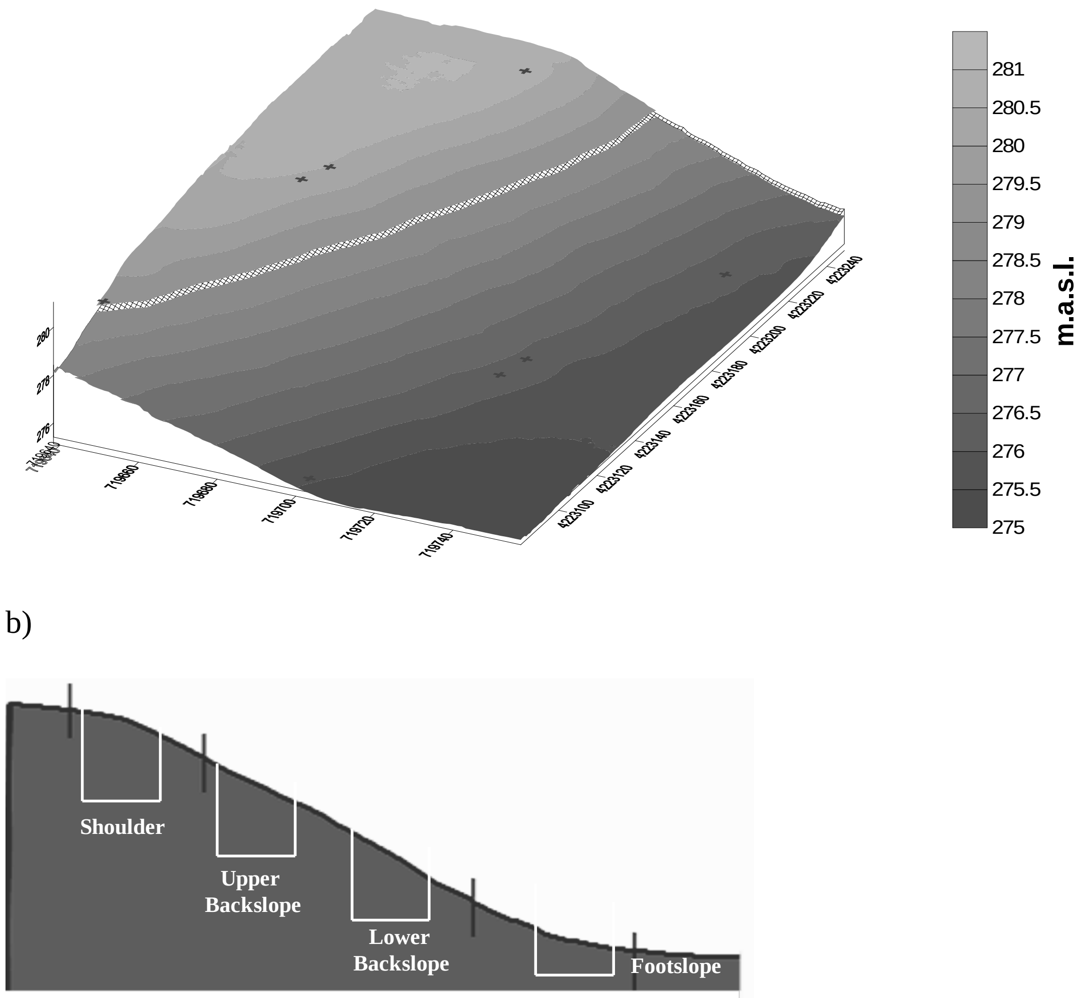


Fig. 1. a) Digital elevation map for the study site (m.a.s.l. = meters above sea level); b) Diagram of the landscape positions/management zones.

The value of $\boldsymbol{p}$ denotes the 'order' of the AR model. Moving average (MA) models, also commonly used, can be described as:

$$X_t = \mu + A_t - \theta_1 A_{t-1} - \theta_2 A_{t-2} - \ldots - \theta_q A_{t-q}$$

where X_t is the time series, μ is the mean of the series, A_t is white noise, and θ_1, ..., θ_q are the coefficients of the model. The value of $\boldsymbol{q}$ denotes the 'order' of the MA model.

The analysis assumes that the observed time series, X_t, is 'stationary' (there is an absence of 'trend', causing the mean and variance to be constant), and generally satisfies an ARMA equation of the form:

$$X_t - \phi_1 X_{t-1} - \ldots - \phi_p X_{t-p} = \mu + A_t - \theta_1 A_{t-1} - \ldots - \theta_q A_{t-q}$$

The coefficients ϕ_1, ... , ϕ_p, for the AR model, and θ_1, …, θ_q, for the MA model, are calculated according to Box and Jenkins (1976). It is possible for either $\boldsymbol{p}$ or $\boldsymbol{q}$ to be zero. The Box and Jenkins (1976) approach consists of three steps. The first step is model identification, in which the observed yield versus time sequence is transformed (detrended) to meet the stationary assumption. The second step is model estimation, in which the orders, ***p*** and ***q***, indicate the number of different time intervals (different time lags) that were selected for the estimated model. In this analysis, the corresponding coefficients were estimated using the Gaussian maximum likelihood method. The third step is forecasting, in which the model uses earlier yield values to forecast later yield values, all values being contained within the observed 20-year time interval. The three steps are repeated, as necessary, to arrive at a model that best replicates, as closely as possible, the patterns in the series and, consequently, will produce more accurate forecasts. The values for coefficients and orders determined for the ARMA models were then evaluated according to our hypothesis/objective. Further, to test each landscape management zone ARMA model, we forecast, for each rotation, 2007 and 2008 corn yields and compared those predictions with the actual yields observed.

RESULTS AND DISCUSSION

Average (across the four landscape positions) annual corn yields for C-C were about 15% lower than for W/S-C (Table 1). The decline in the standard deviation was not proportional, resulting in a greater coefficient of variation (CV) for C-C yields. Both average annual corn yield populations exhibit negative skew, hence some deviation from normality (Table 1). The same “rotation effect” was observed by Porter et al. (1997), Porter et al. (1998), Yamoah et al. (1998), and Jaynes and Colvin (1997).

Average (across the two rotations) annual corn yields, for the individual landscape positions, were 8.3±2.9, 9.2±2.7, 8.9±2.6 and 9.3±2.5 Mg ha^{-1} for shoulder, upper backslope, lower backslope and footslope positions, respectively. The W/S-C yields were greater than the C-C yields at all landscape positions (not shown), but the highest yielding landscape position differed between rotations. The greatest C-C yield was observed in the lower backslope, while the greatest yield in the W/S-C rotation was found in the footslope. Corn yields at the shoulder position exhibited greater variation, regardless of rotation (not shown), but W/S-C yields were more consistent in the footslope (not shown). Jaynes et al. (2003) reported lower corn yield in C-C and C-S rotations for shoulder positions. Lower corn yields at these positions are believed due to soil properties resulting from erosion (e.g. less organic matter, shallower topsoil, more skeletal fragments, shallower total profile depth), resulting in reduced plant available water holding capacity.

Original yield versus time sequences at individual landscape positions, for both rotations (Fig. 2), exhibited a small upward trend (average slope of 0.13 Mg ha^{-1} yr^{-1}). Eghball and Power (1995) explained the presence of long-term, “deterministic” variation (yield increase independent of rotation) as a consequence of production improvements via better crop genetics and increased and better management of nutrition and weed and pest control.

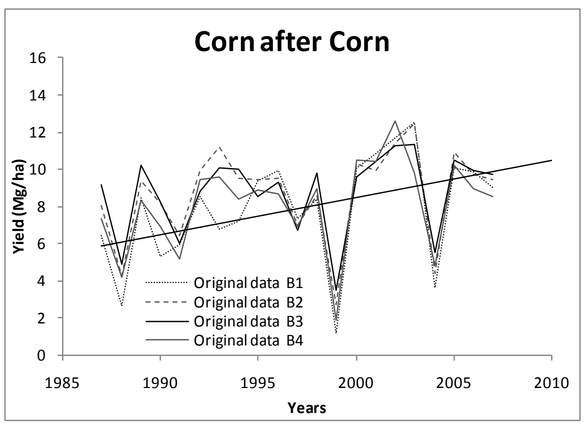
Despite differences in corn yield between landscape positions, Spearman rank correlation analysis confirmed that much of the observed inter-annual yield fluctuation was similar over the field. Rank correlations (not shown), by management zone, and within a given rotation, were all above 0.80, which is high. A high rank correlation indicates that the different soil-annual weather combinations experienced over the years of the experiment affected management zone corn yields in a similar manner (Lamb et al., 1997).

Table 1. Population statistics for average annual corn yield, by rotation.

Parameter	C-C	W/S-C
	Mg ha^{-1}	
Mean	8.3*	9.6*
Median	9.1	10.6
Standard Deviation	2.5	2.7
Skew	-0.91	-1.07
Minimum	2.3	2.6
Maximum	11.7	12.9
**CV (%)	30.8	27.8

*Significantly different at the 95% level of confidence.
**CV = coefficient of variation.

a)



b)

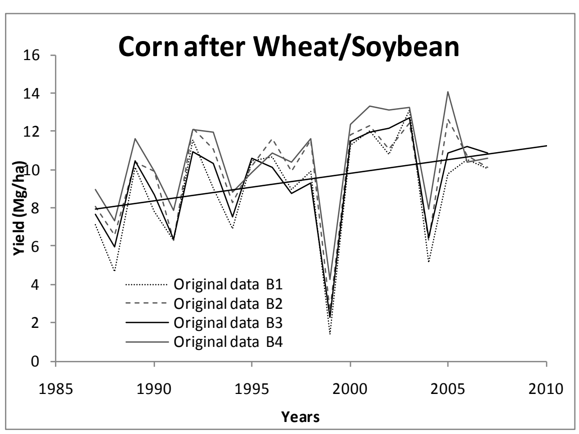


Fig. 2. Yield versus time sequence (time series) for: a) corn after corn (C-C) and; b) corn after wheat/soybean (W/S-C).

The different rotations did result in different rank correlations among management zones (not shown). With C-C yields, the shoulder and lower backslope exhibited the lowest rank correlation, and although the yield magnitude was different, the most similar positions, in terms of yield fluctuations, were the upper backslope and footslope. The C-C yields in the lower backslope were least consistent with the field-average, and it is interesting to note that this position gave the highest yielding C-C corn.

Rank correlation among W/S-C yields exhibited a different pattern (not shown). The shoulder exhibited a high rank correlation with the lower backslope and a low correlation with the footslope, opposite that observed for C-C yields. Lower backslope yields also exhibited the lowest rank correlation with the upper backslope, again opposite that observed for C-C yields. In general, upper backslope, lower backslope and footslope were more similar, and the shoulder most dissimilar.

When ARMA models were fitted to the detrended yield values, inspection of the plots of autocorrelation and partial autocorrelation found that all time series models were stationary. Table 2 contains the results of the ARMA model fitting process, and presents the best AR and/or MA components of the models representing each corn yield-time sequence, including the model order (the numeral following the model component, e.g. AR1 or MA1). In this study, model order was either 1 or 2. Table 2 also gives values for the mean (μ), and AR and MA lag coefficients. The lag interval information appears in parenthesis below the coefficients.

Table 2. ARMA model parameters for each rotation, at each landscape position.

	C-C (corn after corn)				W/S-C (corn after wheat/soybean)			
Position	Model	μ	AR	MA	Model	μ	AR	MA
Shoulder	AR1	-0.517	0.592 (lag 3)	0	AR1	-0.550	0.630 (lag 3)	0
Upper Backslope	AR1 MA1	0.017	0.701 (lag 5)	0.527 (lag 1)	AR2	-0.131	-0.593 (lag 1) -0.485 (lag 2)	0
Lower Backslope	AR1	-0.222	0.474 (lag 3)	0	AR1	-0.310	0.642 (lag 3)	0
Footslope	AR1	0.453	0.626 (lag 3)	0	AR1	-0.044	0.384 (lag 1)	0
Field Average	AR1 MA1	-0.029	-0.516 (lag 5)	0.527 (lag 4)	AR1	-0.398	0.655 (lag 3)	0

With C-C yields, time series analysis found that present yield, at the shoulder, lower backslope, and footslope positions, was positively related (AR and MA coefficient) to the yield observed three years before (Table 2). In the upper backslope, highest yielding for C-C, present yield was positively related to the yield observed five years before (Table 2). The greater temporal lag indicates that the upper backslope was less stable, in this rotation. With W/S-C yields, the analysis again found only one lag that significantly explained future yield behavior (Table 2), except for the upper backslope, where two lags were required. Present W/S-C yield was related to yield only one to three years prior; generally shorter than the lags needed to relate earlier to later C-C yields. Corn yields in the W/S-C rotation have been more "stable" during the 21-year experiment, though this was not equally true across the four zones. For both rotations, the shoulder and lower backslope exhibited similar temporal yield behavior, yield autocorrelation at a three-year lag, in both rotations. The W/S-C yields were more stable than those for C-C in the upper backslope and footslope management zones, with a yield autocorrelation at lags of only one or two years.

The negative values for μ do not annul the effect of the positive model outcomes. Although lags smaller than the largest value could be selected, the analysis found, except in one instance, that there was only one period (lag) that significantly explained "future" corn yield behavior. When shorter lag intervals allow estimation of future yield, there is a more stable temporal response. Longer lag times indicate that more years of yield data are required for forecasting.

Model forecasting results, comparing the yields observed in 2007 and 2008 with the values predicted using the temporal models, are summarized in Tables 3a and 3b.

Table 3a. Summary of observed and predicted yields of monoculture corn (C-C), for each landscape position, for 2007 and 2008.

Year	Landscape Position	Observed	Predicted	Observed-Predicted	Difference (%)
		Yield (Mg/ha)			
2007	Shoulder	9.88	11.89	-2.01	-20.3
	Upper Backslope	9.73	9.71	0.02	0.2
	Lower Backslope	9.95	10.46	-0.51	-5.2
	Footslope	8.96	9.76	-0.80	-8.9
2008	Shoulder	9.04	6.08	2.96	32.7
	Upper Backslope	9.41	8.65	0.77	8.1
	Lower Backslope	9.76	7.62	2.14	21.9
	Footslope	8.57	6.68	1.89	22.0

In general, predicted yields were more similar to observed yield values the first year (2007) of estimation, and the absolute difference between observed and predicted values was greater for the second year (2008) of estimation (Tables 3a and 3b). In all cases, observed corn yields were contained within the 95%

confidence interval surrounding the values predicted from the temporal models (data not shown).

The 2007 corn yields, for both rotations, were overestimated in most landscape management zones, but the opposite was observed in 2008 (Tables 3a and 3b). The poorest yield predictions were consistently observed for the shoulder management zone, while the best yield predictions were usually made for the upper backslope (Tables 3a and 3b). Predicted yields were a bit closer to those observed for C-C corn than for W/S-C corn in 2007, but this was not the case in 2008.

Table 3b. Summary of observed and predicted yields of corn grown in rotation (W/S-C), for each landscape position, for 2007 and 2008.

Year	**Landscape Position**	**Observed**	**Predicted**	**Observed-Predicted**	**Difference (%)**
		Yield (Mg/ha)			
2007	Shoulder	10.51	12.31	-1.80	-17.1
	Upper Backslope	10.74	11.99	-1.25	-11.6
	Lower Backslope	11.18	12.24	-1.06	-9.5
	Footslope	10.41	10.98	-0.57	-5.5
2008	Shoulder	10.07	6.99	3.09	30.6
	Upper Backslope	10.14	9.29	0.85	8.4
	Lower Backslope	10.90	8.10	2.80	25.7
	Footslope	10.60	12.29	-1.69	-16.0

CONCLUSION

Corn yields in the W/S-C rotation were more “stable” during the 20-year (1987 to 2006) time period than those in the C-C rotation. The lag predicting this year’s yield was only 1 to 3 years earlier for W/S-C corn, but was 3 to 5 years earlier for C-C corn. This “rotation effect” on the temporal stability of yield was evident for the field as a whole management unit, but was especially apparent for two of the four landscape management zones. Thus, crop rotation choices can complicate landscape management zone delineation. There was an effect of landscape on yield stability, and corn yields at the least stable landscape position (shoulder) were not well predicted by the individual rotation yield time series models. It is notable, however, that yield predictions two years into the future were made similar by use of models for individual rotations. And although differences between predicted and observed yield were sometimes near 30%, they were often below 20%, demonstrating the potential utility of these temporal models.

REFERENCES

Box, G.E.P., and G.M. Jenkins. 1976. Time Series Analysis: Forecasting and Control. Holden-Day, San Francisco, CA.

Crookston, R.K., J.E. Kurle, P.J. Copeland, J.H. Ford and W.E. Lueschen. 1991. Rotational cropping sequence affects yield of corn and soybean. Agron. J. 83:108-113.

Eghball, B., and J.E. Power. 1995. Fractal description of temporal yield variability of 10 crops in the United States. Agron. J. 87:152-156.

Hendrix, J.W., K.J. Jones and W.C. Nesmith. 1992. Control of pathogenic mycorrhizal fungi in maintenance of soil productivity by crop rotation. J. Prod. Agric. 5:383-386.

Hu, Q., and G. Buyanovsky. 2003. Climate effects on corn yield in Missouri. J. Applied Meteorology. 42:1626-1635

Jaynes, D.B., T.C. Kaspar, T.S. Colvin and D.E. James. 2003. Cluster analysis of spatiotemporal corn yield patterns in an Iowa field. Agron. J. 95:574–586.

Jaynes, D.B., and T.S. Colvin. 1997. Spatiotemporal variability of corn and soybean yield. Agron. J. 89:30-37.

Koenning, S.R., D.P. Schmitt, K.R. Baker and M.L. Gumpertz. 1995. Impact of crop rotation and tillage system on *Heterodera glycines* population density and soybean yield. Plant Dis. 79:282-286.

Lamb, J.A., R. H. Dowdy, J. L. Anderson and G. W. Rehm. 1997. Spatial and temporal stability of corn grain yields. J. Prod. Agric. 10:410:414.

Liebman, M., and T. Ohno. 1997. Crop rotation and legume effects on weed emergence and growth: Applications for weed management. p. 181-221. *In* J.L. Hatfield et al. (eds). Integrated Weed and Soil Management. Ann Arbor Press, Chelsea, MI.

Linden, D.R., C.E. Clapp and R.H. Dowdy. 2000. Long-term corn grain and stover yields as a function of tillage and residue removal in east central Minnesota. Soil Till. Res.56:167-174.

Peterson, T.A., and G.E. Varvel. 1989. Crop yield as affected by rotation and N rate: III. Corn. Agron. J. 81:735-738.

Porter, P.M., J.G. Lauer, D.R. Huggins, E.S. Oplinger and R.K. Crookston. 1998. Assessing spatial and temporal variability of corn and soybean yields. J. Prod. Agric. 11:359-363.

Porter, P.M., J.G. Lauer, W.E. Lueschen, J.H. Ford, T.R. Hoverstad, E.S. Oplinger and R.K. Crookston. 1997. Environment affects the corn and soybean rotations effect. Agron. J. 89:441-448.

Raun, W.R., H.J. Barreto and R.L. Westerman. 1993. Use of stability analysis for long-term soil fertility experiments. Agron. J. 85:159-167.

SAS Institute Inc. 1997. SAS/STAT® Software: Changes and enhancements through release 6.12. SAS Institute, Cary, N.C.

Varvel, G.E. 1994. Rotation and nitrogen fertilization effects on changes in carbon and nitrogen. Agron. J. 86:319-325.

Yamoah, E.E., G.E. Varvel, C.A. Francis and W.J. Waltman. 1998. Weather and management impact on crop yield variability in rotations. J. Prod. Agric. 11:219-225.