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WITHIN FIELD VARIABILITY IN WHEAT GRAIN YIELDS OVER NINE YEARS IN OKLAHOMA*

C. N. Washmon,[1,†] J. B. Solie,[1] W. R. Raun,[2] and D. D. Itenfisu[1]

[1]Department of Biosystems and Agricultural Engineering and [2]Department of Plant and Soil Sciences, Oklahoma State University, Stillwater, OK 74078, USA

ABSTRACT

Wheat grain yield levels are known to vary from 1 year to the next and this variability is frequently attributed to differences in rainfall. However, within field variability of wheat grain yields as a function of time has not been extensively evaluated. Wheat grain yields from selected fields in Oklahoma were monitored over a 9-year period using satellite imagery. Yields for each $25\,m \times 25\,m$ area within each field were estimated from NDVI measurements obtained from LANDSAT scenes in north-central Oklahoma. Minimum, maximum, mean, standard deviation, and coefficient of variation (CV) values were collected from six locations from 1991 to 1999. Coefficient of variations for wheat grain yield ranged between 16 and 38% for the same field. The wide range in CVs could be partly explained by the changes in

*Contribution from the Oklahoma Agricultural Experiment Station.
†Corresponding author. E-mail: washmon@okstate.edu

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average grain yield where CVs tended to be greater when mean yields were lower. Because CVs for the same field had such a wide range (from year to year), these results suggested that the expression of spatial variability was a function of the environment in which wheat was grown. Therefore, if within field CVs could be predicted (mid-season satellite images of variable growth using NDVI), the potential response to added nutrients may also be established, and in-season nutrient additions adjusted accordingly. Furthermore, knowledge of the CV mid-season for a particular field could be equated to the response index which various researchers have used to determine topdress fertilizer needs.

INTRODUCTION

In the past few years there has been an increasing demand for new technologies to assist farmers in making decisions for inputs and to manage variability within fields. Looking at historical data has been suggested to allow for increased accuracy in management decisions. Baier[1] stated that correct decisions are dependent on timely and accurate information. Crop yield maps are designed to represent the relationship between the crops and their environment. When looking at historical yield to create one of these models, there are many causes for error and that must be addressed.

Many different variables can be acquired and used to make input decisions. Larson[2] compared crop yields between soil types and found that managing spatially variable fields based on the variability of soil type increased net returns. What information do we need to make an appropriate decision? Bakhsh et al.[3] used a statistical approach to characterize the spatio-temporal variability within a field. They found that overall, yield variability was not stable spatially or temporally. Their objective was not to develop a yield model, but they hypothesized that one major cause of yield variation was interaction among soil water retention capacity, drainage, and rainfall patterns. Decisions to treat the variability within the field have to be made in-season to accurately account for these factors in that particular growing season. These results suggest that decisions based upon historical data are based on probability, rather than certainty and that to make deliberate management decisions, information must account for the environment within the current crop year of interest.

Gopalapillai and Tian[4] conducted a study using aerial color infrared imagery to correlate crop reflectance with yield potential and to identify the spatial yield pattern within a field. This study only used images collected within the growing season investigated. The in-season yield predictions had up to 91% prediction success.

There have also been studies to show that the spatial variability that occurred in yields was based on the slope and aspect. Timlin et al.[5] studied the effect of hillslope on both spatial and temporal corn grain yield. They found that the intra-annual differences in weather patterns had the largest effect on grain yield in fields with large hillslopes. Sloped regions drained better in high rainfall years, and retained less water in drier years.

There are many proposed uses for satellite imagery in agriculture. Much historical data can be obtained from satellite image archives for past years, but the usefulness of this information is not clear. This study addresses the within-field variability that is detected from year to year using satellite imagery and the impact this information may have on use of satellite imagery.

MATERIALS AND METHODS

A time series of LANDSAT five Thematic Mapper (TM) scenes of north-central Oklahoma, with radiometric and geometric corrections, spanning the period 1991 to 1999, were obtained from Earth Observation Satellites, Inc. (EOSAT). Images were georeferenced to US Geological Survey digital 7.5 min orthophoto quadrangle maps and then resampled to a Universal Transverse Mercator grid, with a 25 m pixel size, using the nearest neighbor algorithm. The TM scenes were chosen so that, insofar as possible, the satellite overpasses occurred at or near the heading stage of winter wheat in the area (mid April to early May). In some years, cloud interference forced the selection of an image slightly outside the optimum time window and in the spring of 1995, no acceptable image was available. In 1997, clouds in the only useable image obscured some of the fields.

Six cooperators were located within the scene for the study. The locations of these fields were all in north-central Oklahoma. They were located near the towns of Red Rock, Pond Creek, Tonkawa, Cherokee, and Hitchcock, OK. Each of the field boundaries was mapped using GPS and the program Field Rover (SST Development Group, Stillwater, OK). At all sites, cropping patterns were the same for each year examined. Those fields that were grazed by cattle were grazed each year during the study period. Sites where N rates, crops, grazing, and/or tillage changed from year to year were not included in this analyses. For each year's imagery, bands three and four, red and near-infrared wavelengths, were calibrated to exoatmospheric reflectance using coefficients provided by EOSAT. These reflectance values were used to calibrate the normalized difference vegetation index, which were a measure of biomass and a prediction of grain yield. Wheat yields from the Oklahoma State University Wheat Pasture Research

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Unit (which is within the bounds of the satellite image) were compared to the NDVI values and a relationship between NDVI and yield derived. A yield prediction equation was developed to estimate wheat yield of each of the cooperator fields. As a result, yield data was obtained for each 25 m × 25 m area in each field.

Farmer cooperators' measured average yields were used to calculate the error in yield prediction for the respective fields. From 1991 to 1999, excluding years with unusable images, the yields for four of the fields were calculated using satellite imagery, and these yields were normalized based on the field average. This normalization was crucial for across year comparisons due to the error created by not having satellite images at the same stage of growth for every year. By not having the images at the same growth stages, normalizing the values by the field averages allowed comparisons to be made among years. The values compared were normalized yields, which represented relative yields of each field element compared to the average yield of the entire field for each respective year. Temporal and spatial variability appeared to be random.

Average yields for all possible combinations of years were calculated, e.g., combinations of 2, 3, 4, 5, and 6 years. Averages were by field element. There were 120 combinations of years, and all combinations were used for error analysis. Each average of two or more years was used as a predictor of all years' yield not used in the calculation of the average value. The error prediction based on the actual value was then calculated for each individual field element. These errors were then averaged across the entire field and the standard deviations were calculated for each prediction combination.

RESULTS AND DISCUSSION

Coefficients of variation (CV) ranged between 16–38, 11–25, 7–17, 11–25, 10–18, and 18–31, at Red Rock, Pond Creek East, Pond Creek West, Tonkawa, Cherokee, and Hitchcock, respectively (Table 1). At each of these sites, the range in CVs almost doubled between the low to high values. A range of CVs this wide from the same fields, where yield data was collected in consecutive years, suggests two things. First, it says that the spatial variability was a function of the environment in which wheat was grown. In other words, the expression of spatial variability depended on the climatic conditions for the year in which the wheat was grown. This assumes that management did not vary from year to year (for a specific location), which was true for each site. The only thing that changed from year to year was climate, planting date, harvest date and possibly wheat variety.

Secondly, the wide range in CVs for wheat grain yield at each site implied that homogeneity in yield changed greatly from year to year. This raises the question, how could a field that was managed the same, fertilized the same, and

Table 1. Wheat Grain Yield Data Estimated Using NDVI Collected from LANDSAT[a]

	Year							
	1991	1992	1993	1994	1996	1997	1998	1999
Location red rock								
Minimum	1.4	0.67	1.27	1.53	0.62	0.82	2.09	1.69
Maximum	3.98	1.99	3.31	4.39	2.94	3.62	4.18	4.37
Mean	2.64	1.08	2.17	2.93	1.17	1.88	3.01	3.36
Median	2.72	1.01	2.18	2.93	1.07	1.75	2.97	3.45
Standard deviation	0.55	0.25	0.38	0.6	0.45	0.63	0.47	0.52
CV	21	23	17	20	38	34	15	15
Pond creek east								
Minimum	0.91	0.83	2.54	0.63	0.98		2.54	2.49
Maximum	2.67	1.67	4.93	4.64	2.8		5.02	4.7
Mean	1.78	1.18	3.89	3.67	2.03		4.09	3.85
Median	1.79	1.18	3.92	3.96	2.05		4.14	3.92
Standard deviation	0.45	0.14	0.51	0.81	0.39		0.46	0.44
CV	25	12	13	22	17		11	11
Pond creek west								
Minimum	1.24	1.3	1.5	1.49	0.68		2.22	2.07
Maximum	2.58	2.07	4.71	3.97	2.3		4.9	4.93
Mean	1.84	1.71	3.65	3.26	1.64		3.94	3.65
Median	1.81	1.7	3.78	3.34	1.69		4.03	3.66
Standard deviation	0.27	0.13	0.59	0.4	0.27		0.48	0.59
CV	15	7	16	12	16		12	16
Tonkawa								
Minimum	0.29	0.74		1.51	1.12	2.13		1.13
Maximum	1.04	2.41		4.06	2.44	4.38		2.53
Mean	0.5	1.52		3.02	1.83	3.42		1.72
Median	0.47	1.45		3.09	1.86	3.45		1.67
Standard deviation	0.13	0.27		0.42	0.23	0.37		0.27
CV	25	17		14	13	11		16
Cherokee								
Minimum	1.35		1.89	1.53	1.35	0.83	1.33	1.32
Maximum	3.78		4.63	2.8	3.05	3.3	4.76	4.57
Mean	2.49		3.69	2.16	2.43	2.38	3.91	3.39

(*continued*)

Table 1. Continued

	Year							
	1991	1992	1993	1994	1996	1997	1998	1999
Median	2.44		3.7	2.2	2.47	2.43	4.07	3.48
Standard deviation	0.46		0.35	0.24	0.28	0.33	0.55	0.57
CV	18		10	11	12	14	14	17
Hitchcock								
Minimum	0.62	0.44	1.01	0.78	0.71		1.1	0.5
Maximum	3.15	1.49	3.56	3.92	2.9		3.92	2.41
Mean	1.99	1.02	2.24	2.48	1.84		1.75	1.14
Median	2.02	1.08	2.24	2.52	1.85		1.6	1.13
Standard deviation	0.36	0.26	0.46	0.51	0.35		0.55	0.35
CV	18	26	20	21	17		31	30

[a]Yield in Mg/ha.

harvested the same result in homogeneity one year and heterogeneity the next year? The wide range in CVs implied that the magnitude of the yields did not simply shift from year to year, but that pattern of yield within a field changed from year to year.

The wide range in CVs can be partly explained by the changes in average grain yield. Taylor et al.[6] reported that as the mean wheat grain yield of 362 published wheat field experiments increased, CVs tended to decrease. When this analysis was performed on the data for this study, the same conclusion could be made (Fig. 1), at least for lower yields.

In examining the prediction errors using historical data, it was apparent there were large differences in error based on the different combinations of years used for the prediction. As the number of years averaged for the prediction increased, the range of error decreased, but even after seven years of data was included, there was still an error range of 12 to 60% (Fig. 2). This showed that prediction errors could not be improved by averaging more years of historical data.

There are many factors that could have affected the variability in the fields from year to year, causing such a large range of CVs for each of the fields. Perhaps the most important of these is weather interaction with soil type and land aspect. Weather interacts in a complex way with topography and soil class to affect crop yields because of the relationships between soil relief, root growth, water retention, and nitrogen mineralization. Other factors that could affect variability are fertilizer nutrients, pH, and tillage.

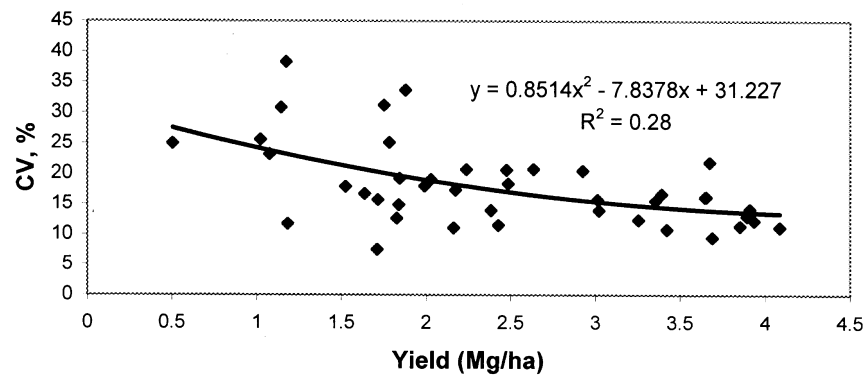

Figure 1. Relationship between the CV present within a field and average yield for six fields from 1991 to 1999.

What does this mean for Precision Agriculture? If the predicted yield CV of a field ranges between 16 and 38%, precision agricultural technologies will have to be weather and site specific. For example, if we knew that the range of obtainable yields was 2000 to 3000 kg/ha in one year, and 2500 to 5500 kg/ha in an ensuing year, and that the distribution of that variability was spatial in nature, then management decisions relative to inputs could be drastically different from

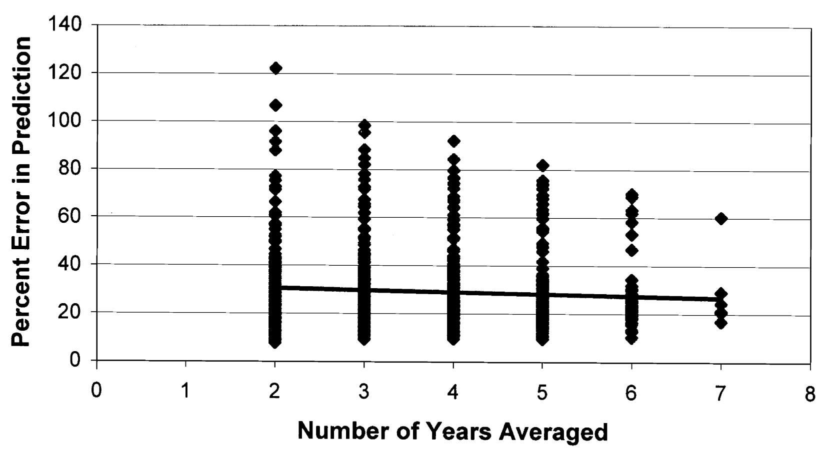

Figure 2. Error in prediction of yield as a function of the number of years used for prediction, six locations, 1991 to 1999.

year to year. Thus, if we had an idea of how variable a site was likely to be in a given year, it would alter both actual rates and ranges of inputs, very similar to that noted for the estimated yield CV. Using the CV measured during the growing season for a specific field may assist in determining the potential yield response to added nutrients.[7] Furthermore, knowledge of the NDVI CV mid-season for a particular field could be equated to a fertilizer response index, which various researchers have used to determine topdress fertilizer needs.

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