WHAT DO WE DO WITH ALL THESE YIELD MAPS?

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Identifying management zones (MZs) within a field is challenging because crop yields typically vary over space and time (Lamb, 1997). In-field variability is the focus of precision agriculture – how to manage it, diminish it, or overcome it. In-field variability reduces the ability to determine consistent yield patterns, and thus management zones.

Producers have expressed frustration in obtaining value from yield maps. Griffin (2000) states, "farmers were struggling to find direct benefits from the yield information that they were spending time and effort gathering." Reasons yield maps are often not generated include: (i) the yield monitor might not be accompanied by GPS, (ii) problems associated with the data analysis, and (iii) owner operators who do little or no field work do not benefit as much from yield maps as those having direct experience with field conditions (Griffin, 2004). Reasons for not utilizing generated data such as yield maps are numerous and include; time to learn electronic skills in order to operate equipment and software, lack of training for producers and industry, uncertainty with using analyzed data to influence decision making, lack of local experts for technical assistance, working with data of differing formats, lack of basic research on yield and soil relationships, and need for a precision agricultural equipment (Kitchen, 2002). Griffin (2004) states, "the inability to process the gathered yield information into meaningful decisions, leads to apathy and discontinuance of future data collection."

A multitude of intrinsic and extrinsic properties can influence crop grain yield, of which, nutrient availability and water stress are most important. Proper fertilizer management can diminish nutrient stress, which leaves spatial variations in water stress responsible for yield variation across fields (Jaynes, 1995). Water stress can occur from either droughty conditions, or excessive moisture conditions.

Over an extended period, multiyear grain yield data can cover the range of grain yields expected, and thus can be used to predict future yields (McBratney, 2000; Pierce, 1997; Tiffany ,2000). A data set of 5 years or more of grain yield data is sufficient to represent a range of expected grain yield outcomes under various weather conditions (Lamb, 1997). Although multiyear data can provide inconsistent and confusing yield patterns, it can provide a foundation by which producers can begin to understand variability. Hopkins (1999) states, "uncertainty should not preclude site specific decisions any more than uncertainty should preclude decisions in any other facet of farm management." Long-term experiments offer unique possibilities to study the effects of management practices on crops and soils over time.

Temporal variation in yield patterns is due to dynamic interactions among climate, landscape, soils, plants, and management practices (Jaynes, 2003). Temporal variability may greatly influence how spatial variability is expressed in a given field. Yield maps, which are used as an indication of past management in site-specific cases, may not be useful in making future management decisions when temporal variability is great (Eghball, 1997).

The deficient temporal stability for yield patterns, makes creating statistical relationships between spatial yield patterns and soil properties difficult at best (Eghball and Varvel, 1997).

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However, a relationship between spatial yield data and soil properties is still observed. Classification of cotton yield was based on six soil properties (pH, extractable Ca and Mg, K saturation, clay content, and soil N/P ration), and the prediction was correct 73% of the time (Ping, 2005). Consistently low, average, and high yield classification can be found for fields when using multiple years of yield data (Cox and Gerard, 2007).

When soil properties and topographic properties can be correlated to differences in grain yield, these soil properties were not consistent across fields (Cox and Gerard, 2007). Although soil properties can be correlated to yield in some cases, proper acquisition of these soil properties can be timely, expensive and can have highly variable results. Grid soil sampling is typically used for establishing management zones for site-specific application of nutrients. The geo-statistical procedures used to estimate values between sample locations require samples to be taken close enough together that they are correlated to one another.

Rather than trying to predict specific yields within a field, we may be more successful in identifying areas within a field that behave similarly among years (Lark and Stafford, 1997; Boydell and McBratney, 2002). Based on yield history, low, average and high yielding classifications can be found for management zones within a given field (Cox and Gerard, 2007). Jaynes (2003) states, "for farming by management zones to be practical, one would like to identify a limited number of temporal yield patterns within a field, and the areas of the field exhibiting similar patterns should form spatially similar, contiguous areas." Lamb (1997) found that the effect of a particular growing season was approximately 100 times greater than location and spatial effect. Lamb (1997) states, "The use of several years of grain yield information in intensively managed corn production was not as precise as needed in determining yield goals for future management decisions."

Predictable patterns of grain yield variability are necessary for implementation of variable rate technology. The objective of this study is to use a database of geo-referenced multi-year grain yield and grain moisture information from multiple fields to:

1. Determine if geo-referenced management zones within a field vary with respect to grain yield or grower return class from year to year, and if so, how much, and is the amount biologically and economically significant.
2. Determine if multi-year grain yield data can be used to accurately predict the following year's grain yield.
3. If grain yield prediction is achievable, can variable rate starter fertilizer prescriptions, based on management zone grain yield classes be either agronomical or economical.

Materials and Methods

Yield maps were collected over a 12 year period on one field (Field A) in Walworth County, WI (42°31'N, 88°38'W) on a Plano silt loam soil (fine-silty, mixed, mesic, Typic Agriudoll). Mean annual temperature and precipitation are 9.4°C and 941mm, respectively. The crop rotation was an alternating corn-soybean rotation. Corn was grown in 1995, 1997, 1999, 2001, 2003, and 2005. Soybean was grown in the alternate years. This field represents a unique dataset due to the high quality spatially referenced grain yield and grain moisture data.

Fields were divided into spatially referenced MZs of 538 ft^2, which remained consistent within a field across years. Means for grain yield and grain moisture were calculated for each MZ within a field for each year data was collected. Combines equipped with commercially available yield sensing systems were used to collect data from 1994-2007.

Individual points were determined unreliable based on several criterions. First, all negative values for grain yield and grain moisture were deleted. Points with GPS positional errors were deleted. Outside headlands were deleted, to avoid significant changes in grain flow while entering and exiting the field. Grain moisture points that were abnormally high, and were not associated with normal grain harvest practices were deleted. Finally, grain yield points that were deemed higher than the agronomical potential for a field under a set of management practices ($\geq$ 18.8 Mg ha^{-1}) were deleted.

Means of grain yield and grower return were calculated for each MZ, within each field, within each year. Overall means were calculated for each MZ, within each field, across all corn or soybean years. Classification of a MZ based upon grain yield and grower return, was achieved by grouping MZs using one standard deviation from the mean into high, medium and low classes. A MZ greater than or equal to one standard deviation above the mean were classified as high, MZs that fell within one standard deviation of the mean were classified as medium, and the MZs less than or equal to one standard deviation below the mean were classified as low. Variance for each MZ, within each field was calculated with the following formula:

$$s^2 = \frac{\sum (X - M)^2}{N - 1}$$

where M is the mean for an individual MZ within a field across years, X is the mean for the same MZ, within the same field, for a particular year, and N is the number of years.

Once a MZ was assigned a grain yield class based on multiyear grain yield data, yield during the following year could be predicted. With combined years' data, each MZ, within each field, was assigned a grain yield class (High, Medium, and Low) and also a grain yield variance class (High, Medium, and Low) for a particular crop. This provides nine treatment cohorts; High Yield-High Variance, High Yield-Medium Variance, High Yield-Low Variance, Medium Yield-High Variance, Medium Yield-Medium Variance, Medium Yield-Low Variance, Low Yield-High Variance, Low Yield-Medium Variance, and Low Yield-Low Variance.

During the last growing season in which corn was grown the producer implemented variable rate starter fertilizer applications. Variable rate fertilizer prescriptions were applied onto fields before management zones (MZs) were established and classified. The variable rate fertilizer prescriptions were based on the intuition of the producer - portions of the field thought to have high yield potential received a high fertilizer treatment, areas of a field thought to have medium yield potential were given a medium fertilizer treatment, and low yielding portions of the field according to producer perception were treated with the low fertilizer treatment. The field received starter with an N-P-K fertilizer analysis of 10-34-0. There were three starter fertilizer rates, which consisted of low, 100 lb/A; medium, 125 lb/A; and high, 150 lb/A.

Once MZs were established, the producer's variable rate fertilizer prescriptions for each field were assigned to the established MZs within each field. For comparison purposes only, variable rate fertilizer prescriptions based on MZs classified using multiyear grain yield and moisture data were created. High yield class MZs would have received the high fertilizer treatment, medium yield class MZs would have received the medium fertilizer treatment, and low yield class MZs would have received the low fertilizer treatment. This allows for a unique comparison between producer intuitions about grain yield potential of a field with actual grain yield potential of a field based on multiyear grain yield data (Figure 1). Soil test results were conducted during the 2006 growing season indicated the field had phosphorus and potassium levels that were both characterized as Excessively High.

Data were analyzed as a completely randomized design using PROC MIXED (SAS Institute, Cary, NC). PROC UNIVARIATE was used to test that data was normally distributed. The experimental unit, a management zone (MZ) was classified based on previous years grain yield data and was not randomly assigned. For the analysis of an individual field for yield prediction, fixed effects were Yield Class, Variance Class and Yield Class x Variance Class interaction, with no random effects. For the analysis on individual fields for variable rate fertilizer application, fixed effects were Cohort (Yield Class-Variance Class), Fertilizer and Cohort x Fertilizer interaction, with no random effects. For the combined analysis across fields, for yield prediction, fixed effects were Yield Class, Variance Class and Yield Class x Variance Class interaction, with field as a random effect. For the combined analysis across fields, for variable rate fertilizer application, fixed effects were Cohort (Yield Class-Variance Class), Fertilizer and Cohort x Fertilizer interaction, with field as a random effect. Effects were considered significant when $P \leq 0.05$. The LSD procedure was used to separate means when the F-Test was significant ($P \leq 0.05$).

Results and Discussion

Temporal variability most likely associated with different weather conditions from year to year did affect consistency of a management zone within the same grain yield or grower return class (Figure 1). Some management zones were consistently in the same high, medium or low grain yield or grower return class across all years, but other MZs changed class depending on growing conditions of a particular year.

Due to the large amount of temporal variation that a particular MZ undergoes, it is important and necessary to have a multiyear dataset that provides information about the performance of a particular MZ across as wide of a rage of weather conditions as possible. A single year's result reflects that particular year's weather pattern. Multiyear data helps to relieve temporal variation by capturing data across extremes of weather patterns. MZs can then be classified within a field using grain yield class or grain yield variation class across all years (Figure 2).

Yield-Management Zone Classification

Management Zones were classified into yield-variance cohorts based on grain yield data collected prior to the year of variable rate fertilizer application. Yield-variance cohorts were analyzed to determine if the magnitude of grain yield differences between them were biologically and economically significant. Corn yield classes are averaged across variance classes. In field A the high yield class, producing 185 bu/A, was higher yielding than the medium yield class (178 bu/A), and both the high and medium yield classes were higher yielding than the low yield class, which produced 172 bu/A (Table 1). The difference between the highest yielding group and the lowest yielding group was 13 bu/A.

Soybean yield classes are averaged across variance classes. In field A the high yield class, producing 48 Mg ha^{-1}, was higher yielding than the medium yield class (46 bu/A), and both the high and medium yield classes were higher yielding than the low yield class, which produced 43 bu/A (Table 1). The difference between the highest yielding group and the lowest yielding group was 5 bu/A. If there were no differences amongst yield classes, this would indicate a lack of variability within a particular field; however, this field had enough variability that it was both biologically and economically significant and worthwhile to manage.

Corn Yield-Management Zone Prediction

During the growing season of variable rate fertilizer application corn grain yield was measured. MZs were previously assigned a yield-variance cohort classification, and yields from either the 2005 or 2006 growing season were used to determine how well MZs were classified. Yield classes are averaged across variance classes. In field A the high yield class, producing 153 bu/A, was higher yielding than the medium yield class (140 bu/A), and both the high and medium yield classes were higher yielding than the low yield class, which produced 123 bu/A (Table 2).

During the growing season following variable rate fertilizer application, prediction of soybean grain yield was measured. MZs were already assigned a yield-variance cohort classification, and yields from either the 2006 or 2007 growing season were used to determine how well MZs were classified. Yield classes are averaged across variance classes. In field A the high and medium yield classes, producing 53 bu/A and 51 bu/A, were similar to one another, and higher yielding than the low yield class, which produced 49 bu/A.

Yield-Variable Rate Fertilizer Evaluation

An evaluation of fertilizer application rate treatments (High, Medium, and Low) averaged across all nine yield-variance cohorts, revealed that variable rate fertilizer significantly affected field A but the high fertilizer rate did not correlate with high yield (Table 2). Previous research **(**Bermudez and Mallarino, 2007), concluded that on average, variable rate application of phosphorus, reduced phosphorus application by 12.4% over a fixed rate application. Variable rate application did not increase yield compared with a fixed rate application.

There was an interaction between yield-variance cohort and fertilizer (data not shown). Within the high yield-high variance cohort, medium fertilizer treatment produced 22 bu/A more than the high fertilizer treatment. Within the high yield-low variance cohort, high fertilizer treatment produced 21 bu/A more than the low fertilizer treatment. Within the low yield-high variance cohort, high fertilizer treatment produced 29 and 25 bu/A more grain yield than the medium and low fertilizer treatments. Within the low yield-low variance cohort, the high and low fertilizer treatments produced 22 and 27 bu/A more grain yield than the medium fertilizer treatment.

Soybean was planted into fields the growing season following the variable rate fertilizer application; however differences among fertilizer treatments were still observed (Table 2).

Conclusions

Annual weather conditions affected classification of cells into cohorts. The range between the highest and lowest yielding MZ within a field averaged 26 bu/A across all fields. Predicting grain yield of MZs across all fields during the year of variable rate fertilizer application was successful. Corn grain yield of MZs based on corn grain yield produced 174, 166, and 150 bu/A in the high, medium and low yield classes. Prediction of grain yield across all fields during the year of variable rate fertilizer application was successful. The magnitude of yield differences within a field was substantial and predictable, but variable rate fertilizer application was not effective in applying inputs to confidently produce a yield response. Averaged across all fields, variable starter fertilizer treatment did not impact corn grain yield.

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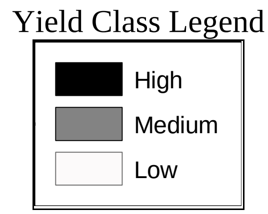
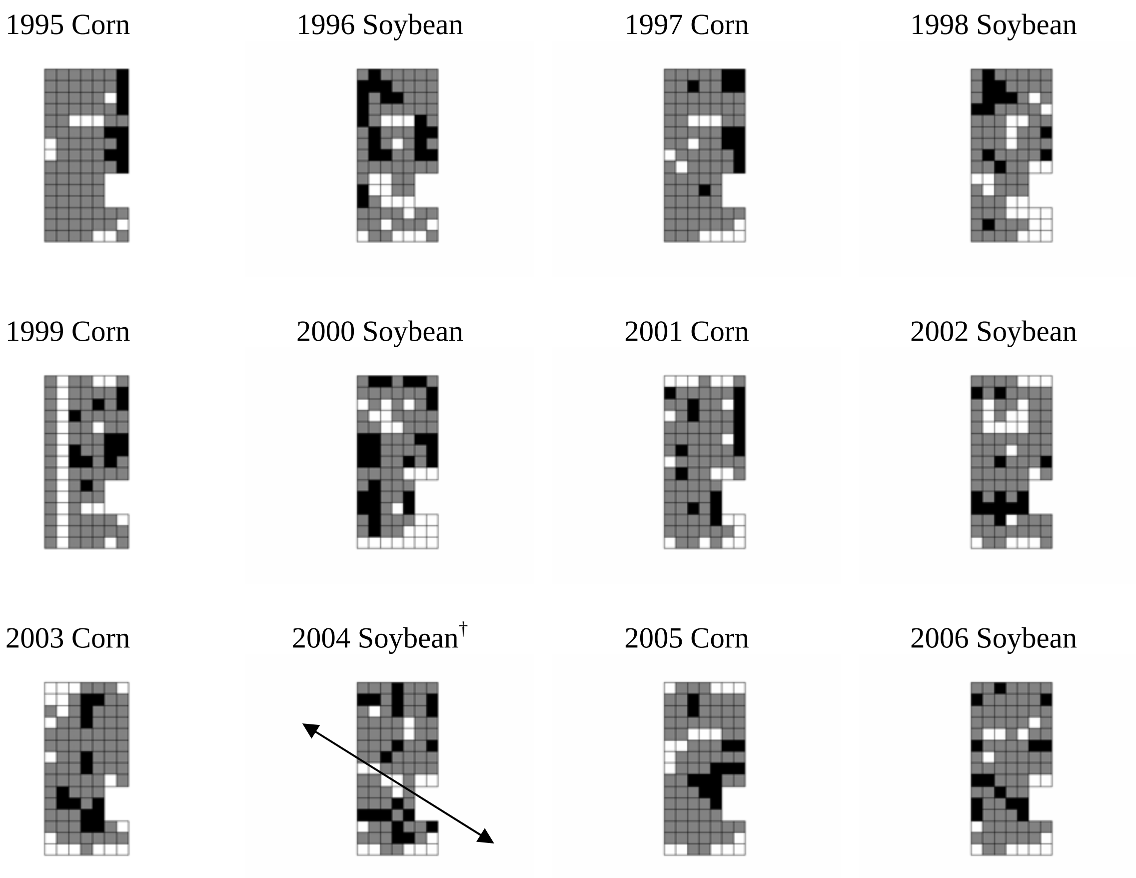


Figure 1. Corn and soybean yield classes for Field A.



† - Missing Data: Gas Pipeline Placed Through Field

Figure 2. Corn and soybean yield classes, variance classes, treatment cohorts of Field A. Data are combined over years.

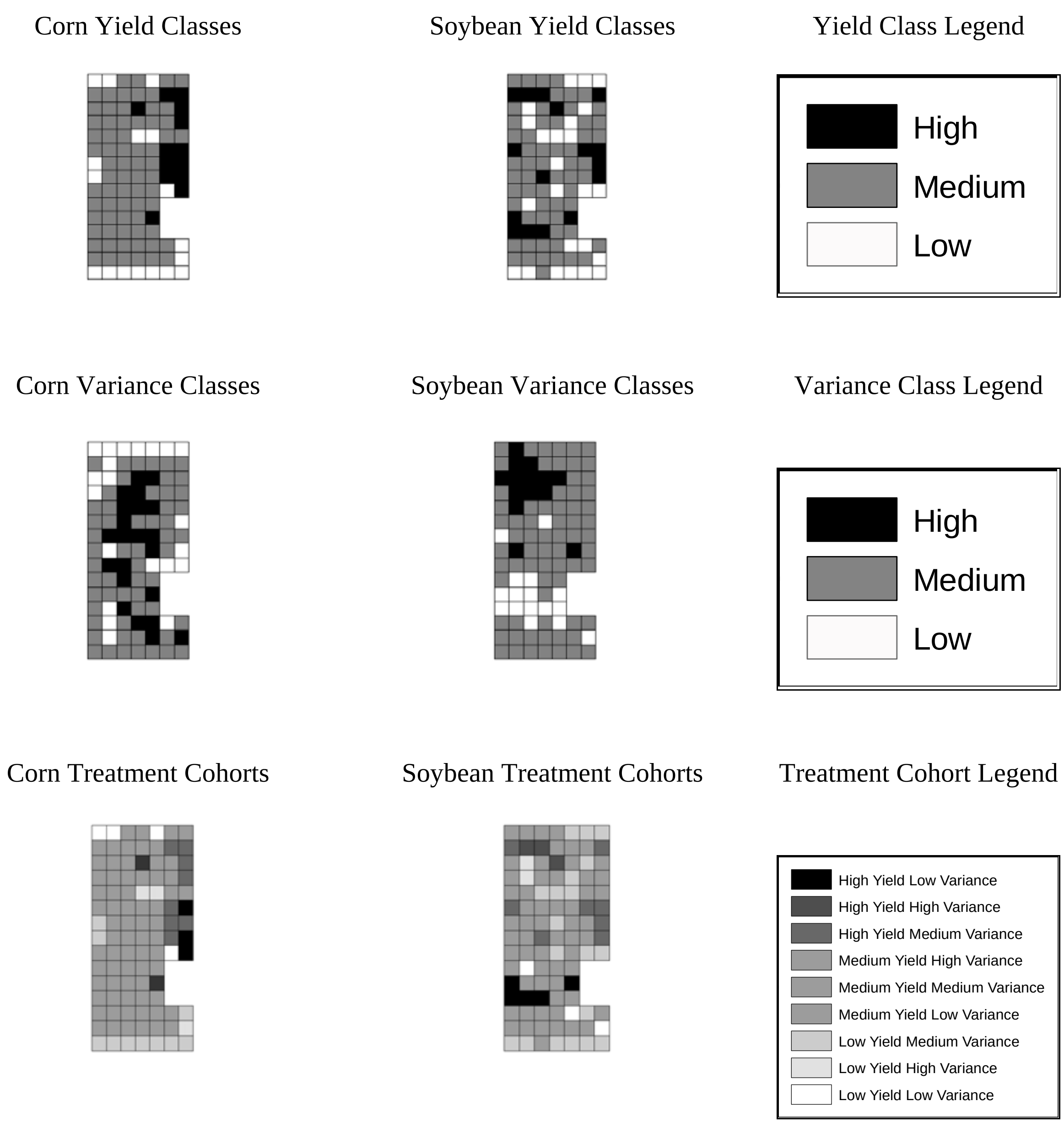


Table 1. Corn grain yield mean and variance of each yield-variance cohort. Values are based upon yield points averaged within a MZ each year and then averaged across years to calculate mean and variance.

		Corn		Soybean	
Yield cohort	Variance cohort	Mean	Standard deviation	Mean	Standard deviation
			bu/A		
High	Low	186	11	48	6
	Medium	185	16	48	7
	High	181	21	48	9
Medium	Low	177	16	46	6
	Medium	178	19	46	7
	High	178	22	46	9
Low	Low	172	13	43	7
	Medium	172	19	43	9
	High	172	27	43	10
LSD(0.05)		3	2	1	1

Table 2. Corn and soybean grain yield of yield-variance cohorts following variable rate application of fertilizer during 2006 and 2007. Cohorts were classified using grain yield and moisture data from five previous growing seasons.

		Grain yield	
Yield cohort	Variance cohort	Corn 2007	Soybean 2006
		Mg ha^{-1}	\$ ha^{-1}
High	Low	148	53
	Medium	153	54
	High	159	51
Medium	Low	143	52
	Medium	142	51
	High	138	51
Low	Low	110	48
	Medium	129	50
	High	127	49
LSD(0.05)		11	2