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Reliability of Yield Mapping System for Estimating Perennial Ryegrass Seed Yield

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Abstract: Seed yield is an important factor to any farmer. Most farmers recognize that yield will vary within a field due to many factors, but they are unaware of the actual magnitude of the yield variability. Yield mapping is a technique whereby the actual yield is measured across an entire field, thereby furnishing an accurate representation of exact field variability. This study, conducted in the Willamette Valley of western Oregon, USA, examined the reliability of the seed yield estimates and yield data patterns generated by a yield monitor from a relatively uniform portion of 76-ha perennial ryegrass (*Lolium perenne L.*) field. Four adjacent parallel lines of yield monitor data, with 27 observations per line, were extracted. The average yield was 2,100kg/ha, with considerable internal variability between lines. To examine the data patterns generated by the yield monitor, the running means of 5, 10, and 20 observations were used to plot the yield estimates. The application of Stein's Two-Stage Procedure for estimating sample size indicated that averaging the data over 15 to 20 points provided an estimate within 5% of the mean, with 95% confidence. In particular, the yield monitor data was sensitive to crop damages such as flooding or water logging.

Key words: Yield monitors, GPS, yield mapping, Stein's two stage, perennial ryegrass, Willamette valley.

INTRODUCTION

Seed yield is highly variable as a result of complex interactions among different factors, such as topography, soil properties, and management practices (Jiang and Thelen, 2004; Kravchenko *et al.,* 2005; Papiernik *et al.,* 2005; Huang *et al.,* 2008). Most producers know that yield variability exists, but they do not know the actual magnitude of the yield variability or the size of areas that differ in yield. Technologies to reduce uncertainties in seed yield exist; however, the speed and magnitude with which these technologies will affect average yield depend on various factors, including the relative importance of different types of uncertainties in farmer decision making and the ability of technologies to reduce each specific source of uncertainty (Hansen, 2002). The availability of tools for the quantitative characterization of spatial analysis technologies inherent to agronomic research offer opportunities for more assessment of the impact of climatic and edaphic factors and better appreciation and presentation of how responses might vary over the target region (White *et al.,* 2002). Among these technologies is the yield mapping system (YMS). In fact, YMS is the first step for many grass seed growers entering into the world of precision agriculture. Yield monitor data reflect systematic and random sources of yield variation, including: climate and soil–landscape features, localized management-induced yield variation, and measurement errors associated with the yield-mapping process itself (Dobermann & ping, 2004). A yield monitor, combined with Global Positioning System (GPS) technology, is an electronic tool that collects data on the crop performance of a particular location for a given year (Parsons *et al.,* 2000). Most yield monitors installed on combines use an impact plate and mass flow sensor (Shearer *et al.,* 1999). As grain leaves the clean grain elevator, it strikes the impact plate (Lems *et al.,* 2000; Loghavi *et al.,* 2008), where a mass flow sensor emits an electronic signal proportional to the mass of grain hitting the plate (Lems *et al.,* 2000). This signal, adjusted according to a calibration equation and moisture content as determined by a moisture sensor, is used to instantly estimate the grain flow mass per unit of time (Grisso *et al.,* 2003).

A yield monitor must be calibrated to provide accurate yield data (Lems *et al.,* 2000; Arslan and Colvin, 2002b), and calibration must be performed for each type of grain harvested at the beginning of the harvest season (Birrell *et al.,* 1996). Accuracy usually improves when several loads are used to perform the calibration (Arslan *et al.,* 2000; Grisso *et al.,* 2002). Re-calibration, especially later in the season, is advisable because average moisture content drops and crop conditions may change significantly (Casady *et al.,* 1998).

In the last decade, yield monitors have become more common on combines in order to better understand how field inputs affect yield variability over a variety of growing years (Digman and Phelan, 2010). A yield monitor, in conjunction with a GPS, provides harvest data that helps farm managers to better integrate precision

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farming components – like variable seeding, fertilizing, etc. – so as to maximize benefits (Lu *et al.,* 1997; Peters and Evett, 2007). Grain yield data may vary dramatically from one site in a field to another; however, the variable yield data alone may be meaningless unless coupled with post-harvest diagnosis of the causes of yield variability (Louhaichi *et al.,* 2001). Yield monitor data contain systematic and random errors that must be removed to create accurate yield maps (Arslan and Colvin, 2002b; Ping and Dobermann, 2005). Simbahan *et al.* (2004) employed a new post-processing algorithm to assess yield data cleaning methods, and found that post-classification majority filtering (PCMF) eliminated numerous patches caused by random variation while preserving yield means, high variance reduction, general yield patterns, and high spatial agreement.

Although imperfect, the yield maps adequately observe the magnitude and location of yield variability (Casady *et al.,* 1998; Grisso *et al.,* 2003). The new "intelligent" version of yield monitors showed a linear relationship between actual yield and the output of the yield monitor, with a prediction error of less than 3% (Li *et al.*, 2005). Xiang *et al.* (2007) used a yield goal map for pre-plant or in-season fertilizer recommendations in precision agriculture.

The purpose of this study was to examine the reliability of individual estimates of yield and patterns of data generated by a yield monitor from a relatively uniform portion of a perennial ryegrass (*Lolium perenne* L.) seed field. In addition, we undertook to identify variation within lines of data (sequential observations) and across lines. We also tested the hypothesis that localized disturbances, caused by narrow flooded channels perpendicular to the combine track, appear in yield estimates. Finally, after the internal variability of the crop within the field was determined, we calculated the sample size necessary to estimate the mean yield within a given confidence interval.

MATERIALS AND METHODS

This study was conducted in a relatively homogeneous perennial ryegrass (*Lolium perenne* L.) seed field, stretching over 76 ha, in the Willamette Valley of western Oregon, USA. To reduce any internal variability, the analysis was delimited to a small portion of the field characterized by soil type uniformity (Woodburn silt loam), flat topography, and the absence of weeds and wildlife grazing. Four adjacent parallel lines of yield monitor data, with 27 observations per line, were extracted from the data set and imported into MS Excel® for statistical analysis. These data included the longitude, latitude, grain flow, time, cycles (seconds covered by the data), distance traveled by the combine, swath width, and percent moisture of the seeds. In the MS Excel® spreadsheet, we calculated the seed yield in kg/ha by dividing the per-second grain flow by the land area harvested (i.e. the distance traveled multiplied by the swath width) in that particular second. We also examined the data for any abrupt intra-field variation in yield patterns.

Stein's Two-Stage Procedure (Steele and Torrie, 1960) was used for hypotheses testing as well as estimation of the required sample size using a preliminary set of observations, usually of small size. In applying Stein's two-stage sampling approach to determining required sample sizes, Adcock (1988; 1997) and Wilson (2008) recommended the following series of steps:

1. Define the width of the confidence interval (2d) and the confidence level required to meet the objectives of the study;
2. Collect sample data in a pilot study and calculate the sample variance;
3. Determine t, using the degrees of freedom of the pilot study and the set confidence level;
4. Calculate n using the following formula:

$$n = \frac{t_1^2 s^2}{d^2}$$

The value n is the estimate of the sample size needed to meet the study objectives, given the variability of the data. A smaller sample size would be inadequate, while a larger sample size would needlessly increase cost and effort.

RESULTS AND DISCUSSION

Yield mapping involves measurements of a harvested portion of a crop over space and time, followed by summarization of those measurements in numeric, graphical, or mapped form. In our test block of the perennial ryegrass field, we had 108 estimates of seed yield with a mean of 2,100 kg/ha and a standard deviation of 261 kg/ha.

Internal Variability In Yield Estimates:

First, we plotted the raw yield data, with each of the combine passes labeled as a line (Fig. 1).

As fig. 1 illustrates, yield estimates for Line A (on the west side of the harvested block) demonstrated a downward trend ($P < 0.0001$), whereas yield estimates for Line D indicated an increasing yield ($P = 0.0059$). As suggested by Stafford (1996), this unusual data obliged a determination of the causes of the yield variability, and accordingly a post-harvest diagnosis indicated that flooding or water logging caused the abrupt yield variations (Fig. 2). Lines B and C did not show a significant trend in the data across the test block ($P = 0.6936$ and $P = 0.1878$, respectively). Each line had considerable internal variability with the following standard deviations: Line A = 247 kg/ha; Line B = 234 kg/ha; Line C = 207 kg/ha; and Line D = 220 kg/ha. These results were similar to those of Arslan and Colvin (2002a), as their yield measurements of adjacent strips were also variable.

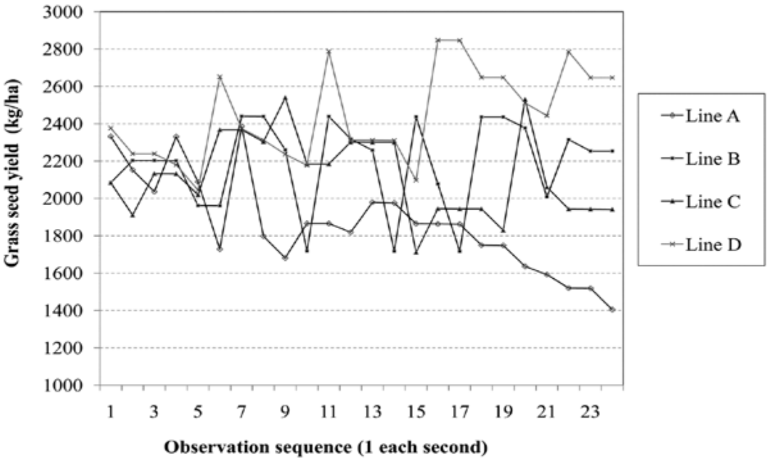

Fig. 1: Comparison of four adjacent lines of yield monitor data from a uniform portion of a perennial ryegrass field in the southern Willamette Valley.

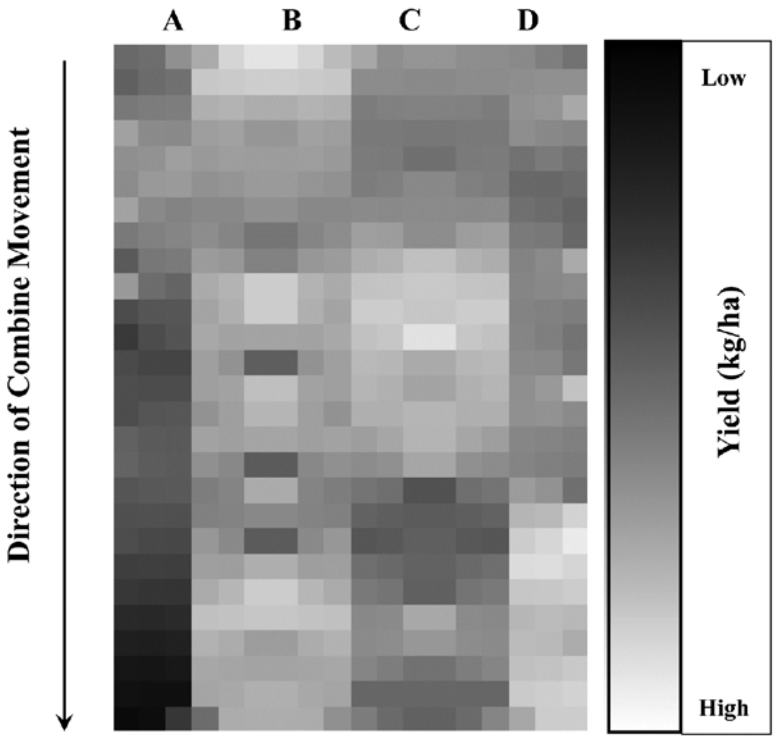

Fig. 2: This is a plot of data from two portions of the field affected by water flooding due to damaged ponds as separated by a narrow strip of perennial ryegrass. The sequence of raw data points is plotted with a heavy black line while running means calculated on the basis of 5, 10, and 20 observations are also graphed.

As demonstrated by Simbahan *et al.*, (2004), we interpolated from point data using an average distance-weight algorithm to provide a continuous surface of yield. Weights were equal to the reciprocal of the distance squared using a 6-point search radius around each interpolated point. Fig. 3 shows the spatial characteristics of interpolated yield within the test block. Except for the bottom-left dark corner, the map in Fig. 3 exhibits a normal variation in estimates as a result of localized field inputs, as mentioned by Digman and Phelan (2010).

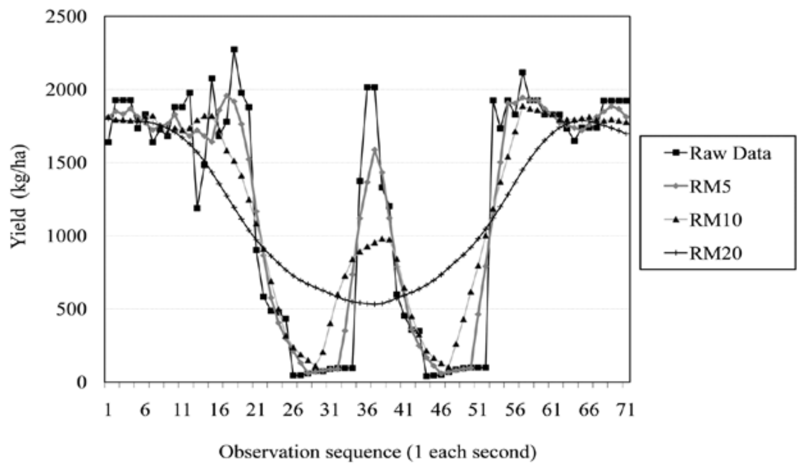

Fig. 3: This map was generated by interpolating estimates of yield (kg/ha) from four lines of combine data. Line A; yield decreased in the lower left portion of the test block.

Examination of Data Patterns:

In order to examine the data patterns generated by the yield monitor (raw data), the running means of 5, 10, and 20 observations were used to plot the yield estimates. Fig. 2 shows how individual estimates bounced up and down, whereas averaging over larger areas (10 or 20 meters) tended to smooth the line and obscured small areas of substantially different yields (Fig. 2). Arslan and Colvin (2002a) also obtained a consistent decrease in yield differences with increased segment lengths, implying that better accuracy is obtained in longer management areas. We further examined the sensitivity of the yield monitor as it traveled through ponded areas or other factors that influenced the yield. Fig. 3 reflects two small, adjacent areas impacted by water flooding, as illustrated by the drop in the yield from 1,905 to 0 kg/ha, followed by a rebound within a few meters. The combine was moving at slightly more than 1 meter per second.

Estimating The Required Sample Size Using Stein's Two-Stage Sampling

Based on Stein’s Two-Stage Procedure to estimate sample size, lines B and C (which showed no increase or decrease across the test block) required 19 and 16 observations, respectively, to estimate the mean within 5%, with a 95% confidence. To be within 10% of the mean, with a 95% confidence, we needed only 5 and 4 yield estimates on lines B and C, respectively (Table I).

Table 1: Statistical inferences and sample size.

	Line			
	A	B	C	D
Number of Observation / Line	27	27	27	27
Mean	1674	1977	1896	1943
Standard Deviation	221	211	185	197
Regression Standard Error	156	214	182	172
Stein's Two Stage Estimates				
‘n’ required for 95% confidence within 5% of the mean	29	19	16	17
‘n’ required for 95% confidence within 10% of the mean	7	5	4	4
*‘n’ required for 95% confidence within 5% of the mean	14	20	15	13

using Standard Error from regression analysis

Conclusions:

Individual yield estimates by a yield monitor may vary substantially from previous or subsequent observations, even over an apparently uniform block of a ryegrass field. The application of Stein’s Two-Stage Procedure for estimating sample size indicated that averaging the data over 15 to 20 points provided an estimate within 5% of the mean, with 95% confidence. Such data averaging, however, masked large differences that occurred over short distances, such as narrow strips of water damage. This implies that short-distance, high-impact effects are best seen in data that has not been averaged, whereas comparisons of areas with 5 to 10%

differences in yield requires data averaging over portions of the field. We encourage continued evaluation of yield monitor data collected under field conditions.

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