Technology & Product Reports

Potato Yield Monitoring on Commercial Fields

J.R. Davenport,¹
C.A. Redulla,¹ M.J.
Hattendorf,¹ R.G. Evans,²
and R.A. Boydston³

ADDITIONAL INDEX WORDS. precision agriculture, precision farming, yield map

ABSTRACT. An accurate yield map is imperative for successful precision farming. For 3 years (1998 to 2000) two to four potato (*Solanum tuberosum*) fields on a commercial farm in southeastern Washington were yield-monitored using commercial yield monitoring equipment without operator interaction. Multiple potato diggers were used to harvest the fields and diggers used were not necessarily the same at each harvest. In all years, yield monitoring data were missing due to equipment failure or lack of yield monitoring equipment on all diggers. Banding, due to dissimilar calibrations, different equipment used, or differential digger performance was observed in 1998 and 2000. Based on experience described here, some yield monitor data need

minimal postprocessing or correction, other data need substantial postprocessing to make them usable, and other data may not be reliable due to equipment failure, improper calibration, or other causes. Even with preharvest calibration, it is still likely that the potato yield monitor data will need differential postprocessing, indicating that yield maps lack accuracy. In addition, comparison to yield data collected at multiple points within the field, this study found that the yield monitor over estimated potato yield. Thus, with some postprocessing, a useful yield map showing within field differences is possible. However, without significant postprocessing, the practice of using multiple diggers and yield monitors for potato harvest, both within and between fields, severely limits the ability to make consistent yield maps in commercial potato operations.

Yield maps are one of the most tangible results of precision agriculture (PA). Farmers, especially of small grain crops, have begun to develop yield maps for their fields. However, adoption of PA is slow. Only 4% of all farms in the United States use some kind of PA practice (Daberkow and McBride, 2000). The percentage of grain farmers practicing PA is at least twice greater than the percentage of conveyor-harvested crop farmers who have adopted PA practices (Daberkow and McBride, 2000). The number of actual field installations of potato or sugarbeet (*Beta vulgaris*) yield monitors in production agriculture was less than 100 units by the end of 1997 (Campbell, 1999).

Yield maps are essential to PA. With proper installation, calibration, and operation of yield monitors, accu-

rate yield maps may be obtained which may aid in making site-specific decisions (Colvin and Arslan, 2001; Pierce et al., 1997). However, yield map development and interpretation is complicated by error in yield monitor data. Yield maps often contain systematic errors that conceal underlying yield variation (Blackmore and Moore, 1999; Doerge, 1999). Yield monitor data sets and maps contain inherent errors, some of which are difficult to correct, and these error-induced patterns must be separated from real yield variation in order to make correct interpretations (Doerge, 1999).

A number of factors contribute to error in yield monitoring and mapping. Proper installation of the system is important although not always grower-friendly (Perry et al., 1999). Improper installation results in erroneous data and start/stop delay, frequently associated with harvester filling at the beginning of harvest (Blackmore and Moore, 1999), is reported to be minimal in controlled conditions but pronounced with standard farm operations (Perez-Muñoz and Colvin, 1996). Yield calculation using an incorrect swath width also contributes to error in yield maps (Blackmore and Moore, 1999). The swath width value on currently available commercial yield monitors for most crops is manually entered by the operator rather than automatically calculated by the system. In grain crops, moisture content can influence accuracy. In tuber and root crops, impurities like rocks, weeds, and adhering soil result in yield calculation error (Campbell et al., 1994; Rawlins et al., 1995). Lag time error, where the estimated time between when the crop was actually harvested and when the mass of that crop was recorded and georeferenced is incorrect, also contributes to error in yield maps (Blackmore and Moore, 1999).

Yield monitoring systems have been reported to have measurement accuracies near 5% for potatoes (Rawlins et al., 1995) and sugar beets (Hofman et al., 1995). Pierce et al. (1997) concluded that the accuracy of yield monitoring systems varies with scale. Yield values calculated across a large area are more accurate than yield values averaged across a small area. Unfortunately, the value of PA is diminished when large field areas are considered.

A number of filtering and smooth-

¹Washington State University, 24106 N. Bunn Road, Prosser, WA 99350-8694.

²USDA/ARS, 1500 N. Central Ave., Sidney, MT 59270-4202.

³USDA/ARS, 24106 N. Bunn Road, Prosser, WA 99350-9687.

Fig. 1. Relative positions of the eight center-pivot irrigated potato fields at a commercial farm in southeastern Washington.

Fig. 2. Yield monitor data after swath width correction at a southeastern Washington commercial farm in 1998. The average yield for a pair of adjacent fields is equivalent to 100% relative yield. White area inside the circle means no data; 1 ft = 0.3 m.

ing algorithms have been proposed to correct yield monitor data (Blackmore and Moore, 1999; Taylor et al., 2000). However, most of these algorithms tend to correct yield monitor errors specific to individual data sets. Some errors can be corrected by careful analysis of the raw yield or flow rate data (Colvin and Arslan, 2000) through automated computer programming. However, Haneklaus et al. (2000) cau-

tioned that extraction of erroneous data cannot be automated, and concluded that time-consuming individual treatment of data sets is required.

With the importance of yield monitoring and mapping in developing PA management and the commercial availability of yield monitoring for potatoes, we undertook to assess this tool. The objective of this research is to evaluate the potato yield monitor

data gathered on a commercial farm in southeastern Washington from 1998 to 2000 in terms of accuracy, consistency, and usefulness.

Materials and methods

DATA COLLECTION. From 1998 to 2000 in a commercial farm in southeastern Washington (long. 119.1°W, lat. 45.9°N), eight center-pivot irrigated potato fields were yield-monitored using a (HM-500 Harvest Master; Inc., Logan, Utah) potato yield monitoring system (mention of trademarks is provided for the benefit of the reader and does not imply endorsement or otherwise). A detailed description of the HM-500 can be found in Schneider et al. (1996). The fields were either planted with the early-season potato variety Shepody or the late-season potato variety Russet Burbank and were either under uniform rate fertilizer (URF) treatment or variable rate fertilizer (VRF) treatment (Fig. 1). The fertilizer rates for the VRF treatment were calculated based on 1-acre (0.4-ha) soil samples using Washington State University guidelines for fertilizer use for potato production in Washington (Lang et al., 1999). Grower equipment was used for harvest. Thus, multiple diggers were used to harvest the fields and the diggers used were not necessarily the same from season to season. In 1998 and 1999, data were downloaded from the yield monitoring equipment to a laptop computer every second day during harvest. In 2000, data were collected every second or third day during the harvest by swapping personal computer memory cards and then uploaded to a laptop computer. Data were collected without digger operator interaction, which is contrary to the procedure advocated in more recent literature (Campbell, 1999).

DATA PROCESSING. Each yield text file in ASCII text format was imported to the Excel (Microsoft Corp., Redmond, Wash.) spreadsheet program. In 1998 and 1999, data were corrected to adjust for the use of incorrect swath width values. Midharvest during 1998 and 1999, and preharvest during 2000, truckload calibration were made where the weight determined by scales of one truckload of potatoes, from a single digger, was compared with the yield monitor truckload weight, calculated based on the flow and Global Positioning System

Fig. 3. Yield monitor data after swath width correction at a southeastern Washington commercial farm in 1999. White area inside the circle means no data. Numbers outside of the figure box are longitude (top and bottom) and degrees latitude (left and right) in degrees (°), minutes (′), and seconds (″); 1 ft = 0.3 m.

Fig. 4. Yield monitor data after truckload correction at a southeastern Washington commercial farm in 2000. Letters inside the circle are the digger designation. White area inside the circle means no data. Numbers outside of the figure box are longitude (top and bottom) and latitude (left and right) in degrees (°), minutes (′), and seconds (″); 1 ft = 0.3 m.

(GPS) time columns of the yield file. Yield values provided by the monitor were then corrected to account for direct measurements taken at the scale. Yield multipliers on yield monitoring systems were changed to reflect the result of truckload calibration. Furthermore, in 2000, rows with either

the GPS coordinates or the yield columns with outlying values (e.g., yield monitor reading = 0 even with potato on the conveyor and rows with yield flow >90 lb/s [41 kg·s⁻¹]) were deleted. After correction, files were saved in a format accessible by ArcView (ESRI, Redlands, Calif.) and used to develop a yield map. The reported yield values are in terms of percent relative yield where 100% is equivalent to the average yield of a pair of circles. Circles were paired by growing season and variety, allowing field-to-field and year-to-year comparisons of the yield monitoring. Thus, the paired circles were 1 and 2, 3 and 4, 5 and 6, and 7 and 8 (Fig. 1).

Before commercial harvest, each field was divided into 1-acre square grids. Yield was determined by harvesting a 10-ft (3-m) row length (point-sample) with a one-row commercial digger at each grid point. Yields for the point samples were determined by weighing the harvested potatoes and then calculating the yield on a per-acre basis. In 2000, averaged yield monitor values were also obtained at each grid point by averaging the yield monitor values of a circular area centered on the grid point and with radius of 49 ft (15 m).

Results and discussion

In 1998 we were able to produce entire field yield maps for circles 1 and 2 in 1998 (Fig. 2). Several problems arose after which resulted in missing data in all other fields. White strips in the yield maps from all other fields (Figs. 2, 3, and 4) represent erroneous or missing data resulting from malfunctioning GPS equipment (circles 3 and 4, Fig. 2), harvest with a third digger unequipped with yield monitoring equipment (circles 5 and 6, Fig. 3), and other equipment malfunctions. In 2000, three diggers were used for harvest and each was equipped with yield monitors. However, data were deleted due to GPS malfunctioning or outlying yield values, 20% of the area harvested in 2000 was considered to have no or missing data (Fig. 4). Files from diggers A and B were most in error and no data were deleted from the digger C yield monitor.

Figure 2 contains yield maps of fields monitored in 1998. The concentric wheel tracks made by the center-pivot irrigation system are clearly visible on the yield map of circle 4 and

A) Circle 1

B) Circle 3

Fig. 5. Relationship between yield monitor values and time values from two circles in 1998. Time value of 0 is midnight and 0.5 is noon.

faintly visible on the yield map of circle 3. The ability to distinguish low yield in a 10-inch (0.25-m) wide band is a strong indicator of the potential accuracy of the yield monitors and maps.

Distinct strips visible on circle 1 (Fig. 2) are described as banding, which occurs when adjacent rows in the field showed different ranges of yield monitor values. Banding is also apparent in circle 8 (Fig. 4). This pattern can result from harvest with different equipment or on different days and does not reflect actual yield patterns. Note that circle 1 was harvested in a span of 9 d while the other fields were harvested in just 2 or 3 d (Fig. 1). It appears that a long harvest period (>3 d) increased the error attributed to the variability in

yield monitor sensitivity. Banding was also noted to varying extents in all five fields studied by Schneider et al. (1996). When banding occurs, postprocessing can be done to smooth the data so that actual patterns of yield variability can become apparent. For example, in Fig. 2 there is no evidence of banding in circle 4 and higher yielding areas in the northeast quarter of the field are evident, whereas the strong banding in circle 1 shows patterns more associated with day of harvest and masking yield differences relative to field position. Thus, for banding, postdata processing could elucidate actual patterns of yield not otherwise apparent. To recalculate the data to remove banding, several techniques

could be used, such as comparing the yield averages between bands and adjusting to a common mean or adjusting to the field average yield value. This would show the patterns of yield variability within the field without biasing the results.

In addition to banding, data point density varied in circles 1, 2, and 8 (Figs. 2 and 4). This was caused by the HM5 software on the different yield monitor systems being inadvertently programmed to report the yield at different time intervals (the default is every 2 s). A smoothing program or an interpolation procedure can easily remedy this situation.

One way of assessing the reliability or accuracy of yield monitoring data are to look at the data distribution. The HM5 output provides date, time, and time-value information, where time value is the decimal equivalent of time of day based on a 24-h clock with 0 occurring at midnight and 0.5 at noon. Figure 5 shows the relationships between relative yield and time value for two circles in 1998. Each cluster of points represents a truckload and overlapping of data points result from either multiple diggers harvesting concurrently or output on successive days. Circle 1 was planted to 'Shepody' while circle 3 was planted to 'Russet Burbank'. In both circles there is a clustering of data near 100% relative yield. However, in circle 1, there is also a high density of data in around 50 which implies that something may not be correct. Figure 6 shows the relative yield data in increments of 20% for circles 1 and 3. In circle 3, 77% of the data fall between 80% to 120% of the relative field yield, but in circle 1 only 42% of the data are in this range, and 15% and 26% of the data in the 40% to 60% and 120% to 140% relative yield ranges, respectively. Although this difference could be related to the different varieties, spatial variability in soil properties, or some other unreported factor, the difference could also be due to yield monitoring error. Further examining the data for circle 1, there was a high percentage of data points <0 (1.8%). The presence of many yield monitor values equal to zero is an indication that there is a problem with the yield monitoring system since the diggers harvested only on rows with standing crops (i.e., areas with yield values >0). Also, the average relative yield (excluding zero values) was 60%

A) Circle 1

B) Circle 3

Fig. 6. Distribution of yield monitor values, as a percent of field average yield, in 20% increments for (A) 'Shepody' potatoes (circle 1) and (B) 'Russet Burbank' potatoes (circle 3) harvested in 1998.

and 74% for the first 2 d of harvest in circle 1, whereas it was between 90% to 120% for all other days.

Scatter plots for the 2000 'Shepody' yield monitoring are presented in Fig. 7, however each scatter plot is digger specific (designated as diggers A, B, and C). The yield distribution from the yield monitor data gathered from digger C (Fig. 7C) shows a similar concentration of data points to circle 3 (Fig. 5B) despite potato varietal differences. We hypothesized that this kind of yield distribution is the expected response when the yield monitoring equipment is functioning properly. Histogram of the yield values constructed from the yield monitor data confirm this (Fig. 8), with 39%, 47%, and 72% of the relative yield between 80 and 120% for diggers

A, B, and C, respectively. With digger A, there was a preponderance of the data in the low range (24% of the yield between 20% to 80% of field average) whereas with digger B the data distribution was flatter and shifted to a higher range (30% of the data falling between 120% to 180% of the field average). Given that the diggers harvest randomly throughout the field, often with diggers following one another in a staggered pattern, this strongly suggests a problem with the yield monitoring data, possibly a problem of calibration between units. We concluded that many of the yield values shown in Figs. 6A and B were erroneous and further postprocessing should be done on the yield monitor data from diggers A and B, if feasible.

The time-value scatter plots (Figs.

5 and 7) also show that there was no obvious bias in the yield values obtained with respect to time of day.

Figure 9 shows the relationship between the yield values from the grid points and the circular area-averaged yield monitor values. Significant r values of 0.42 and 0.29 were obtained from the yield monitor data of diggers A and C, respectively. However, a nonsignificant r was obtained from the yield monitor data of digger B further supporting our theory of erroneous yield monitor data from digger B. Slopes for all of the equations were less than 1, indicating that the yield monitoring data overestimates the yield. The apparent overestimation may be due to the inability of the yield monitoring equipment to differentiate between potatoes and rocks, to additional weight from soil adhering to potato, or other factors, all of which suggest that while yield monitoring data may be a good indicator of relative differences across the field, it may not be as reliable for absolute yield data.

The manufacturer's suggested calibration, completed twice in 2000, did not eliminate yield monitor data error. The calibration was done by truckload, and the truckload weight as reported from the monitoring equipment from diggers A and B appeared to tally with the truckload weight from the load scales. But what seemed to be in error were the individual yield values which translated into different yield distribution (Figs. 7A and B and 8A and B versus Fig. 7C and 8C).

Choosing the right location for, and proper mounting and alignment of the weighing rollers are critical to obtain accurate weight measurements (Muffoletto, 1999; Pierce et al., 1997). Field conditions offer many opportunities for misalignment to occur during digger operation. Further, misalignment is unlikely to be at the same degree for each digger, and thus would cause differences in performance among different yield monitoring systems. In large commercial operations, at least two diggers operate simultaneously, introducing this additional source of variability to the potato yield map.

Start/stop delays (Perez-Muñoz and Colvin, 1996; Pierce et al., 1997) and turning error were also observed. Turning error occurs when a digger leaves the end of a row with a full conveyor then dumps potato tubers

from the previous row into the truck at the start of a new row. This error manifested itself through unusually high yield values at the field edges (circle 7 of Fig. 4). Postprocessing by exclusion of peripheral yield monitor values can rectify this problem.

Conclusions

This study showed the collection of data across eight different fields over a 3-year period where a minimum of postprocessing was conducted. In most cases, yield monitoring an entire field was not possible due to mechanical difficulties. Even when it was possible to yield monitor an entire field, yield monitoring data directly converted into a yield map showed a need for some level of postprocessing. Unlike small grain crop harvesting, where one combine may suffice, potato harvesting on commercial farms needs at least two potato diggers operating simultaneously, and the use of multiple diggers and yield monitors resulted in a need for postprocessing. Even when multiple diggers were calibrated following the manufacturer's suggested procedure, data from the multiple diggers did not rectify well. In addition, the comparison of yield monitoring data to point samples collected for yield indicated that the yield monitor over estimated yield. Given these find-

Fig. 7. Relationship between yield monitor values and time values from the three yield monitoring systems used in 2000. Time value of 0 is midnight and 0.5 is noon.

A) Data from yield monitor of digger A

B) Data from yield monitor of digger B

C) Data from yield monitor of digger C

Fig. 8. Distribution of yield monitor values, as a percent of field average yield, in 20% increments for 'Russet Burbank' potatoes harvested in 2000 with three different diggers (a, b, and c).

ings, we believe that, once the data are postprocessed, a potato yield map using commercial equipment could be useful to the grower in terms of showing differences in yields in a given field. However, the apparent over estimation of yield and variability from machine to machine, the results are neither accurate nor consistent.

Literature cited

Blackmore, S. and M. Moore. 1999. Remedial correction of yield map data. *Precision Agr.* 1:53-66.

Campbell, R.H. 1999. Recent advances in yield monitoring of conveyor harvested crops, p. 1101-1106. In: P.C. Robert, R.H. Rust, and W.E. Larson (eds.). *Proc. 4th Intl. Conf. Precision Agr.* ASA-CSSA-SSSA Press, Madison, Wis.

Campbell, R.H., S.L. Rawlins, and S. Han. 1994. Monitoring methods for potato yield mapping. *Amer. Soc. Agr. Eng. Paper* 94-1584.

Colvin, T.S. and S. Arslan. 2000. A review of yield reconstruction and sources of errors in yield maps. CD paper no. 10. In: P.C. Robert, R.H. Rust, and W.E. Larson (eds.). *Proc. 5th Intl. Conf. Precision Agr.* ASA-CSSA-SSSA Press, Madison, Wis.

Daberkow, S.G. and W.D. McBride. 2000. Adoption of precision agriculture technologies by U.S. farmers. CD paper no.

Fig. 9. Relationship between averaged yield monitor value (averaging of yield monitor values from circular area of radius = 15 m [49 ft] and centered over a grid point) and grid point yield value (from 3-m [10-ft] long row harvest) at two southeastern Washington potato fields in 2000 (k is an integer, representing weight/area, which is the same for both axes).

59. In: P.C. Robert, R.H. Rust, and W.E. Larson (eds.). Proc. 5th Intl. Conf. Precision Agr. ASA-CSSA-SSSA Press, Madison, Wis.

Doerge, T.A. 1999. Yield map interpretation. *J. Prod. Agr.* 12:54-61.

Haneklaus, S., H. Lilienthal, E. Schnug, K. Panten, and E. Haveresch. 2000. Routines for efficient yield mapping. CD paper no. 96. In: P.C. Robert, R.H. Rust, and W.E. Larson (eds.). Proc. 5th Intl. Conf. Precision Agr. ASA-CSSA-SSSA Press, Madison, Wis.

Hofman, V.L., S. Panigrahi, B.L. Gregor, and J.D. Walter. 1995. In field monitoring of sugarbeets. *Amer. Soc. Agr. Eng. Paper* 95-2114.

Lang, N.S., R.G. Stevens, R.E. Thornton, W.L. Pan, and S. Victory. 1999. Irrigated potato nutrient management guide for central Washington. *Wash. State Univ. Ext. Bul.* 241.

Muffoletto, C. 1999. HM-500 Yield Mapping System v.3.00. HarvestMaster Inc., Logan, Utah.

Perez-Muñoz, F. and T.S. Colvin. 1996. Continuous grain yield monitoring. *Trans. Amer. Soc. Agr. Eng.* 39:775-783.

Perry, C.D., J.S. Durrence, D.L. Thomas, G. Vellidis, C.J. Sobolik, and A. Dzubak. 1999. Evaluation of commercial cotton

yield monitors in Georgia field conditions, p. 1227-1240. In: P.C. Robert, R.H. Rust, and W.E. Larson (eds.). Proc. 4th Intl. Conf. Precision Agr. ASA-CSSA-SSSA Press, Madison, Wis.

Pierce, F.J., N.W. Anderson, T.S. Colvin, J.K. Schueller, D.S. Humburg, and N.B. McLaughlin. 1997. Yield mapping, p. 211-243. In: F.J. Pierce and E.J. Sadler (eds.). *The state of site-specific management for agricultural systems*. ASA-CSSA-SSSA Press, Madison, Wis.

Rawlins, S.L., G.S. Campbell, R.H. Campbell, and J.R. Hess. 1995. Yield mapping of potato, p. 59-68. In: P.C. Robert, R.H. Rust, and W.E. Larson (eds.). *Site-specific management for agricultural systems*. ASA-CSSA-SSSA Press, Madison, Wis.

Schneider, S.M., S. Han, R.H. Campbell, R.G. Evans, and S.L. Rawlins. 1996. Precision agriculture for potatoes in the Pacific Northwest, p. 443-452. In: P.C. Robert, R.H. Rust, and W.E. Larson (eds.). Proc. 3rd Intl. Conf. Precision Agr. ASA-CSSA-SSSA Press, Madison, Wis.

Taylor, R.K., D.L. Kastens, and T.L. Kastens. 2000. Creating yield maps from yield monitor data using multi-purpose grid mapping (MPGM). In: P.C. Robert, R.H. Rust, and W.E. Larson (eds.). Proc. 5th Intl. Conf. Precision Agr. CD paper no. 186. ASA-CSSA-SSSA Press, Madison, Wis.