A Web-Based Calculator for Estimating the Profit Potential of Grain Segregation by Protein Concentration

C. T. Martin, J. D. McCallum, and D. S. Long*

ABSTRACT

By ignoring spatial variability in grain quality, conventional harvesting systems may increase the likelihood that growers will not capture price premiums for high-quality grain found within fields. The Grain Segregation Profit Calculator was developed to calculate the cutoff value to use for segregating wheat (*Triticum aestivum* L.) into two lots on the combine such that the prices received for average protein levels in the two lots maximize profit. The calculator is written in Java with Microsoft Visual Studio 2010 components to allow for web-based functionality. A graphical user interface helps users input the price schedule and the mean and standard deviation of grain protein concentration of their field; the potential increase in profit from segregating the grain into two distinct lots is then calculated. The results of segregation of dark northern spring wheat were used to illustrate the calculator. Based on a 17-yr average high premium price schedule, the effect of mean protein and standard deviation on marginal returns was examined. Revenue from grain segregation was found to be sensitive to three factors within grain production: (i) the average level of a field's protein, (ii) the protein variability within a field, and (iii) premium schedules being paid in the marketplace.

Grain protein concentration (GPC) is an important non-grade-determining factor that influences the U.S. dollar value of the dark northern spring (DNS) subclass of hard red spring wheat (*Triticum aestivum* L.). Prices are quoted at Portland, OR, in relation to a standard grade, which is no. 1 DNS wheat at a GPC of 140 g kg^{-1}. Typically, a bonus, or premium, is added to the price of wheat for each 2.5 g kg^{-1} change in GPC above this standard, whereas a discount is subtracted from the price for each 2.5 g kg^{-1} in protein below this standard. Discounts are weighted more than premiums. For example, in 2012, premiums were US$14.70 to US$29.40 Mg^{-1} above 140 g kg^{-1} GPC, whereas discounts were US$36.75 Mg^{-1} below 140 g kg^{-1} (December 2012 average cash grain bids for DNS wheat, Pacific Northwest Grain Market News, search.ams.usda.gov/mndms/2013/01/LS20130111WPNWGRAIN.PDF).

Many studies have shown that farm fields are spatially variable in GPC due to differences in environmental conditions including soil fertility (Reyns et al., 2000; Delin, 2004), topography (Fiez et al., 1994), plant-available water (Stewart et al., 2002), and the previous year's cropping inputs (Fiez et al., 1994; Long et al., 2008). In practice, because of time constraints and the assumption that the wheat is homogenous, growers tend to bin the grain together that is produced in a farm field. By mixing the grain together, conventional harvesting systems diminish the ability of growers to capture premiums for high-quality grain found within fields.

Grain segregation by protein content has been proposed to maximize revenues in markets that offer protein premiums (Stafford, 1999; Thylén and Rosenqvist, 2003; Meyer-Aurich et al., 2008). Segregation can be accomplished on the farm by harvesting different zones of grain quality within a field and delivering the grain from each zone separately to the elevator (Tozer and Isbister, 2007). It can also be achieved by sampling each hauling vehicle for GPC at the elevator and using this information to segregate the grain into different batches (Herrman et al., 2002). The first approach requires prior knowledge of harvesting zones, grain quality and yield differences between zones, and price schedules to ascertain whether grain segregation would be profitable. The second approach usually requires the GPC and yield for different fields within a harvesting region as needed to plan the organization of grain segregation in anticipation of buyer specifications for grain with a specific protein content (Le Bail and Markowski, 2004).

A third possibility is the use of near-infrared (NIR) spectroscopic techniques pioneered by Norris (1964). Optical NIR sensors have been implemented for combine harvesters to map GPC within farm fields (Stafford, 2000). These "in-line" systems have the ability to rapidly and accurately measure GPC in a process stream during harvest. On-combine accuracies have been reported to be within 5.7 g kg^{-1} GPC for winter wheat (Maertens et al., 2004), 6.6 g kg^{-1} GPC for DNS wheat (Long and Rosenthal, 2005), 3.1 g kg^{-1} GPC for soft white winter wheat (Long et al., 2008), and 4.5 g kg^{-1} for Australian hard spring wheat (Whelan et al., 2009).

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Abbreviations: DNS, dark northern spring; GPC, grain protein concentration; GSPC, Grain Segregation Profit Calculator; NIR, near infrared.

On-combine NIR sensing creates an opportunity to segregate DNS wheat by GPC during harvesting. Although on-combine grain segregation systems are currently not in place, the question remains how growers could utilize this technique to take better advantage of available price premiums and improve profitability. In Australia, Stewart et al. (2002) studied the spatial variability of site-specific durum wheat (*Triticum durum* Desf.) within an 11-ha field in which the average GPC was 123.7 g kg^{-1}. They found that segregating the grain into two batches at a cutoff value of 121.5 g kg^{-1} GPC would have increased profits by AUS\$34 ha^{-1} over harvesting the grain all together. Segregating the grain exploited the arbitrary division of protein grades used to establish the value of wheat.

We have developed a web-based software, the Grain Segregation Profit Calculator (GSPC), that can help growers calculate the cutoff point to segregate grain into two bins and optimize marginal returns based on price schedules that are known at the time of harvest. The objectives of this study were to report the practical basis behind the GSPC, outline the algorithms used, and apply GSPC to evaluating the potential improvement in returns from future on-combine segregation of DNS wheat.

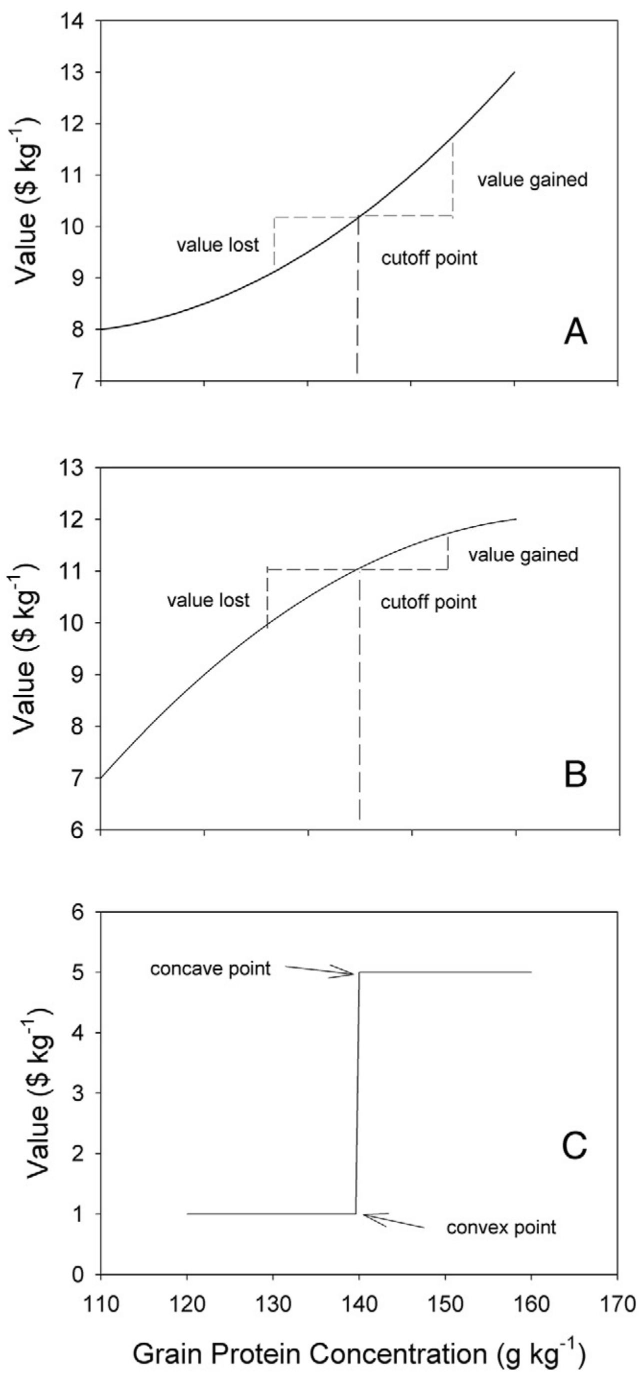

Fig. 1. (A) Concave price function where the value gained above a cutoff point of 140 g kg^{-1} protein on the continuous curve is less than the value lost below that point, (B) convex prince function where the value gained above a cutoff point is greater than the value lost at that point, and (C) stepwise price schedule consisting of a single price step having both convex and concave features. Dollar values on the y axis are arbitrary.

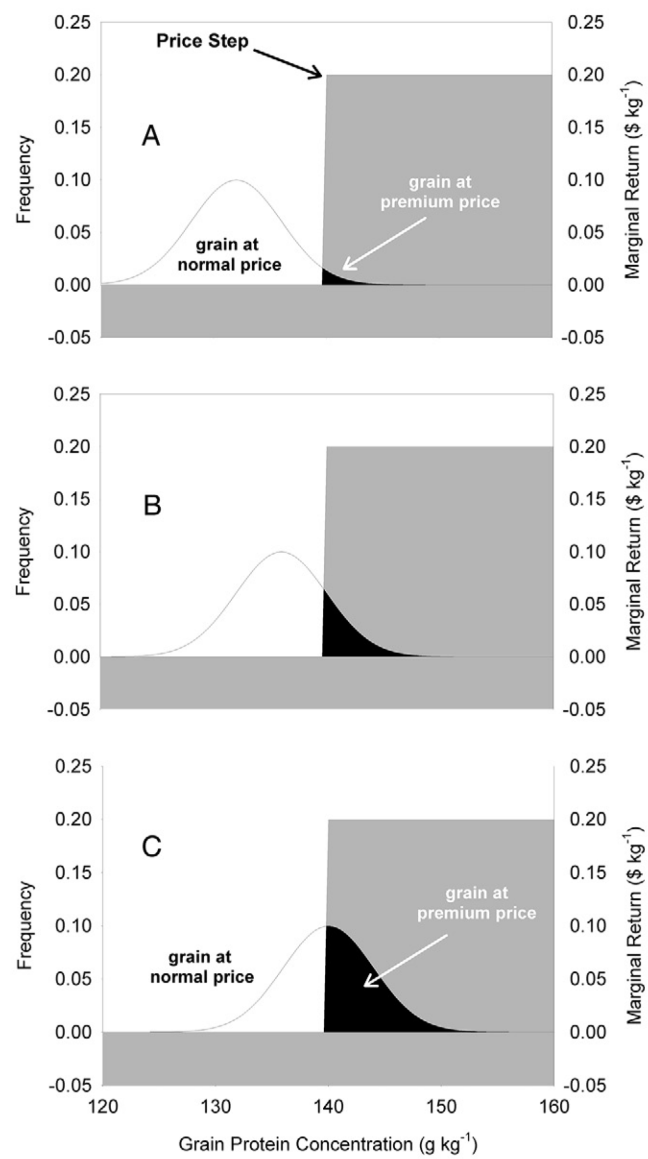

Fig. 2. Illustration of grain segregation using a single stepped price schedule, with a price step at 140 g kg^{-1} protein and a normal protein distribution. Marginal return from grain sold at a premium price is (A) initially small when the mean is well below the price step; (B) further increases in the marginal return are possible as the mean approaches the price step, (C) before disappearing when the price step is reached.

HOW GRAIN SEGREGATION CAN IMPROVE MARGINAL RETURNS

Sivaraman et al. (2002) developed a general mathematical model to determine optimal grain blending and segregation strategies by protein for hard red winter wheat. They found that most of the benefit of grain segregation may be achieved with only two bins, resulting in two distinct lots of grain. Segregation was profitable if a plot of price vs. protein was convex, i.e., the slope of a price function increased above a cutoff point, with further increases in protein such that the value gained from segregation exceeded the value lost (Fig. 1A). Segregation was unprofitable if the price function was concave, i.e., the slope decreased above a cutoff point, with increasing protein such that the value gained was less than the value lost (Fig. 1B).

As shown by Sivaraman et al. (2002), a convex price function can lead to a potential gain from segregation, whereas a concave function will not. That work, however, was based on continuous mathematical functions. Real price schedules for DNS wheat are discontinuous, stepwise functions (Fig. 1C). Each price step on the price schedule is a point of discontinuity and can be viewed as either concave or convex at that point. Below, we show that the potential gain from segregating grain by GPC depends more on the distribution of the grain about the price steps than the overall structure of the price schedule.

The effect of a stepped price schedule on varying mean protein is illustrated in Fig. 2. A normally distributed GPC is shown with different means superimposed on a price schedule with a single price step at 140 g kg^{-1} protein. In this simplified example, grain with <120 g kg^{-1} protein receives no premium and $\geq$140 g kg^{-1} grain receives a US\$0.20 kg^{-1} premium. Using the price step as a segregation cutoff value, if the mean falls below the price step (Fig. 2A), there is still a little grain available to segregate into a higher protein bin and gain some value. As the mean further approaches the price step (Fig. 2B), there is a larger portion of high-value grain to segregate into the higher protein bin, and the value from segregating grain would increase. At the price point (Fig. 2C), half of the grain is of higher value, but the price point of $\geq$140 g kg^{-1} protein allows the whole batch to be included in the higher protein bin. This would secure the premium price for the whole load and would be the equivalent of not segregating at all. Hence, the marginal return, the value gained from segregation, falls to zero even as the value of the grain increases. The purpose of the GSPC is to compute optimum cutoff points and marginal returns for segregation over multiple price steps. Due to discontinuous price schedules, there is a potential gain from segregating any batch of grain except one whose mean falls on a price point.

PROGRAM DESCRIPTION

Microsoft Visual Studio (Microsoft Corp.) was used to develop the GSPC, which enabled the calculator to be used over the Internet with a web browser. The advantages of web-based software include accessibility from any computer with a web browser and Internet connection and no need to download, install, and maintain software. Operation of the GSPC involves a series of four steps (Fig. 3). To start a session, the user is prompted for the mean GPC and standard deviation of the grain (Fig. 4). This input is accepted for definition of the areal frequency distribution of the GPC, which is assumed to be normal.

Next, the price schedule is defined by entering protein values and their associated market prices. To promote use by growers, the GSPC was designed with all inputs in U.S. customary units. Values of GPC (%) must be entered from least to greatest in ascending order (e.g., 12, 12.25, 12.5, 12.75, 13, 13.25, 13.5, 13.75, 14, and so forth). For price schedules decreasing with protein, a zero protein value should be input first as needed to define a lower limit (e.g., 0, 12, 12.25, and so forth). Similarly, prices in US\$ per bushel are input (e.g., 1.6, 1.9, 2.2, 2.5, 2.8, 3.1, 3.4, 3.7, 4, and so forth) so that all protein values have an associated dollar value. Prices can also be specified in terms of the price spread or the difference between a standard level and a certain protein level.

Selecting the "Show me some example data" button will automatically populate the price schedule with values for

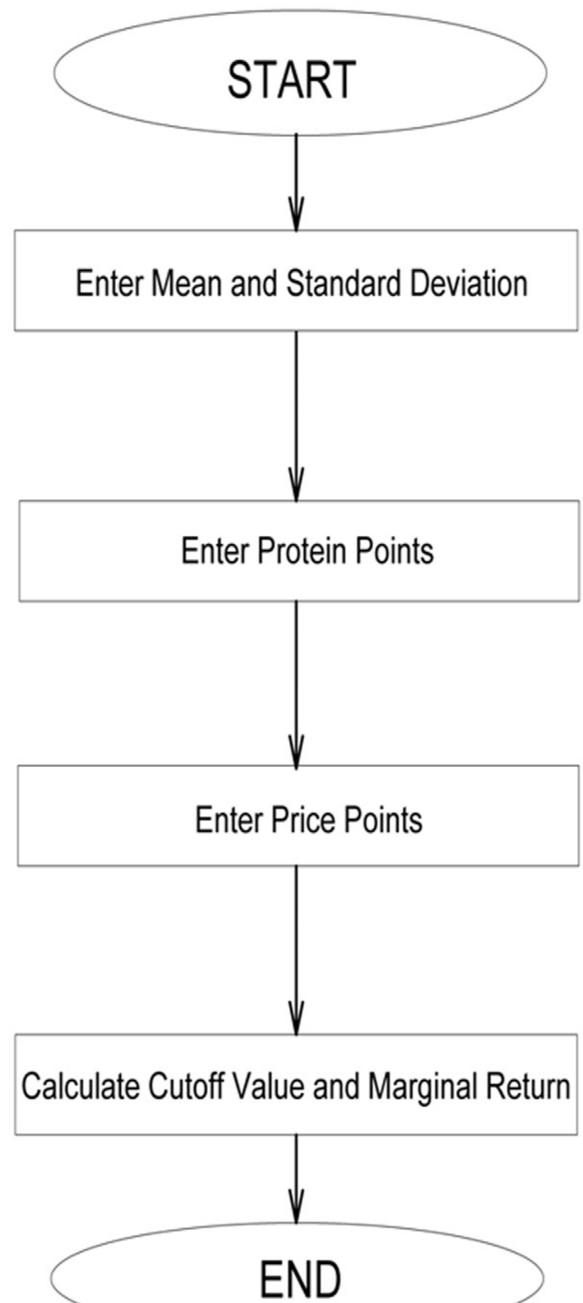

Fig. 3. Diagram of information flow through the Grain Segregation Profit Calculator.

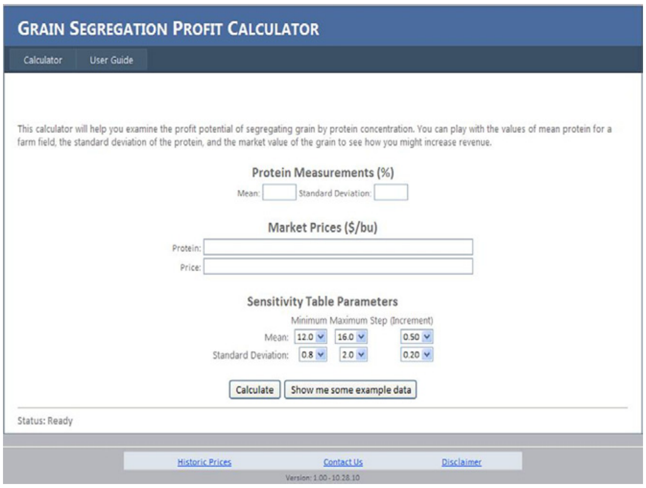

Fig. 4. User interface in the Grain Segregation Profit Calculator for entering protein measurements (mean protein and standard deviation) and market prices used by a price schedule.

protein and price as shown in Fig. 5. Example data are for a hypothetical batch of DNS wheat having mean protein of 13.5% and standard deviation of 1.2%. Whole values of GPC at 12, 13, 14, and 15% appear on the first line under "Market Prices" and correspond to price spreads of –US$0.41 bu^{-1}, –US$0.34 bu^{-1}, US$0.00 bu^{-1}, and US$0.21 bu^{-1}. These prices are 17-yr (1994–2010) average market quotes at Portland, OR, based on data obtained from the Montana Wheat and Barley Committee (Great Falls, MT).

Once this information has been entered, the calculation of the optimal cutoff point can be made by pressing the "Calculate" button. The optimal cutoff point is defined as the value of GPC to use for segregating wheat into a low-protein bin and a high-protein bin such that prices received for average protein levels in the two bins maximize the marginal return. The optimal grain segregation scheme that maximizes the return for this example is given within the area under the heading "Solution." The example results show that segregating grain into two bins will yield an extra US$0.20 bu^{-1} at an optimal cutoff of 13%. The low bin will contain 34% of the grain at 12.4% average protein and the high bin will contain 66% of the grain at 14% average protein. In addition, a graph is drawn to show how revenue from segregation may change across a range of cutoff values (Fig. 5).

The calculator can also be used to assess the effect of varying the mean protein and standard deviation on the results of grain segregation. Values for mean protein and standard deviation are entered using drop-down lists in the area under the heading "Sensitivity Table Parameters" (see Fig. 5). Possible values for protein range from 8 to 20% in increments of 0.1, 0.2, 0.25, 0.5, or 1.0% and for the standard deviation from 0.8 to 2.0% in steps of 0.1, 0.2, or 0.5%. After all of the parameters are entered and the "Calculate" button is clicked, the calculator populates a series of tables with data for the specified range of protein values and standard deviations. Tables are reported for the optimal cutoff value, average protein content of the high bin, average protein content of the low bin, potential profit per bushel, and volume of grain in each bin. If no optimal result is found, the calculator returns a default value of 8 to the cells

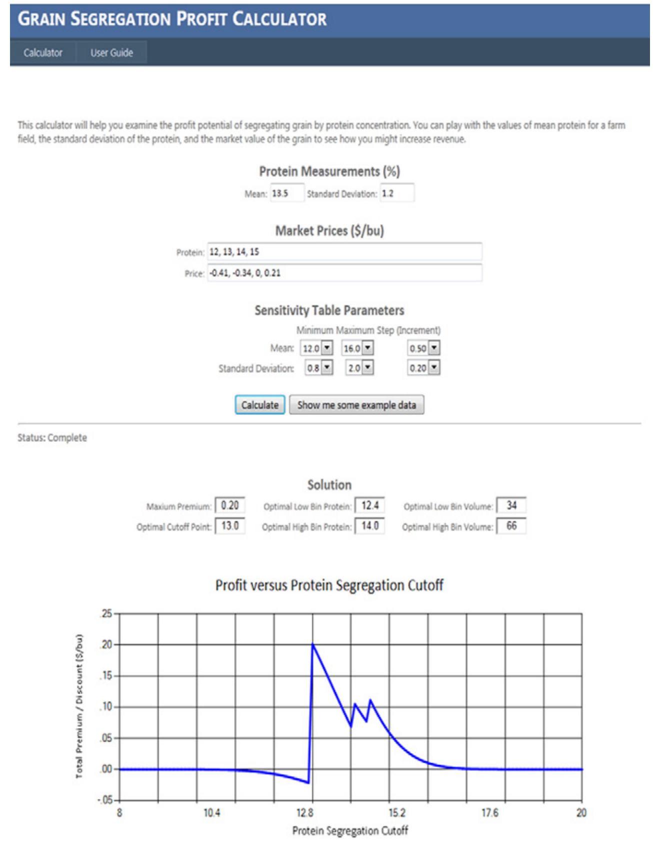

Fig. 5. User interface in the Grain Segregation Profit Calculator showing the sensitivity table parameters, optimal segregation cutoff values, and a graph of marginal return vs. cutoff values.

of the table for the optimal cutoff value and a value of 0 to the cells of the table for potential profit.

Given a stepwise price schedule containing all the prices for a given grain protein concentration, the grain segregation solution consists of allocating the grain into two bins so that the allocation maximizes the marginal return. Briefly, the method utilizes an algorithm comprised of the following steps:

1. Using Algorithm AS 111 (Beasley and Springer, 1977), generate the normal distribution of grain protein concentration for the user-specified mean and standard deviation and compute the area below a default initial cutoff value of 8.0% (low bin).
2. Compute the area above this cutoff (high bin) by subtracting the low-bin area from unity (Wichura, 1988).
3. Compute the mean protein (one-half of the low-bin area) using the inverse normal distribution algorithm AS 241 (Wichura, 1988).
4. Compute the mean protein of the high bin as in Step 3.
5. Compute the U.S. dollar value of the low-bin and high-bin fractions by multiplying their mean protein times the grain price for an appropriate protein concentration. Grain prices have been entered by the user and are stored in a lookup table.
6. Combine the prices for low- and high-bin grain and compare the result with the price of grain at the overall mean. This difference is the marginal return.
7. Repeat Steps 1 to 6 at default intervals of protein content to generate a table and plot of marginal return vs. cutoff

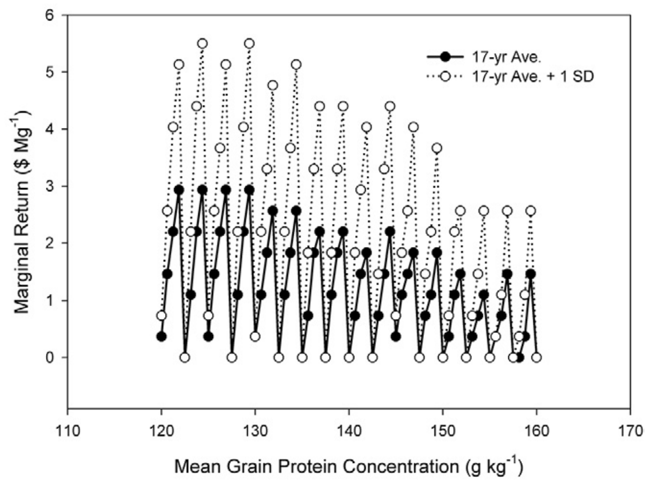

Fig. 6. Marginal return from segregation vs. mean grain protein concentration under two pricing scenarios: average of 17-yr (1994–2010) prices and average of 17-yr prices plus one standard deviation.

value. Optimization of the solution occurs when a cutoff value is selected so that marginal revenue is maximized. Optimum values are reported in the solution.

GRAIN SEGREGATION PROFIT CALCULATOR RESULTS

To illustrate GSPC results, mean protein was manually entered in 65 steps between protein concentrations of 12 and 16% in increments of 0.0625%, with a fixed value of 1.0 for the standard deviation. Grain prices for DNS wheat were averages for the 17-yr period and were entered into the calculator for each 0.25% increment between 12 and 16% protein concentration. Overall, the marginal return from segregation gradually decreased from US\$2.94 to US\$1.47 Mg^{-1} as the mean protein increased from 120 g kg^{-1} (12%) to 160 g kg^{-1} (16%) (Fig. 6). This decrease apparently is due to the reduced price differential above 140 g kg^{-1} (14%) protein. In addition, the marginal return varies in a cyclical pattern, increasing from zero when the mean protein corresponds with a price point to a maximum before falling back to zero at the next price point. Thus, the GSPC results show that the best marginal returns occur when the average protein of a batch of grain is slightly below a price point. The zero marginal return at a price point is due to the entire batch being eligible for the increased price. In other words, when 100% of the grain is in the high-valued bin, there is no advantage from segregation. Between price points, grain increases in value with increasing mean protein because of a concomitant increase in the volume of higher value grain as the mean protein moves to the next price point.

To evaluate the effect of a price differential on marginal returns, a high-price scenario was created by entering the 17-yr average prices plus one standard deviation, which increased the price differential between 120 and 140 g kg^{-1} protein from US\$28.67 to US\$52.19 Mg^{-1}. Again, mean protein was varied in the 65 steps as described above. Figure 6 shows that an increase in the price differential will increase marginal returns. For instance, at 129.375 g kg^{-1} mean protein, returns grew from US\$2.94 to US\$5.51 Mg^{-1} when the price differential

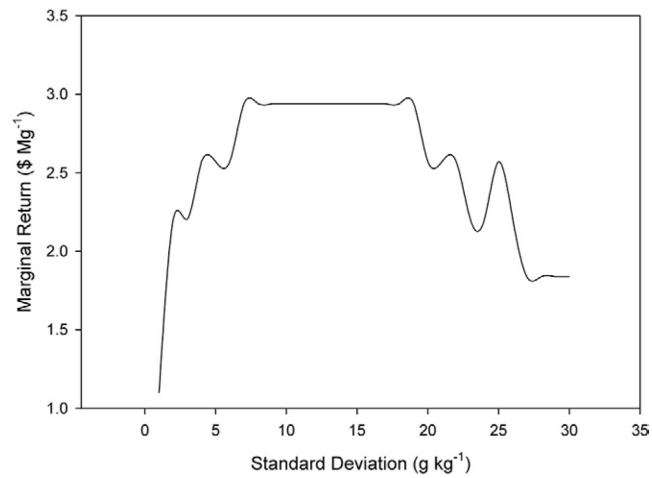

Fig. 7. Marginal return from segregation vs. the standard deviation of grain protein concentration.

was increased. Thus, grain segregation may add substantially more value to DNS wheat in years with high protein premiums.

To study the effect of GPC variance on marginal returns, the standard deviation was varied in GSPC stepwise from 0 to 3% in 0.2% increments, with a fixed value of 12.9375% (129.375 g kg^{-1}) for mean protein concentration. Marginal returns increased rapidly from US\$1.10 to US\$2.94 Mg^{-1} as the standard deviation increased from 2 g kg^{-1} (0.2%) to 8 g kg^{-1} (0.8%) (Fig. 7). Returns stabilized at US\$2.94 Mg^{-1} between standard deviation values of 8 g kg^{-1} (0.8%) and 19 g kg^{-1} (2.0%). Apparently, increasing the standard deviation >8 g kg^{-1} sufficiently widened the distribution of grain so that more could be distributed to the higher valued price points. Returns diminished, however, when a standard deviation of 19 g kg^{-1} was reached, after which grain was distributed to price points >160 g kg^{-1} protein where the price differential ceased.

CONCLUSIONS

The GSPC was developed to explore whether growers might use grain segregation to take better advantage of protein premiums to increase the value per unit. The software is designed for cereal crops that are consistently priced based on the GPC such as DNS wheat and hard red winter wheat, but it could be adapted to any crop having a pricing structure. This study found that marginal returns from segregation will depend on the price differential between different protein points at the time of harvest as well as the frequency distribution of protein within a field. Low mean protein, moderately variable grain, and strong protein premiums all favored positive marginal returns in DNS wheat sold in a pricing schedule for each 2.5 g kg^{-1} change in protein. Greater returns would be possible for grain sold in pricing systems that utilize larger protein increments (e.g., soft white winter wheat or hard red winter wheat).

The calculator has limited application because combine harvesters currently are not designed to segregate grain. We have successfully developed an on-combine grain segregation system consisting of two bins and a NIR optical instrument programmed to automatically control a mechanism that diverts grain to either bin based on in-stream readings of the GPC.

An advantage of this approach is that prior knowledge of harvesting zones is not required. The results from this research will be released in 2013. Once combines are adapted for grain segregation, the calculator will be a potentially useful tool to assist a grower with making marketing decisions for their grain crops. A grower may not have the mean protein concentration and standard deviation in advance of harvest, but a test swath can be harvested to obtain these values. The economic feasibility of on-combine grain segregation will depend on the ability of the marginal returns discussed here to cover the full costs of segregating the grain. Such an economic analysis was beyond the scope of this study.

The extreme sensitivity of marginal returns to the position of the cutoff value, relative to each 2.5 g kg^{-1} incremental change in DNS wheat protein, suggests that the GPC must be sensed at accuracies within this limit. Currently, in-line optical sensors that are designed for use on combines can measure to within 5.0 g kg^{-1} protein concentration. Therefore, grain segregation apparently may be better suited for crops with pricing schedules that pay to the nearest 5.0 g kg^{-1} protein concentration. Accordingly, the expected benefit of segregation probably would be larger for hard red winter wheat than for DNS wheat because a larger protein increment allows a larger portion of the grain to receive added premiums.

The GSPC, users guide, and historic price data can be accessed at http://ag.montana.edu/grainsegregationprofitcalculator/ (verified 9 Jan. 2013). A spreadsheet version of the software was written for use with Microsoft Excel. A copy of this software is available from the corresponding author on request.

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