Profitability Maps as an Input for Site-Specific Management Decision Making

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ABSTRACT

For over a decade, farmers have been collecting site-specific yield data. Many have formed doubts about this investment because of their inability to directly apply this information as feedback for improving management. The objective of this case-study analysis was to investigate how site-specific decisions can be improved by transforming a long-term multiple-crop yield-map dataset into profit maps that contain economic thresholds representing profitability zones. Ten years (1993–2002) of cleaned yield map data [4, 5, and 1 yr for corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], and grain sorghum (*Sorghum bicolor* L.), respectively] were collected for a 35.6-ha claypan-soil field in Missouri. Actual input costs and crop prices, published custom rates for field operations, and region-specific land rental prices were used to transform yield maps into profitability maps by year, by crop, and overall for 10 yr. Profit maps revealed large field areas where net profit was negative, largely due to negative profit from corn production on areas where topsoil was eroded. The areal extent and degree to which other unique field features affected profitability, such as a tree line and a drainage way, are discussed. This analysis demonstrates how changing yield into profitability metrics can help a producer consider and then decide on different management options. We explore how assessment and exploratory analysis with profitability mapping supports multiple aspects of the decision process, including *identification*, *development*, and *selection*. The decision process discussed supports a producer's need to manage fields with incomplete information and where satisficing rather than optimizing behavior often occurs. This analysis demonstrated how profit mapping can be of value for a producer and provides impetus for the precision agriculture community to consider profit mapping protocols and standards.

Several researchers have suggested that acquiring a multi-year database of yield maps may be essential for evaluating site-specific crop management opportunities (McBratney et al., 2000; Pierce et al., 1997; Tiffany et al., 2000). The number of years of data needed to represent the range of possible yield outcomes for each crop grown on a field is site-specific, dependent on a stochastic interaction of crop, climate, and soil landscape. Past research indicates that 5 yr or more of yield data may be required to represent the range of possible yield outcomes for each crop grown on a field (Lamb et al., 1997; Dobermann et al., 2003; Schepers et al., 2004). Practical limitations reduce the utility of yield maps for optimized decision making, at least until sufficient yield-years are measured. On the other hand, Hopkins et al. (1999) encouraged the use of multiple years of yield data despite the fact that such data may actually give confusing information, pointing out that "uncertainty should not preclude site specific decisions any more than uncertainty should preclude decisions in any other facet of farm management."

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Meanwhile, farmers have expressed frustration in obtaining value from yield maps. Griffin (2000) reported that farmers who recognized the need to accumulate several seasons of yield data still had not converted the previous year's data into maps in time to use them for the next year's field management decisions. He concluded that "farmers were struggling to find direct benefits from the yield information that they were spending time and effort gathering." Griffin et al. (2004) suggested that yield maps are not created because (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. Given these points, the inability to process the gathered yield information into meaningful decisions likely leads to apathy and discontinuance of future data collection.

Another challenge associated with analyzing and interpreting crop yield maps is determining to what extent multiple-year datasets containing a mixture of different crops can be aggregated. Spatial yield expression is often crop specific (Kitchen et al., 1999), yet when evaluating effects of long-term management on production systems, year-by-year comparison is required. Thus, summarizing yield maps of multiple crops requires some type of standardization process. Although various techniques have been used, perhaps the

Abbreviations: cCRP, continuous Conservation Reserve Program; PAWC, plant-available water holding capacity.

most common standardization for multiple years of yield maps is to divide yield of each cell by the field mean for that year (Blackmore, 2000; Kitchen et al., 2005a). Such standardization is useful as input into statistical packages but conveys little information to producers for identifying economic opportunities for specific field areas.

Transforming the data from yield to some economic metric also enables the aggregation of several years of data from different crops. This allows evaluation of the cropping system as a whole. Economic metrics that have been explored include gross revenue (Stull et al., 2001), profit (Cook et al., 1996; Wild and Colvin, 2002; Yang et al., 2002) and internal rate of return (Curless et al., 2002). While these previous studies demonstrated economic metrics, they did not discuss the implications of their methodology for the creation and use of economic maps in management decision making.

Revenue maps have the same weakness as yield maps for multi-year comparison. The yield and corresponding revenue maps will have different scales but the general "topography" of the maps will be proportional. Additionally, revenue maps of different crops over time in the same field may show wide swings in revenue and at the same time have similar profits. For example, corn and soybean are often grown in rotation in the U.S. Midwest, suggesting that they have similar profit potentials. But corn gross revenue consistently averages about 1.4 times that of soybean gross revenue (USDA NASS, 2006). The higher variable cost of corn production relative to soybean production is not communicated in revenue maps. Any costs that are not uniform across the field, such as from variable rate fertilizer applications, are also lost in revenue maps.

Profit maps that incorporate costs and revenues overcome the problems of revenue maps because they include sufficient economic information to permit the aggregation of several years of data for different crops on the same field. Practical problems with creating profit maps include the selection of crop prices and input costs necessary for estimating profit. Yang et al. (2002) created profit maps using representative high and low prices to evaluate the impact of price on break-even analysis. Stull et al. (2001) used 5-yr average prices for a 10-yr simulated economic analysis. Wild and Colvin (2002) used 10-yr average prices. Estimation of production costs is another concern in creating profit maps. Yang et al. (2002) used a budget generator to estimate equipment costs and presented custom rates for comparison. The use of a budget generator permits the allocation of fixed costs over different land acres when doing scenario analysis that involves adding or subtracting acres and field activities. Wild and Colvin (2002) used current (at the time of the analysis) estimated costs of production separated into fixed and variable production costs. Stull et al. (2001) used actual variable production costs collected from the producer in a single year, a recent 3-yr average land rental rate, and estimated costs associated with establishing filter strips.

Return on investment maps can be used to evaluate different management alternatives once profit maps reveal them. Return-on-investment maps are an additional step beyond profit maps, and would help rank alternatives to facilitate the selection of where to invest scarce resources.

Our objective was to investigate and demonstrate, through a case study, how site-specific management decisions can be facilitated by transforming long-term multiple-crop yield-map datasets into profit maps. Within the framework of creating profit maps, we emphasize the use of economic thresholds to create profitability zones. A final point of this investigation was to discuss how such profitability mapping enhances decision making for the producer.

MATERIALS AND METHODS

Yield and Budget Data

This analysis was performed on 10 yr of yield data available for a 35.6 ha field in central Missouri. This field presents a unique dataset for demonstrating the use of yield maps because of the amount of information that has been accumulated. First, few field-scale experiments have 10 yr of continuous, high-quality spatially-referenced, cleaned yield monitor data. Second, the field–although conventionally managed with uniform inputs applied across the field–has been part of research projects that have accumulated extensive spatial information on soil characteristics and growing conditions. This information provides insight into yield variation and associated agronomic interpretations that occur due to spatial processes.

Approximately 34.4 of the 35.6 ha were cropped, with the remaining area in a tree line or used for research equipment (e.g., weather station). Each year, one or more tillage operations prepared the soil for planting. Inputs such as fertilizer and herbicides were applied according to University of Missouri recommendations. Additional details regarding the management systems employed on this field can be found in Lerch et al. (2005). Soils of the field were characterized as claypan soils with surface textures ranging from silt loam to silty clay loam (Lerch et al., 2005). Claypan soils often exhibit spatial variation in crop productivity (Kitchen et al., 1999).

Combines equipped with commercially available yield sensing systems were used to collect data for 1993–2002 yield maps. Individual points where yield data were unreliable due to combine operation or yield sensor issues were removed so that the resulting yield map represented the actual yield as closely as possible. Based on our experience (Sudduth and Drummond 2007) and that of others (e.g., Robinson and Metternicht, 2005), yield data points were removed for reasons such as GPS positional error, abrupt combine speed changes, significant ramping of grain flow during entering or leaving the crop, unknown or variable crop swath width, and other outlying values. Our intent was to remove any questionable data from the point dataset so that map development would not be significantly affected by operational outliers.

Cleaned yield monitor data was interpolated with the geostatistical technique of block kriging (Webster, 1985). The best-fitting semivariogram interpolation function was determined separately for each year and applied to estimate yield for each 10-m square grid within the field, in a procedure similar to that suggested by Birrell et al. (1996).

Corn was grown in 1993, 1997, 1999, and 2001. Grain sorghum was grown in 1995 because excessive rainfall delayed planting beyond a satisfactory date for corn planting. Soybean was grown in the alternate years. The crop price used in the analysis was the higher of the appropriate loan rate or the local average harvest time price (September to November) in the year of harvest (USDA NASS, 2006).

Costs of inputs such as seed, fertilizer and chemicals were obtained from detailed farm records and used in the analysis. Such cost data capture incentives offered to the producer for inputs and any remedial activities that would not necessarily have been planned in a "budgeted" analysis (e.g., rescue weed treatments). Detailed records of field activities such as cultivating, planting, and spraying were priced using published custom rates (Plain et al., 2001). Land was charged a region-specific rental price (Plain and White, 2003).

Profitability Calculations and Classification

Our estimate of revenue included the actual revenue associated with crops harvested and any government payments tied to that harvest. Loan deficiency payments were included; direct and counter-cyclical payments were not. All direct crop input and equipment costs were included. General business overhead such as subscriptions and legal fees were not included in the estimate of profit.

Annual whole field revenue for crop c in year y ($R_{y,c}$) was calculated as follows:

$$R_{y,c} = \sum_{g} p_c Y_{c,g} \quad [1]$$

where p_c = maximum of the average harvest time price or loan rate for the year in which the crop was grown; $Y_{c,g}$ = yield for each 10-m square grid, g, in the field.

Annual profit in year y (Π_y) was calculated as

$$\Pi_y = \sum_{c} (R_{y,c} - L_y - V_{y,c} - E_{y,c})\, \delta_{y,c} \quad [2]$$

where L_y = land charge in each year; $V_{y,c}$ = variable cost of seed, fertilizer, and chemicals for each year and crop; $E_{y,c}$ = equipment ownership and operation costs of actual field activities attributed to each year and crop; and $\delta_{y,c}$ = 1 if crop c was planted in year y, 0 otherwise. Production costs were attributed to the crop year that benefited from the activity regardless of the calendar year in which they were incurred. A custom charge for making the maps was included, but associated human capital costs were not. Our reasoning here was that human capital costs such as training and analysis time, though possibly extensive, are overhead associated with farm management. The profit estimated in the maps becomes a return to management, including human capital.

Specific crop profit (Θ_c) maps included data from all the years a single crop (corn or soybeans) was grown:

$$\Theta_c = \frac{1}{n_c} \sum_{y} \sum_{c} \Pi_y \delta_{y,c} \quad [3]$$

where n_c = number of years crop c was grown.

The all crop-years profit (Ω_F) map averaged the profit of all years and all crops:

$$\Omega_F = \frac{1}{n} \sum_{y} \Pi_y \quad [4]$$

Table 1. Profitability zone description and interpretation.

Profitability zone	Description	Profit equation
1	land, variable, and machinery costs are 100% covered	$\Pi = R - L - V \geq 0$
2	land and variable costs are 100% covered	$R - L - V \geq 0$
3	land costs are 100% covered	$R - L \geq 0$
4	no costs are 100% covered	$R - L < 0$

where n = number of years of data used to generate the map.

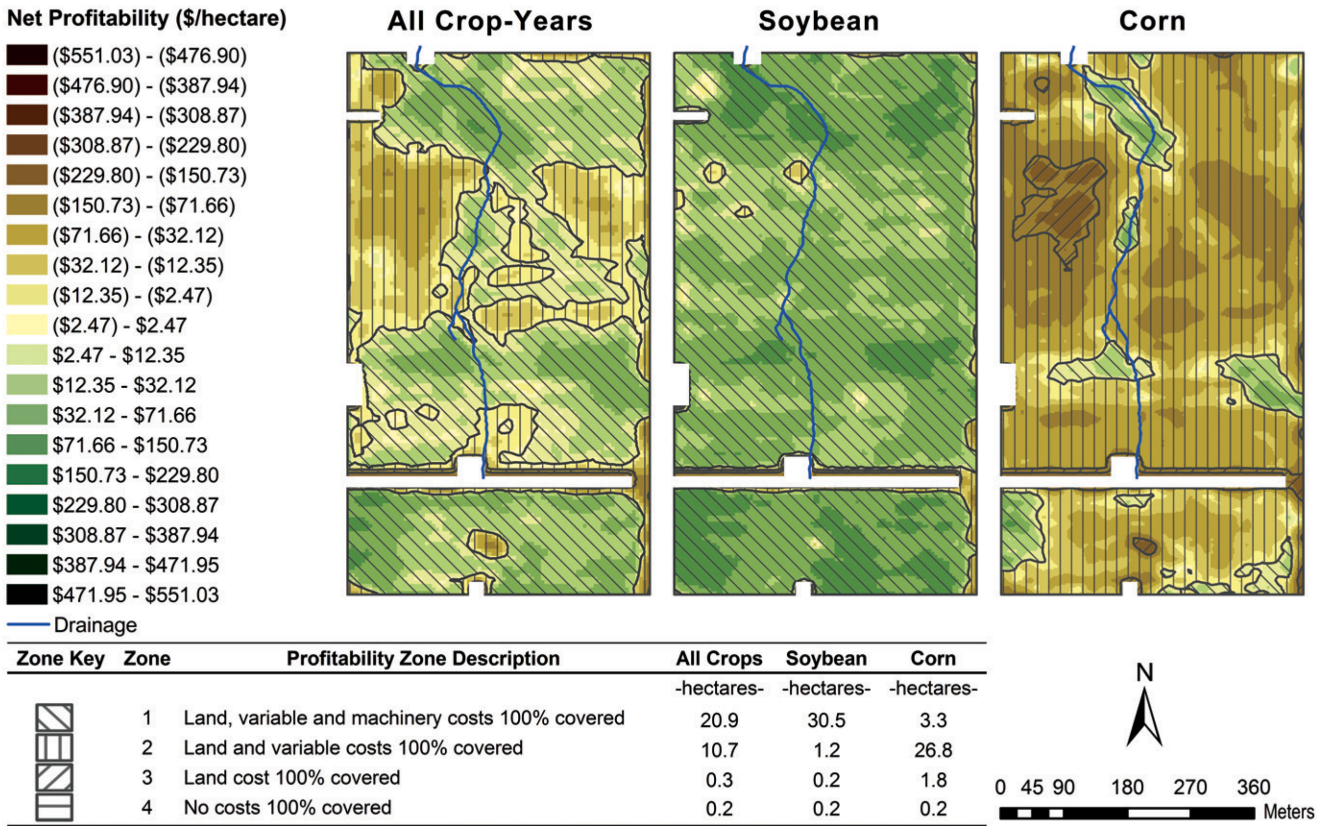
The same legend was employed for all maps (annual profit, crop profit, and all crop-years profit) so that the different types of maps could be quickly and visually compared. Because the range of profits between years, Π_y, will not necessarily overlap, any comparison between years requires a consistent legend. It is expected that the range of the all crop-years profit estimation, Ω_F, is an average of annual profit, Π_y, will be less than the range of either Π_y or Θ_c. To provide good visual differentiation on the all crop-years map, the legend was chosen to be a logarithmic-like scale for the five classes on either side of zero profit and a linear scale for the last five classes at each extreme. Thus, the categories closest to zero profit have a smaller range than the categories at the extremes.

In addition to displaying estimated profit on the maps, a set of economic thresholds was included to delineate profitability zones. Similarly, Wild and Colvin (2002) created profit maps using key decision points as category limits. Here we use color to display profit level and lines to display profitability zones. In so doing, information presented in the map was increased without adding undue complexity. The economic thresholds we chose delineate profitability zones according to the key variables in the annual profit equation (Eq. [2]). Table 1 explains the calculation and economic importance of each zone. Profitability zone 1 is where profit is positive. Revenue covers all costs of production. Profitability zone 2 is the area where revenue covers land and variable costs but not all machinery costs. Profitability zone 3 is the area where revenue covers land costs, some but not all variable costs, and no equipment costs. Profitability zone 4 is the portion of the field where only some of the land costs and none of the variable and equipment costs are recovered. While we chose this specific priority order for defining the profitability zones in this analysis, the most appropriate priority order may vary from one producer to the next, depending on their perceived importance of asset and cost variables.

RESULTS AND DISCUSSION

Net Profit Maps Overlaid with Profitability Zones

The underlying economic data used to create the profit maps are presented in Tables 2 and 3. The average profit (net income) of all crops over all years is estimated at −$1.43 per cropped ha. Corn and soybean profit maps and the overall crop-years profit map (Fig. 1) and annual profit maps (Fig. 2) are provided; the legend for both maps is located on Fig. 1. This common legend for all maps covering the full range of profit seen over the 10-yr period allows visualizing differences within field, between years, and between years and averages. With this legend, one quickly observes that 1994, 1999, 2001, and 2002 were unprofitable years over most of the field (Fig. 2). Years 1993 and 1996 yielded a profit over the entire field. The other years yielded an overall profit but had portions of the field that were unprofitable.



Zone Key	Zone	Profitability Zone Description	All Crops	Soybean	Corn
			-hectares-	-hectares-	-hectares-
	1	Land, variable and machinery costs 100% covered	20.9	30.5	3.3
	2	Land and variable costs 100% covered	10.7	1.2	26.8
	3	Land cost 100% covered	0.3	0.2	1.8
	4	No costs 100% covered	0.2	0.2	0.2

Fig. 1. Field average profit maps with profitability zones overlaid (average of four corn-years, five soybean-years, and one-sorghum year). Profit values enclosed in parentheses in the legend represent a net loss.

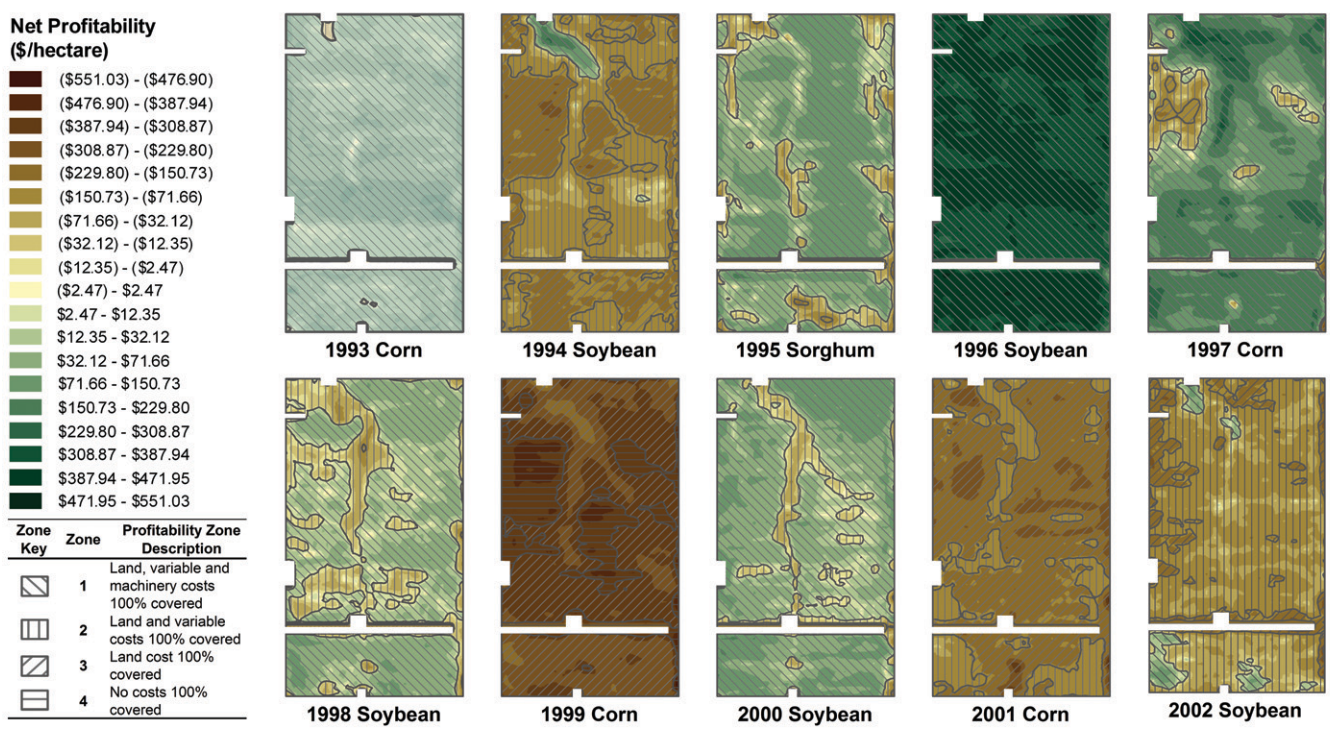


Fig. 2. Annual profit maps with profitability zones overlaid. Profit values enclosed in parentheses in the legend represent a net loss.

Several features of the field are easily observed on some of the profit maps. For example, a drainage running north-south through the middle of the field (shown as a blue line in Fig. 1) appears to have subtle effects on average profit maps (see all crop-years and corn panels in Fig. 1) but has a more pronounced effect on many of the annual maps (Fig. 2). The drainage way had both positive (e.g., 1994 and 1997) and negative (e.g., 1998 and 2000) impacts on within-field profit for individual years, because yield was affected by differences in growing season precipitation in the different years (Kitchen et al., 2005b). Consequently, when averaged, less effect was observed.

Another example of a distinctive field feature is a tree line (white horizontal bar in maps) that divides the field about 150 m north of the south edge of the field. This tree line is the vestige of a fence row that before 1980 separated a pasture (south portion of the field) from cropped ground (north portion of the field). The tree line is represented as being 20 m wide because it straddles two rows of 10-m grid cells. It is actually much narrower in some places, and yet affects yields with negative net profit across a swath over 60 m wide (Fig. 1, all crop-years). Along the east side and part of the north side of the field, tree lines also define the field edge and impact crop yield several meters into the field. Depressed yields along tree lines are caused by interplant competition for water and light and field edge traffic and planting patterns. Other areas of the field (white blocks in maps) do not produce a crop because they contain research equipment.

The all crop-years profit map reveals large areas where net profit has been negative (yellow-brown to brown in Fig. 1). A significant portion of the northern half of the field is in profitability zone 2, where land and variable costs, but not all equipment costs, are covered by revenue. The area delineated as profit zone 2 is sufficiently large and aggregated that it could be managed differently from the rest of the field.

Averaged over the 5 yr of soybean production, profitability was positive over most of the field (Fig. 1). Except for small portions around the tree line, the entire field is in profitability zone 1. Most areas of the field that are in zone 2 of the all crop-years profit map are in zone 1 of the soybean map.

The corn map indicates that, on the average, corn profitability was negative over most of the field. A substantial portion of the field that is in profitability zone 2 of the all crop-years profit map is in profitability zone 3 for corn production. Profitability zone 3 revenue covers the entire land rental charge, but only some fraction of the variable costs.

The decision to create profitability zones based on economic thresholds imparts a distinctly managerial economics perspective to profit maps. The color representation in the figures, while spatially showing profit gradients, does not necessarily convey the areal extent of manageable problems. Profitability zones create category breaks at values economically important for management decisions. Most other published profit maps have used uniform categories that evenly divide the range of profits without consideration of whether the category limits are economically important (e.g., Cook et al., 1996; Yang et al., 2002). The use of economic thresholds to establish profitability zones differs from creating management zones using unsupervised classification techniques as others have done (Fleming et al., 2000; Schepers et al., 2004; Jaynes et al., 2003; Kitchen et al., 2005). Rather than grouping portions of a field into zones based on statistical nearness, the emphasis is placed on economic relevance. The components of the profit equation

Table 2. Whole field income and expenses by year and crop.

Year	Crop	Gross income	Expenses: Land	Expenses: Equipment	Expenses: Agronomy inputs	Expenses: Total	Net income
		$ ha^{-1}					
1993	corn	665.08	141.27	123.77	243.84	508.86	156.19
1994	soybean	315.31	138.38	129.06	179.20	446.64	−131.34
1995	sorghum	481.51	149.82	129.90	164.55	444.29	37.24
1996	soybean	785.27	152.64	131.46	132.08	416.15	369.12
1997	corn	675.31	158.15	104.25	292.57	554.97	120.34
1998	soybean	405.57	161.19	106.01	130.82	398.01	7.56
1999	corn	193.16	166.97	142.31	210.76	520.03	−326.87
2000	soybean	500.41	168.03	136.80	162.22	467.05	33.36
2001	corn	453.96	175.52	142.04	320.10	637.68	−183.72
2002	soybean	387.81	178.34	137.81	167.98	484.10	−96.32
Average	corn	496.88	160.47	128.10	266.82	555.39	−58.51
Average	soybean	478.86	159.70	128.22	154.47	442.39	36.47
Average	all crops	486.35	159.04	128.35	200.40	487.78	−1.43

Table 3. Breakdown of equipment and agronomy input operating costs by year and crop.

Year	Crop	Equipment: Preplant cultivator	Equipment: Preplant disk	Equipment: Spraying	Equipment: Planting	Equipment: Row cultivation	Equipment: Combining	Equipment: Postharvest chisel	Equipment: Mowing stalks	Agronomy inputs: Fertilizer	Agronomy inputs: Herbicide and pesticide	Agronomy inputs: Seed
		$ ha^{-1}										
1993	corn	15.42	0.00	21.42	17.15	0.00	53.40	0.00	16.38	100.56	89.55	53.72
1994	soybean	14.88	16.43	19.17	19.35	9.69	49.54	0.00	0.00	49.43	106.29	23.47
1995	milo	14.88	0.00	9.54	19.35	13.54	53.45	0.00	19.15	83.65	60.34	20.56
1996	soybean	14.88	16.43	9.59	19.35	0.00	49.54	21.67	0.00	40.54	65.93	25.60
1997	corn	17.49	0.00	10.06	21.08	0.00	55.62	0.00	0.00	130.22	95.87	66.47
1998	soybean	17.49	0.00	10.40	21.94	0.00	56.17	0.00	0.00	0.00	99.93	30.89
1999	corn	17.49	19.05	10.06	21.08	0.00	55.62	0.00	19.00	88.21	62.96	59.58
2000	soybean	18.31	18.83	20.51	23.97	0.00	55.18	0.00	0.00	0.00	103.04	59.18
2001	corn	18.31	0.00	21.10	23.15	0.00	57.43	0.00	22.04	186.20	74.95	58.96
2002	soybean	36.62	0.00	22.04	23.97	0.00	55.18	0.00	0.00	40.12	53.72	74.13
Average	corn	17.18	4.76	15.66	20.61	0.00	55.52	0.00	14.36	126.30	80.83	59.68
Average	soybean	20.44	10.34	16.34	21.72	1.94	53.12	4.33	0.00	26.02	85.78	42.65
Average	all	18.58	7.07	15.39	21.04	2.32	54.11	2.17	7.66	71.89	81.26	47.26

become the categories that define profitability zones, and correspond to what has been found to be managerially relevant in the economics literature.

Identification and Development of Management Options

A producer/consultant observing these maps would rely on personal experience of the field or seek additional information, such as soil maps, to diagnose the problems visually evident. A map of this field generated in other research (Lerch et al., 2005) shows that profitability zone 2 of the all crop-years profit map (Fig. 1) corresponds to an area of highly eroded claypan soil with low plant-available water holding capacity (PAWC). Droughty conditions occurred during the growing season in 2 of the 4 yr corn was grown. With corn's relatively high demand for water interacting with the low PAWC of shallow soils, attention is quickly drawn to this area of the field. The description *marginal*, a subjective term often used with this type of soil, has been *quantified* with this numeric analysis to literally show the degree of historic economic liability in this crop production system. Such large areas of negative net profit should evoke a response by the producer to consider changes. Since zone 2 represents uncovered machinery costs, the producer may choose to reduce this cost category with no-till management so that profit is possible. The producer might also question whether 4 yr of corn production data, including two abnormally dry years, is sufficient information to warrant changes, or analyze their risk exposure due to planting corn on such high variability field areas. Any consideration of removing corn altogether should also prompt a feedback that considers the impact of crop type and rotational effects on crop yields.

The 0.6-ha tree line (white in the maps) has no revenue and has not been managed to produce revenue, but still incurs a rental charge. Tenants often rent fields where a portion is unproductive, such as in a tree line, grassed waterway, or pasture. A tenant could use profit maps to demonstrate to the landowner that not only is the tree line unproductive but its impact extends into the cropped portion of the field. Such information could be used to renegotiate rents or discuss management actions that the tenant might be permitted to take. For example, removing the tree row or using a tree root plow to cut the roots are management options that could reduce or minimize the impact of the trees on profitability. A partial budget would be applied to the tree line to determine if the expected revenue increase due to higher yields would exceed expected cost increases from management activities in the zone. Such analysis would likely use projected or average prices rather than the historical prices that were used to create the individual profit maps. Government payments or cost share for conservation practices to support keeping or enhancing field-edge trees would be pertinent revenues to also consider in the decision process.

Field surface drainage areas are important features that control the movement of sediment and agrochemicals offsite. These areas are frequent targets for application of conservation practices such as grassed waterways. The average profit map indicates the land immediately adjacent to the north-south drainage is profitable (zone 1) for almost its entire length. The fact that the drainage is in profitability zone 1 indicates that all actual rental rates are earned and any retirement of the land would reduce profit unless more than 100% of rent was paid to the farmer. This information could be used to determine involvement in government conservation programs. The USDA continuous Conservation Reserve Program (cCRP) pays 120% of average county rental rate for qualifying land put into conservation practices. The producer or consultant could analyze the costs and benefits of retiring this land, using the computerized budgets that generated the map, to determine if the 20% additional payment for conservation would be sufficient to offset the loss of a productive area.

While the average soybean map indicates profitable production along the full length of the drainage, maps of individual soybean years (Fig. 2 soybean panels) do not give as clear a picture. The areas adjacent to the drainage were unprofitable 4 of the 5 yr that soybeans were grown. The extreme profitability of the 1996 soybean crop offset the loss in the other 4 yr to help create an average soybean profit. Conversely, during the 4 yr that corn was grown, the depositional soils adjacent to the drainage were more profitable, or less unprofitable, than the other areas of the field. The profit along the drainage for corn production differs from that for soybean production. If corn is dropped from the rotation because it is deemed unprofitable, the incentive needed to justify enrolling the area in cCRP may decrease because soybean profit along the drainage area was positive only one of the past 5 yr that the soybean crop was grown. Conversely, if corn production is continued, enrolling this area in cCRP could further reduce the net income due to corn production.

One of the overriding questions in deciding whether or not to create profit maps is if they add any pertinent information to the decision process, information that is not present in yield, soil, and elevation maps. Fraisse et al. (2001) created management zones for the same field using soil and landscape information within an unsupervised classification scheme. As one might expect, a comparison of that zone map with profitability zones obtained in this analysis shows some similarities. However, differences are also obvious. This too should be expected since the zones delineated in the profit maps provide information on crop response to the entire suite of growing influences specific to this field: management, border effects, pests, weather, soil resource, and the interactions of all these. For example, the zones created by Fraisse et al. (2001) give no information regarding the effect of the tree line or drainage way on the profitability of the field. The profit maps draw attention to this effect. Even knowledge that is common sense (e.g., that drainage ways affect yield immediately adjacent to them) influences decisions when presented within a context where economic thresholds are visible and losses are calculable.

Profitability Mapping as a Decision Aid

Farmers accumulating geo-referenced yield data face an unstructured decision process (meaning no predetermined and explicit set of responses exist [Mintzberg et al., 1976]). They possess what they deem to be useful data, but currently struggle with identifying the opportunities to apply it in management decisions. Previously, different aspects of decision making have been alluded to when dealing with yield and profit maps. Swinton and Lowenberg-DeBoer (1998) cautioned growers and consultants in drawing inferences from yield maps because of the interaction between controllable and uncontrollable factors in determining yield. A case study by Davis et al. (2002) found that farmers made their site-specific management decisions intuitively, incorporating subjective information with the quantitative data from yield monitors. We suggest that the opportunity for yield maps to facilitate decisions is even greater than that alluded to with these examples.

We believe that three different and distinct steps of producer decision making—namely *identification, development,* and *selection*—can be enhanced as yield maps are converted into profit maps. These steps have been described previously in a general discussion on decision making (Mintzberg et al., 1976). Although stated as "steps" here, they are aspects of decision making that are not necessarily sequential (Ohlmer et al., 1998). As such, they are functions of the decision making process that occur and reoccur and in different order, depending on the complexity of the decision being made.

During the *identification* step, a producer recognizes and diagnoses crises, problems, and opportunities (several examples of this step were illustrated in the previous section). The visual presentation of profit variation across fields, combined with the farmer's understanding of the landscape, create associations that offer managerial opportunity to identify problems.

The *development* step involves activities that lead to a set of potential solutions to a problem (also illustrated in the previous section). Except when ready-made solutions exist (e.g., apply herbicide to a severe grass infestation), *development* is often a complex and iterative procedure. It is a step where new strategies are examined and designed. *Development* is characterized by dynamic factors, including feedback delays and comprehension cycles. Feedback delay involves waiting for the results of previous actions while comprehension cycles involve pursuing various leads that offer insight but bring the decision maker back to information already assessed. These processes of the *development* step describe how profit mapping offers valuable information in searching for and designing alternatives that address problems and opportunities.

Selection involves evaluation and choice. With *selection*, new perspectives and ideas are generated when alternative management scenarios are examined through some type of evaluation routine. Once management strategies have been identified, a producer may see reason to choose one strategy over another. As an example, using various crop prices when creating profit maps could enhance the evaluation and selection of strategies. Using both high and low market prices in profit mapping permits bounding of expected profit and scenario analysis. The use of average prices reduces the variability of net income that occurs from price movements; variability that may overwhelm yield differences within a field. Using actual prices in the year of harvest (as was done with this case study) merges the variability of yields and prices to give an accurate *historical* estimate of profit. With this method of pricing, results in maps from 2 yr with different prices will appear to be quite different, even when the underlying yield maps are similar. Thus, scenario analysis using high, low, long-term average, and actual crop pricing may assist in the *selection* step of the decision.

Profit maps need to be formatted to provide input into all decision steps: *identification*, *development*, and *selection*. Profit maps should be developed in ways that are flexible enough to convey information regarding multiple opportunities over multiple years as yields, prices, and management practices change. The common and logarithmic-linear legend we used in this case study is an example of formatting to convey a full decade of historical profitability on a few maps. Profit maps can foster the sequential evaluation of decision alternatives as decision makers continually assess the situation, and the context and nature of the problem or opportunity.

This profit analysis framework meets the producer's need to manage fields with incomplete information and where satisficing rather than optimizing decision making occurs. We believe this exercise is useful even without a statistically representative sample of yield-years for several reasons. First, it represents reality. Field level yield and profit are dependent on variables both controlled and uncontrolled by the producer. The impact of each variable is understood but perhaps not quantifiable. The creation of profit maps is not intended to give decision makers perfect information, but more useful information. Second, statistically representative data, while desirable, are not necessary for all steps of decision making. Even in the *selection* phase of decision making, utility theory (Smith and Mandac, 1995) and Bayesian analysis (Winkler, 1972) incorporate the decision maker's subjective input, not just statistically derived probabilities, into the process.

CONCLUSIONS

Profit maps expand the use of yield maps by allowing the aggregation and comparison of yield data across crops and across years in a metric (dollars) that is useful for managerial decision making. The all crop-years profit map, which incorporates all years' profit data, provides a picture of profitability over time and space. By incorporating cost and price data, it allows the decision maker to see what areas of the field were above or below economic benchmarks across years. Individual crop profit maps, on the other hand, allow the decision maker to assess how specific areas of the field differ in profitability by crops over years.

The way in which information in a profit map is presented can affect the perception of the map. This paper presents a viable way to create maps using profitability zones rather than unsupervised classification of soil and landscape data as others have done. Profitability zones, defined by cost categories, integrate information regarding natural resources (e.g., soil, water availability) and cropping strategies (e.g., crop rotation, fertilizers, tillage) to aid in the decision process. The use of profitability zones provides a quick reference to breakeven points where producers might have incentive to make changes.

Profit mapping creates a learning experience for the producer and decision making is facilitated. Recognizing the importance of the *identification, development*, and *selection* steps of decision making guides the way profit maps are created and used. The framework presented here recognizes that the dataset needed for optimization in the *selection* step may not be attainable by producers within the time-line they desire. Often, detailed analysis is necessary before alternatives can be identified and evaluated regarding the proper course of future actions to take. Within a GIS framework, modifications to the underlying budgets of the whole field or specific zones (e.g., assign land along the drainage ditch to cCRP by designating the cCRP rental payment as revenue and estimating the amortized establishment costs) can provide estimates of profitability changes along with displaying the impact of the modification in map form.

As more fields have long time-series of quality yield data, farmers will benefit from profit mapping methodologies that point out possible management opportunities via identification and development processes. The decision process is important for understanding how farmers will find value in profit maps. The decision process also presents a framework within which the precision agriculture community can evaluate profit mapping protocols and establish profit mapping standards.

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