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Estimating whole farm costs of conducting on-farm research on midwestern US corn and soybean farms: A linear programming approach

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ABSTRACT

Precision agricultural technologies such as GPS-enabled automated guidance, yield monitors, and controller-driven variable rate applicators have reduced but not eliminated the costs of conducting on-farm trials. Farm decision makers often contemplate the benefit side of the profitability equation when considering on-farm trials. However, the cost portion of the equation must be considered to make informed decisions. This study estimates the whole-farm costs of conducting on-farm trials using a modification of the classic down-time model in a linear programming framework with comparisons to previously estimated potential benefits. Results indicate that after accounting for the whole farm costs there are still benefits to on-farm trials. Whole farm costs vary significantly dependent upon the type of on-farm trial undertaken. When on-farm trials cause planting and harvesting field operations to be conducted outside the optimal time, crop yields may be adversely affected. Therefore, farm decision makers should consider research questions that do not necessitate adversely impacting these windows until experience has been gained.

KEYWORDS: precision agriculture; yield monitor; GPS; down-time model; on-farm research

1. Introduction

Culminating from recent advancements in agricultural technology and shifts in price/cost structures, farmers are motivated to conduct their own on-farm[5] trials. However, on-farm trials are not costless. Reasons farmers often cite for not conducting on-farm trials include: (1) interference with other farming operations, (2) reduced yield and/or increased costs of inferior inputs or non-optimal rates (rates that are too high or too low), (3) increased probability of implementing an experiment based on a faulty experimental design or inappropriate analysis, and (4) inaccessibility to appropriate software, computation, and/or human resources. This study addresses the first point regarding on-farm trials interfering with other farming operations.

The commercialization of instantaneous yield monitors reduced the time commitment of harvesting on-farm trials, motivating some farmers to re-examine field-scale on-farm planned comparisons (Taylor *et al.*, 2011). In addition to increased numbers of farmers conducting on-farm trials, some farmers are implementing more trials on their farms (Griffin *et al.*, 2008). Similar to yield monitors reducing data collection time requirements during harvest, time requirements during other times have decreased for on-farm trial implementation with the adoption of automated controllers and automated guidance. According to most recent estimates by Schimmelpfennig and Ebel (2011), yield monitor adoption is between 35 and 45 percent of planted acres of corn, soybeans, and winter wheat based on the United States Department of Agriculture Agricultural Resource Management Survey (ARMS). Also based on ARMS, Griffin (2009b) reported that conducting on-farm experiments is the most common use of yield monitors in cotton and third most common in corn and soybean production.

Some farmers have been reluctant to devote efforts necessary to properly conduct on-farm trials because they recognize the potential interference with other farming operations during both the implementation and data collection phases. Implementation of on-farm trials is best discussed relative to before, during, or after planting. For instance, tillage comparisons may occur prior to planting, cultivar trials or seed treatments

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[5] Throughout the manuscript, on-farm will be used to describe farmer managed trials being conducted on their farms. These trials are conducted at a landscape or field scales rather than small plot scale.

implemented during planting, and foliar fungicide treatment comparisons implemented after planting. Field equipment and human capital may have to be diverted away from other farming operations so that the experiment can be implemented. When an experiment implemented during planting period causes other fields to be planted too soon before or in particular too late after the optimal period, then yield potential is adversely impacted (Nafziger, 2014). Even though precision agriculture technologies such as automated controllers and yield monitors have reduced field operation time requirements, it has not been eliminated. Calibration of yield monitors per manufacturers' recommendations occurs during harvest. If weigh scales are available in the field, it is anticipated that calibration takes two hours although a portion of this time crop is being harvested (Griffin, 2010).

With most yield monitor manufacturers, corn harvest is associated with two calibrations, one for wet corn and one for dry corn; additional calibrations are suggested when harvesting different corn hybrids (Doerge *et al.*, 2006). Therefore, a cultivar trial may require multiple calibrations such as one for each treatment whereas other types of on-farm trials with a single cultivar such as tillage comparisons, seeding rates or seed treatment may have a single calibration for the whole experiment.

Estimating the benefits of on-farm trials is more difficult than estimating the costs. The rational decision maker should be cognizant of initial cash outlays as well as expected yield penalties incurred due to implementing the field experiment. Using mathematical programming, the cost of conducting on-farm trials from a whole-farm[6] profitability perspective is estimated for a representative U.S. Midwestern corn and soybean farm. Specifically, the model set forth will allow for the investigation of how the initiation of these experiments impact timeliness of other operations that must be conducted across the operation.

2. Methods

A linear programming (LP) model was used to determine optimal solutions to maximize contribution margins. LP is a mathematical tool for optimizing an objective function (Dantzig 1949) such as maximizing contribution margins with respect to a set of whole-farm constraints on land, labour, and capital under a given weather regime (Doster *et al.*, 2010). Contribution margins are total crop sales revenue minus total direct costs, and can be considered returns to resources or fixed costs such as land, unpaid labour, and machinery. The base for comparison was a representative sized U.S. Midwestern corn and soybean farm with single equipment set with one corn planter, one soybean planter and one harvester. The base was modified in a series of LP runs. The scenario was modelled as a classic down-time problem and specified as a linear programming model in the standard summation notation and written as in Boehlje and Eidman (1984) as:

$$Max\ \Pi = \sum_{j=1}^{n} c_j X_j \tag{1}$$

[6]Throughout the manuscript, whole farm refers to the notation that conducting on-farm trials will have cost implications across the entire operation.

subject to:

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_i \text{ for } i = 1 \ldots m \tag{2}$$

$$X_j \geq 0 \text{ for } j = 1 \ldots n \tag{3}$$

where:

X_j = the level of the jth production process or activity,

c_j = the per unit return to the unpaid resources ($b_i's$) for the jth activity,

a_{ij} = the amount of the ith resource required per unit of the jth activity,

b_i = the amount of the ith resource available.

The j production processes or activities include corn and soybean grown in rotation. The i resources include the (1) amount of land available for crop production, (2) amount of available labour expressed as combination of number of people, number of hours per day, and number of days suitable for fieldwork per period, and (3) the availability of your machinery based on number of machines of each type, number of hours per day that the machine is available, and working rates in acres per hour for each crop production task. The remaining variables X, c, a, and b are the activity levels, per unit returns, production resource requirement, and resource constraints, respectively. Griffin *et al.* (2005) and Griffin (2009a) iterated over a range of working rates of specific field machinery (b_i) to model the economics of adding higher accuracy guidance systems to existing field equipment. Nistor and Lowengberg-DeBoer (2006) changed hours per day constraint to model increased labour availability for controlled drainage. Robertson (2006) evaluated the long-term profitability of continuous corn by altering the X_j matrix of cropping systems. Several other studies have performed analyses by changing given resource availability and activities in specific ways including machinery (Danok *et al.*, 1980), cropping systems and rotations (Bender *et al.*, 1984; Cain 2006; Doering *et al.*, 1997; Foltz *et al.*, 1991; Mellor 2005), financial and risk management (Brink and McCarl, 1978a, 1979b; McCarl *et al.*,1977), harvest and on-farm drying systems (Davis and Patrick 2002), and climate change ramifications (Doering *et al.*, 1997; Pfeifer and Habeck 2002).

The above-mentioned studies acknowledge several limitations of LP. Deterministic LP model does not take into account any stochastic properties or risk. The input parameters are used as 'exact' values; therefore, the results are only as good as the information provided to the model. The LP model has 'perfect foresight' meaning that if all field operations are not able to be completed, then that hectare will not even be planted.

Given the capabilities and limitations of this LP model, four basic assumptions of on-farm trials guided this study. On-farm trials: (1) were implemented at time periods with the highest potential corn production, (2) were harvested in the time period with highest potential

Table 1: Good field days required to calibrate yield monitor

Number calibration sessions	Hours required for each yield monitor calibration						
	0	1	2	3	4	5	6
1	0.0	0.1	0.2	0.4	0.5	0.6	0.7
2	0.0	0.2	0.5	0.7	0.9	1.2	1.4
3	0.0	0.4	0.7	1.1	1.4	1.8	2.1
4	0.0	0.5	0.9	1.4	1.9	2.4	2.8
5	0.0	0.6	1.2	1.8	2.4	2.9	3.5
6	0.0	0.7	1.4	2.1	2.8	3.5	4.2
7	0.0	0.8	1.6	2.5	3.3	4.1	4.9
8	0.0	0.9	1.9	2.8	3.8	4.7	5.6
9	0.0	1.1	2.1	3.2	4.2	5.3	6.4
10	0.0	1.2	2.4	3.5	4.7	5.9	7.1

Note: assumes harvest can occur 8.5 hours per good field day.

corn production, (3) were implemented and harvested on a good field day and (4) diverted 100% of resources away from crop farming operations while being implemented and/or harvested. This diversion of labour and machinery resources was effectively modelled by reducing the number of days suitable for fieldwork and may be more relevant to farmers inexperienced with conducting planned on-farm trials rather than experienced farmers who may conduct experiments more efficiently.

Although yield monitors have reduced the time required to harvest on-farm trials, delays relative to production practices result due to yield monitor calibration, weighing loads, or other practices. Proper calibration of a yield monitor has been estimated to take at least two hours if a weigh scale is available in the field. It is expected that Midwestern corn and soybean farms utilizing yield monitor information would calibrate once for soybean and once each for wet and dry corn, additional calibrations may be important if the farm is conducting on-farm trials. Table 1 presents the days required for calibration under differing scenarios. There are several realistic examples where the farmer would calibrate four or more times per season. If planned comparisons include hybrids, then an additional calibration may occur for each treatment.[7] If the yield monitor was calibrated four times, taking 2 hours per calibration, then the number of good field days for harvest would be reduced by 0.9 days, thus influencing harvest timeliness.

The number of yield monitor calibration events for a given on-farm trial determines the number of days suitable that will need to be offset at the end of the season. At the very least, an evaluation of Table 1, may inform decision makers on the time cost of conducting on-farm experiments. Furthermore, making agricultural equipment manufacturers aware of this time cost could help to drive improvements in the current calibration methods to reduce the required time commitment.

Representative Farm Scenario

A base farm that was considered timely with respect to planting and harvesting was chosen for this study. Tillage operations on the 1,214 ha conventional tillage farm included a 12.8 m field cultivator covering 11.1 ha hr^{-1} after harvest of both corn or soybean and a 5.5 m chisel plough following corn harvest covering 4.4 ha hr^{-1}. Corn was planted to 0.76 m rows with a 24-row planter at 8.6 m hr^{-1} and soybeans planted to 0.38 m rows with a 31-row split-row planter at 8.5 ha hr^{-1}. It was expected that planting takes 11.8 suitable field days. Corn was harvested with a 12-row header at 3.6 ha per hour and soybean is harvested with a 9.1 m platform at 4.98 ha hr^{-1}. Corn and soybean can be harvested 10 and 7 hours per day, respectively. Total harvest time takes 28.4 suitable field days. Both corn and soybean acreage received post-emerge herbicide applications with a 27 m self-propelled sprayer.

Representative long-run prices were chosen so that LP model results were useful for long-term planning. Eleven-year average long-run corn and soybean planning prices were \$98.43 Mg^{-1} and \$229.65 Mg^{-1}, respectively, for 1999 to 2009[8]. Corn and soybean base yields were expected to be 1.73 Mg per ha and 0.53 Mg per ha, respectively, when planted and harvested in the optimal time periods. Per ha variable costs were \$452 and \$262 for corn and soybean, respectively.

The base yields for corn and soybean were the best yields in a typical year when planted and harvested in the respective time periods with highest production potential. In other words, yields are not expected to be higher than the base yields in a typical year; however, lower yields are expected when planting and/or harvesting operations were conducted during time periods before or after the time period with the highest yield potential. For instance, the week of April 26 to May 2 has the highest corn yield potential with the next week of May 3 to 9 considered having the next best corn yield potential (Table 2). The time period September 27 to October 10 has the highest corn yield potential when planting occurs in the April 26 to May 2 time period (Table 2). It was assumed that if the farm manager implements an on-farm trial with anticipation of gathering data useful for farm management decision making, then the experiment would be implemented and harvested during the time periods with highest yield potential for the respective crop. The planting time period with the greatest yield potential for soybean was

[7] It should be noted that cultivar trials are not recommended as on-farm experiments where the yield monitor is used to distinguish yield differences. Each calibration may alter the ability of the yield monitor to adequately determine relative yield measurements.

[8] \$US. In mid-September 2014 \$US1 was approximately equivalent to £0.62 and €0.78 (www.xe.com)

Table 2: Corn yield potential by plant and harvest time period as a percentage of the very best yield

Planting Periods	Harvest Periods				
	September 20 to 26	September 27 to October 10	October 11 to 31	November 1 to 14	November 15 to December 5
	Yield Adjustment (%)				
Apr 22–25	90	96	94	90	85
Apr 26–May 2	0	100	98	94	89
May 3–9	0	95	98	94	89
May 10–16	0	92	94	90	85
May 17–23	0	0	84	84	79
May 24–30	0	0	74	74	69
May 31–June 6	0	0	0	0	56

two weeks later than corn, May 10 to 16, while the harvest time period for highest soybean yield potential was the same as corn (Table 3).

Planting and harvest period yield penalties expected for corn (Table 2) and soybean (Table 3) were estimated for the Midwestern corn and soybean farms. Other regions and crops may have increased or decreased penalties. This could substantially alter analysis results for other crops and locations.

Other LP model parameters were assigned based upon prior information of farmer behaviour. There were two full time labourers and four hired hourly labourers available for \$10 hr^{-1} who could work 5, 6 or 6.5 days wk^{-1} depending on the time period. In general, tractors and implements could be used 12 hours day^{-1}. Acreage was constrained such that corn and soybean were grown in a one-to-one rotation.

Whole-farm Analysis

To simulate the effect of conducting an on-farm trial, the days suitable for fieldwork were modified in each model run. Days suitable are the days that fieldwork can be conducted when it is not raining, the soil is not too wet, and the crop is able to be harvested (Williams and Llewelyn 2013; Griffin, 2009c). The number of days suitable for fieldwork is reduced as resources are diverted away from other field operations during implementation and harvesting, according to assumption four of the model. Each LP run changed information relative to time required to implement and/or harvest an on-farm trial by modifying the days suitable for fieldwork.

Three scenarios representing different time requirements to implement on-farm trials were used: 1) no additional time, 2) one-half day, and 3) one full day. Therefore, the days suitable for fieldwork were adjusted for the planting (April 26 to May 2) time period by removing 0, 0.5, and 1.0 from the current 2.4 suitable field days, respectively. The 2.4 suitable field days for April 26 to May 2 time period were determined to be the days suitable for fieldwork in the 75th to 85th percentile worst year.

The planting days suitable for fieldwork were held constant at 2.4, while the harvest time period was modified by removing 0, 0.5, and 1.0 days from the current 8.2 suitable field days for September 27 to October 10 for the 55th to 65th worst years. In additional scenarios, days suitable for fieldwork during the planting period and harvesting period were changed together; omitting 0, 0.5, and 1.0 days from the available days suitable for fieldwork. This resulted in nine additional scenarios as shown in Table 4.

3. Results

LP results indicated a reduction in contribution margin compared to the base situation of no on-farm trials; where contribution margin is defined as returns to land, unpaid labour, and management. This reduction occurs because of yield penalties incurred from diverting planting and harvesting time away from production.

Table 3: Soybean yield potential by plant and harvest time period as a percentage of the very best yield

Planting Periods	Harvest Periods				
	September 20 to 26	September 27 to October 10	October 11 to 31	November 1 to 14	Nov 15 to December 5
	Yield Adjustment (%)				
Apr 26–May	92	98	96	93.5	89
May 3–9	92.1	98.1	96.1	93.6	89.1
May 10–16	0	100	98.1	96.1	91.1
May 17–23	0	99.9	98	96	91
May 24–30	0	0	94	92.5	89
May 31–June 6	0	0	90	88.5	85
June 7–13	0	0	85	83.5	80

Table 4: Costs from planting and harvesting on-farm trials

Reduction in days suitable April 27–May 2	Reduction in days suitable October 11–31		
	0	0.5	1.0
0	$0	$859	$1,818
0.5	$2,684	$3,543	$4,501
1.0	$5,448	$6,307	$7,266

In the scenario where the planting operation was delayed for one-half day, a $2,684 reduction in contribution margin resulted (Table 4). Contribution margin is decreased by $5,448 when a full day's resource is devoted to the on-farm trial and away from planting.

Like planting operations, yield penalties were associated with harvest operation delays. Although one motivation for farmers to conduct on-farm trials with precision agriculture technology is that yield monitors have reduced the time requirements at harvest, some delay of harvest may still be necessary to carry out proper on-farm testing. In scenarios where the yield monitor may need to be calibrated for differing hybrids, moisture, or even if weigh wagons or spot checks were used instead of yield monitors, harvest operations may be delayed. When harvest operations were delayed by 0.5 and 1.0 days during the September 27 to October 10 time period, contribution margins decreased by $859 and $1,818, respectively, considerably less than if the planting operation were delayed by the same time.

The before-mentioned results of harvest operation yield penalties assumed no delayed planting. Although planting time delays without harvest time delays may be possible with yield monitors, the converse is not likely if on-farm trials were implemented at planting. A sensitivity of both planter and harvest time delays are presented in Table 4. When days suitable for fieldwork during both the planting and harvesting time periods were both reduced by 0.5 days, a reduction in contribution margin of $3,543 resulted. When days suitable for planting were decreased by one full day while the harvesting period days suitable was reduced by 0.5 days a $6,307 reduction in contribution margin was calculated. When one full day was removed from both planting and harvesting time periods, a $7,266 reduction in contribution margin was calculated.

Since planting and harvest yield penalties are mutually exclusive in these scenarios, the impacts are independent and additive meaning that the same values are added moving columns from left to right or moving rows from top to bottom. Removing half a day from harvest regardless of the planting time penalties will cause an $859 reduction in revenue. Likewise, removing half a day from planting time will reduce revenue by $2,684 regardless of how many fieldwork days reduced during harvest time.

4. Discussion

Griffin (2006) reported several on-farm research results including corn hybrid trials. He reports that a 1.83 metric ton per ha statistical difference between two corn hybrids for an estimated $8.77 per ha difference between corn hybrids after product costs (Table 5). Assuming that half the 1,214 ha farm was in corn production, that the farmer chooses a single hybrid and that the hybrid would be available on the market for at least one year, then the estimated total whole-farm benefit of the on-farm experiment would be $5,323 [($8.77 * 1,214)/2=$5,323]. Assuming that one-half day were taken in the spring and fall to implement and harvest the corn hybrid comparison, yield penalty costs would have been $3,543 resulting in a net benefit of $1,780 per farm. However, if planting took a complete day, then the yield penalty costs would have been $6,307 (Table 4), $984 more than the expected benefit of the experiment. This simple example based on a real-world experiment demonstrates that understanding both the costs and the benefits of an on-farm experiment is important for farm management decision making. With this example, a recurring loss is expected from an annual on-farm hybrid test. However, positive returns are possible if downtimes were reduced or different set of experimental factors were tested.

5. Conclusions

Conducting on-farm trials is not a costless venture. Diverting one-half day of resources away from production

Table 5: Example of Potential Benefits

	Corn 1	Corn 2
Expected yield MT ha^{-1}	62.235	60.405
Gross returns \$ ha^{-1}	509.0	495.0
Product cost (\$ bag^{-1})	158.9	151.9
Produce applied (bags ha^{-1})	0.89	0.89
Total product cost (\$ ha^{-1})	141.35	135.13
GR minus product (\$ ha^{-1})	368.65	359.88
Difference	8.77	

Note: Adapted from Griffin (2006).

to plant on-farm trials cost nearly $2,700. Diverting one full day of planting time reduced crop revenue by nearly $5,500. However, at this point in time it is unknown what the long-term benefits to a farming operation might be by conducting on-farm trials versus relying upon university recommendations based on traditional small-plot experiments.

Additional losses are incurred when there are additional delays at harvest. While yield monitors may reduce the time required to collect on-farm trial data, delayed harvest operations lead to reduced yield potential and crop quality. However, when harvest operations were delayed, whole farm profitability decreased by over $800 when harvest resources were diverted for 0.5 days and nearly $3,900 when diverted for 2.0 days.

In scenarios where both the planting and harvesting time periods are affected by on-farm trials, even greater costs occur. If both operations require all farm resources to be diverted away from production for one full day, yield reductions associated with implementing and harvesting the on-farm trial cost over $7,000 in reduced contribution margin. These costs are solely due to yield penalties associated with farm equipment being diverted away from other farming operations, and do not include inputs, application costs, other direct costs, human capital, analysts, or other fees associated with on-farm testing.

Many studies and extension publications stress the importance of yield monitor calibration. Regardless of the number of times the yield monitor was calibrated, some delay of harvest occurs. Whether yield monitor calibration intervals are a function of on-farm trials or exist otherwise impacts the partial budgeting for on-farm trials. If an on-farm trial is to be harvested with a yield monitor, it is likely that the farm manager would properly calibrate the yield monitor to increase the probability of collecting data usable for farm management decision making. Without a formal use of yield monitor data, calibration would still be important but may have lesser value to the farm manager. Unlike some farm operations such as transportation of equipment, yield monitor calibration is assumed to always occur during a good field day because grain suitable for harvest is necessary.

Farmers considering on-farm trials for the first time should consider implementing trials during time periods other than planting such as midseason herbicide or fungicide applications to minimize yield penalties and downside risk. In addition to being implemented at planting time, cultivar trials may require additional calibrations and results have time limited usefulness due to the short duration that cultivars remain available on the market. In addition, turn-around time on proper analysis for cultivar trials may not be sufficient to obtain early-order discounts, especially for corn hybrids which may be due by the end of harvest. As experience of the farmer increases, they may opt to implement on-farm trials at planting. Other precision agriculture technology such as automated controllers, automated boom shutoffs, and automated row shutoffs reduce the costs and human error associated with implementing on-farm experiments. Overall, the costs of individual on-farm trials are highly dependent upon the efficiency and ability of the individual farmer to manage and plan for the required field operations.

Emerging technologies such as on-the-go applicators and telematics should be evaluated for their incremental value for on-farm experiments. Telematics allow automated wireless transfer of data between field equipment and cloud based computing. On-the-go applicators have ability to design and implement an experiment without human intervention. The value of broadband connectively in rural areas should be estimated to indicate to the industry and policy makers the foregone value of being able to effectively use agricultural telemetry.

About the authors

Dr Terry Griffin, of the University of Arkansas, earned his Bachelor's degree in Agronomy and Master's degree in Agricultural Economics from the University of Arkansas, and a PhD from Purdue University. His doctoral research developed methods to analyze site-specific yield monitor data from field-scale experiments using spatial statistical techniques. Terry has contributed to outreach efforts of the Land Grant System in Arkansas, Illinois and Indiana. Terry and Dana have three wonderful children.

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Dr Lowenberg-DeBoer has 25 years of worldwide experience in agricultural research, teaching, outreach and administration. He currently serves as Associate Dean and Director of International Programs in Agriculture (IPIA) at Purdue University, coordinating all international programs for the Purdue College of Agriculture. His research focuses on the economics of agricultural technology.

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