Using Profitability Map to Make Precision Farming Decisions: A Case Study in Mississippi

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Abstract.

Recent development in precision agriculture technologies have generated massive amount of geospatial data of farming, such as yield mapping, seeding rates, input applications, and so on. However, producers are still struggling to convert those precision data into farm management decisions to improve productivity and profitability of farming. Indeed, deriving accurate decisions at each site of the field requires complex and comprehensive modeling of crop yield responses to various inputs (fertilizer, water, seeds, etc.) that are very complicated and varying across growing conditions (soil, weather, slope, etc.). Even the most state-of-the-art crop growth simulation models still have difficulty to reach that accuracy level, and can easily generate large margin of errors in some parts of the field. While the accurate modeling of crop growth is still an ongoing research effort in plant and soil sciences, this study explores an alternative decision-making method from the economic perspective. The main idea is a simple profit mapping approach that constructs high resolution spatially explicit profit maps for the crop fields and stops planting the unprofitable areas within the fields. As a case study, 21 corn-soybeans fields' geospatial production data were collected from a farm in the Mississippi Delta from 2012 to 2016. Profitability maps are calculated at resolution of 10-meter grids by computing the crop sale revenue and direct costs of farming operation for each grid. Based on the assumed price scenario that is similar to the current market (corn $3.5/bushel, and soybean $10/bushel), about 4% of the total 88,023 grids are unprofitable over the period 2012 to 2016. The total amount of profit loss from those grids is $6,896 annually, which can be avoided by retiring those grids from production. When crop prices decline, the profit gain from retiring unprofitable grids will further increase. This study provides an illustration of a simple yet useful approach to convert digital farming data into decision making, and quantifies the profit improvement that can be achieved at whole farm level.

Keywords. *Profitability mapping, Precision Agriculture, spatially explicit budgeting, whole farm.*

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Introduction

The fast development of precision agriculture technologies has enabled producers to collect massive amount of precision farming data. However, producers are still struggling to extract values out of the data and turn data into farming decisions. With the help of yield mapping, producers can easily identify some low performing parts within a field. Their first reaction is normally finding out the reasons and improving those parts. That is also the major idea directing the usage of precision agriculture data. While in the ideal scenario that is true, however, in order to achieve that the producers need to know the exact crop yield response to various factors at that specific area. That response is also changing rapidly across different parts of the same field. The process based crop growth simulation models are a major tool to estimate the response relations. However, applying the simulation models in the subfield level is a very complex and challenging task. Many agronomists and agricultural engineers are working on the model building and parameterization. But so far no reliable models are ready to process the precision farming data at the fine spatial units.

While producers are waiting for researchers to develop applicable tools to use the precision farming data, is there any other second best solutions that still allow producers to achieve some improvement using their data? In recent years, the profitability mapping idea has gained growing attention. The idea is quite simple. Just turn the yield map into profit map, and make decisions based on profit. If some parts of the fields are consistently showing negative profit, then producer can simply retire those parts of the fields to reduce the loss. A growing number of media reports can be found in recent years about profitability mapping, and suggestions such as retiring the unprofitable parts of the fields have been raised. Profitability mapping software has also become more readily available and easier to use by many major farming software providers. However, there are still some basic questions that are yet to be answered: (1) How do the within-field unprofitable areas look like for a normal farm? (2) How much profit loss occurred in those unprofitable areas for a farm, and is it large enough to cause producers' attention? (3) What exact strategies can be used to retire the unprofitable land parts, and how much benefits can be achieved? Only a few academic studies have been conducted on profitability mapping, including Stull et al. (2001), Yang et al. (2002), Wild and Colvin (2002), and Massey et al (2008). But those existing studies mainly focus on describing the spatial variability in profit, sometimes just for one specific field. No alternative management practices have been given to the producers, and no quantification of the profitability gain has been estimated of those alternatives. With the lack of those type of study, even with the assistance yield mapping tools, producers can only make decision based on subjective opinion or very rough accounting calculation.

This study conducts a whole farm analysis of profitability mapping. In total we collected 21 fields from a Mississippi farm. We create profitability maps for each of the 21 fields over the period 2012 to 2016, and identify the unprofitable areas within the fields. We then quantitatively estimate the average annual loss caused by those unprofitable areas, and discuss approaches to turn the map into precision farming decisions that will eliminate those loss. It gives an overall sense to producers on how much economic benefit they can gain by exploring the profitability mapping tool.

Literature Review

There are several existing studies in profitability mapping of crop fields. Yang et al. (2002) calculate the profit map of ten fields in Texas in 1998, and shows the strong spatial variability in profit. Stull et al. (2001) simulate the 10-year profit maps using 5-year average prices and production costs collected from the producer in a single year. Wild and Colvin (2002) creates profit maps in an Iowa corn field. Massey et al (2008) create profit maps using 10 years of yield data for a 35.6 ha field in central Missouri. Those studies mainly focused on the process of creating profit maps and demonstrating the spatial variation in profit within field. But they did not proceed to give an estimate of the overall loss of unprofitable zones, and to examine the aggregate economic gain of using profitability mapping tool.

Many agriculture management software providers have developed profitability mapping tools. For example:

- AgSolver (https://apps.agsolver.com/)
- Granular (https://www.granular.ag/granular-profit-maps/)
- Trimble (http://www.farmworks.com/products/view)
- AgDNA (https://agdna.com/)
- Haley (http://www.haleyequipmentinc.com/new-precision-farming-page/data-management/farm-works-mapping/)
- Omnia Precision Agronomy (http://www.omniaprecision.co.uk/)

This list is far from complete. Also, more agriculture management software providers are joining this service. It can be expected that in the near future profitability mapping will become a standard feature for most major agriculture management software.

A growing number of farming news reports have mentioned the tool of profitability mapping. It is widely recognized that farmers can use agriculture software to collect information from their fields over several years. They can use profitability mapping to track areas which produce consistent economic gains or losses. Farmers can then make management decisions accordingly. But how to act "accordingly" and how much economic benefits can be achieved by doing so is still a research question yet to be answered.

Data and Method

This study looks at a whole farm operation in the Mississippi Delta region. We collected 21 fields that contain precision farming data from 2012 to 2016. A summary of the fields are shown in Table 1. The average size of fields is 103.6 acres, with the largest 336.7 acres and the smallest 21.6 acres. In total the land area is 2175 acres. All the fields are on a corn and soybeans rotation planting schedule. The farming data we collected include high resolution geo-referenced yield, seeding, fertilizing, and spraying data. The farm uses JohnDeere system. The original data are point data from the yield sensor, seeding sensor, and spraying sensor. We aggregate the original points into grids of 10 meter by 10 meter square cells. In total the sample contains 88,023 grid cells.

Profit for each grid cell is calculated as crop sale revenue subtracted by costs, as:

$$\pi_{it} = pY_{it} - C_{it}\,, \qquad (1)$$

where π_{it} is the profit of grid *i* at year *t*, Y_{it} is the crop yield of grid *i* at year *t*, *p* is the crop price, and C_{it} is the farming operation cost of grid *i* at year *t*. Cost here includes (1) seeding, (2) fertilizer, (3) herbicide and pesticide spraying, and (4) fuel and labor.

The way we calculate grid level profitability is different from prevailing approach in two aspects. First, the crop price we choose is not actual historical prices. Instead, we pick the current crop price, or any other predicted prices that are likely to happen. We keep the price constant and multiply with various years historical yields. We use constant price to eliminate profit variability caused by price variability. It is also easier to calculate profits of hypothetical price scenarios. Second, the costs here only include the direct operation costs, while the fixed costs are not included. The major parts of fixed farming costs include machine equipment ownership costs, land rents, loan interests, and overhead costs. From economic standpoint those costs are sink costs, and cannot be saved by any micro field level operations. Even if some parts of the field are not planted at all, the producers still need to pay rents and interests, and the machines will depreciate anyway. When producers changes the management practices in some parts of the field, only those direct costs such as seeding, fertilizer, spraying will be affected. Therefore, though it is legitimate to include fixed costs in calculating the accounting profit, when making micro level management decisions it is more appropriate to be based on direct costs only.

Table 1. List of crop fields

Field ID	Size (acres)	Average profit ($/acre)	Unprofitable area (%)	Profit gain ($)
1	150.8	273.8	0.3	19.7
2	149.9	64.6	20.9	2549.3
3	67.1	40.8	25.7	1136.9
4	78.8	265.5	0.1	7
5	24.8	161.5	1	7.5
6	35	179	0.8	6.4
7	25.8	177.7	2.7	24.3
8	179	206.6	0.5	26.3
9	45.3	218.4	0.1	0.2
10	336.7	206.8	3.8	1316.9
11	86.8	164.6	1.1	26.1
12	29.7	207.9	0.1	0.4
13	65.8	222.2	0.2	1.9
14	226.5	222.7	2.7	372.5
15	21.6	196.2	0.3	2.2
16	312.3	154.2	4.4	1380.9
17	76.4	249.4	0.4	13.2
18	85.6	224.3	0	0.1
19	67.3	237.4	0	1.2
20	27.7	153.6	0.4	3
21	82.3	233.4	0	0

The corn price used in this calculation is $3.5 per bushel, and the soybeans price is $10 per bushel. The prices are obtained from the recent period future market price information. Regarding the cost data, unfortunately there are substantial amounts of missing values in the original farming data records. As a compromise we also use the Mississippi State enterprise budgets (Mississippi State University) for the direct costs information of Mississippi Delta corn and soybeans. Corn direct costs are $550 per acre, and soybeans are $427 per acre.

After calculating each grid's profit for all years from 2012 to 2016, we then take the average across years and calculate the five-year average profit for each grid:

$$\pi_i = \frac{1}{5}\sum_{t=2012}^{2016} \pi_{it} \ . \qquad (2)$$

Due to the large risk in weather conditions over time, farming profitability of any single year is not solid enough to make any decisions. Producers require a long history and draw conclusions based on average profit. Though our five-year period is not a very long history, it has shown reasonable variability in weather conditions across years. In general, 2013 and 2014 are good years for most fields, while 2015 and 2016 are bad years. But that also varies by field. Some specific fields also had high yields in 2014 even though most fields performed poorly. That again points out the importance of making decisions based on multi-year average rather than any specific year.

Results

Profitability maps

The calculated five-year (2012 to 2016) average profitability maps for 21 fields of the sample farm are displayed in Figure 1. The maps are at the 10-meter grid level (due to the differing in field sizes the visual presences of the grids vary across fields). On average all the 21 fields included in this study are profitable during the 2012 to 2016 time period. The most profitable field gains an average profit of $273.8 per acre (field 1). The least profitable field gains a positive $40.8 per acre (field 3). This result may appear contradictory with most previous profitability mapping studies which normally find some fields are unprofitable as a whole. One of the major reason is that we only include direct costs in the calculation of profit, while fixed costs are not included. Therefore the profit amounts tend to be higher than the actual accounting profit. When further including the fixed costs of farming (such as equipment maintenance, depreciation, and overhead expenses), the low profitability fields will become unprofitable (results not shown here but are available upon request).

It is noteworthy to mention again that the profits calculated here are not the actual profits of the sample farm. We did not use the actual historical crop prices and farming costs in the calculation. Instead, we use the historical yield data and the current term (2018) prices and costs information. Therefore, the profits we obtained are predicted profits conditional on current price and cost scenarios. If different scenarios are chosen the profit calculation will be different. Based on the current crop prices and farming operation costs, the whole farm level average profitability of land is $193.8 per acre. The total annual profit of the farm is $421,592.6. Again, this profit only includes direct operation costs. When fixed costs are further included the number will be reduced. For instance, the per acre fixed cost for Mississippi corn and soybeans is around $100. Deducting this number and the final average profit reduces to around $100 per acre, and total profit shrinks to around $200,000. But fixed costs are long term investment, and changing management operations in micro field level cannot change fixed costs immediately. Therefore we only report the direct costs calculated profit and use that as base to compare different management decisions.

Extensive spatial variability can be observed in the profitability within field. Green and yellow colors represent profitable grids, while red and orange color represent unprofitable grids. Most fields have some unprofitable grids, regardless the average field profit. In general, the unprofitable grids are concentrated more in certain fields (2, 3, 10, 14, and 16). Other fields' unprofitable area is less than 1% of the field size. The percentage of unprofitable area for each field is listed in Table 1. For the whole farm, about 4% of field area returns negative profit. The histogram distribution of grid level profits for the farm's 88,023 grids are shown in Figure 2.

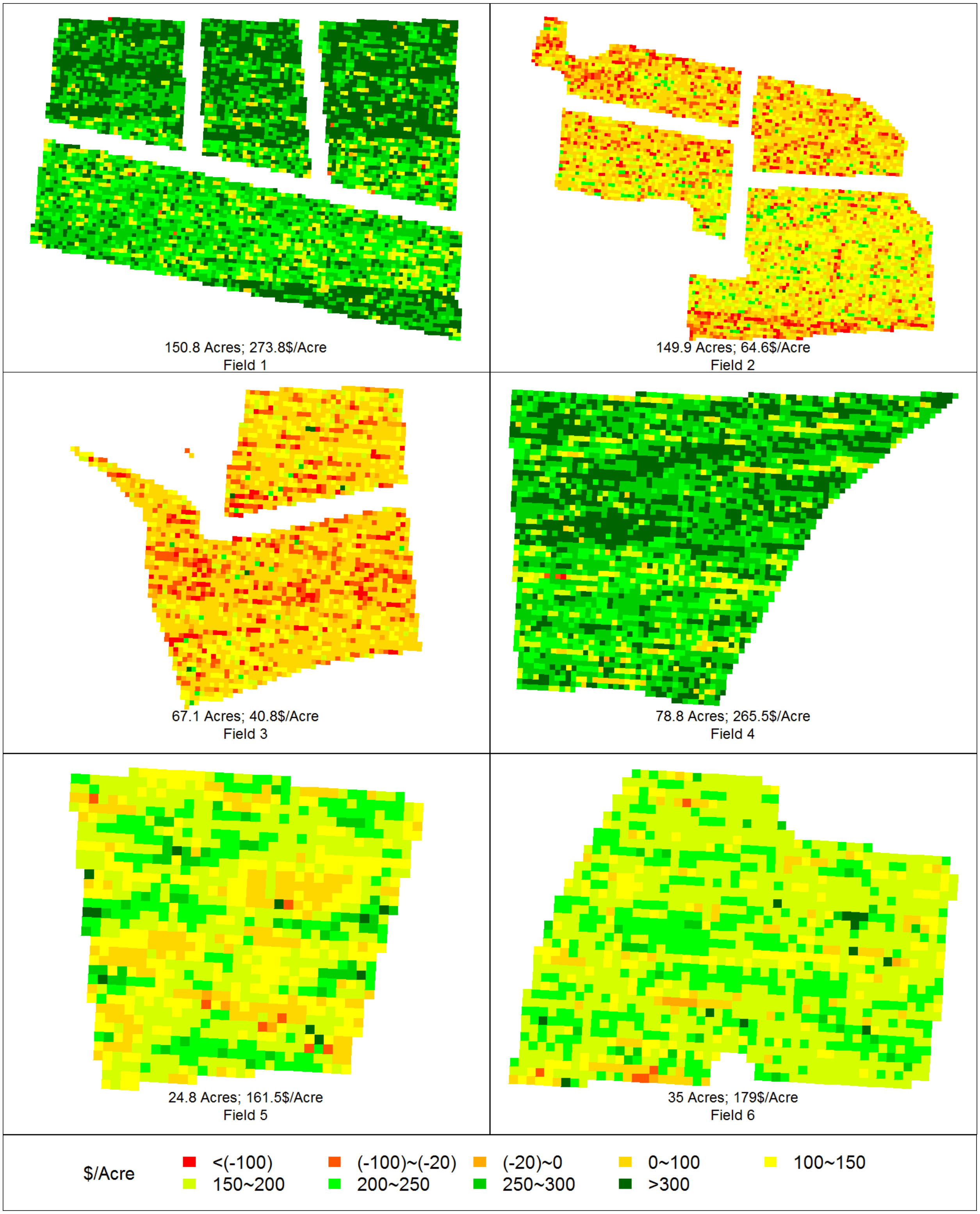

Figure 1. Profitability map of 21 fields in the sample farm (2012 to 2016 average, 10m grids)

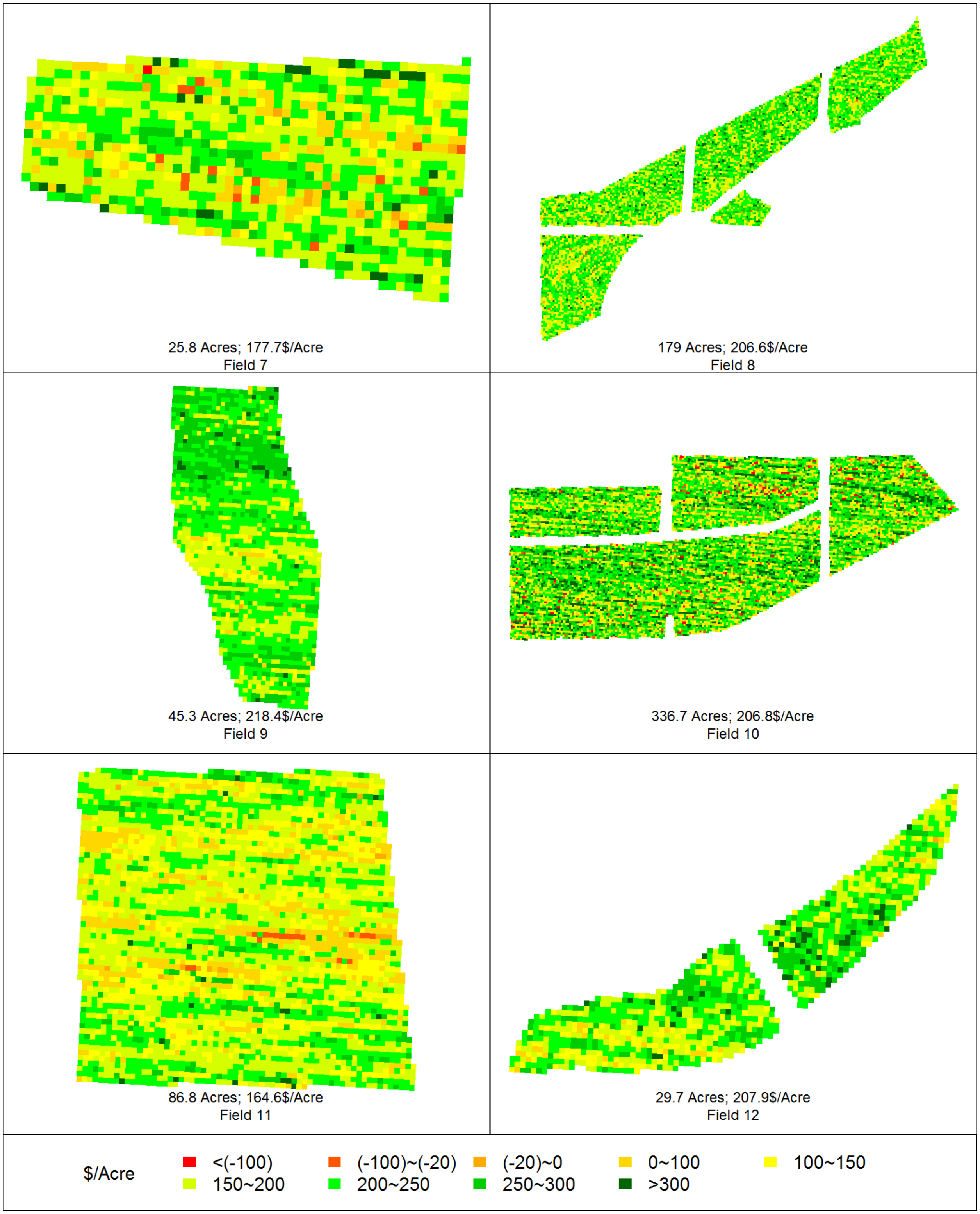

Figure 1 (cont'd). Profitability map of 21 fields in the sample farm (2012 to 2016 average, 10m grids)

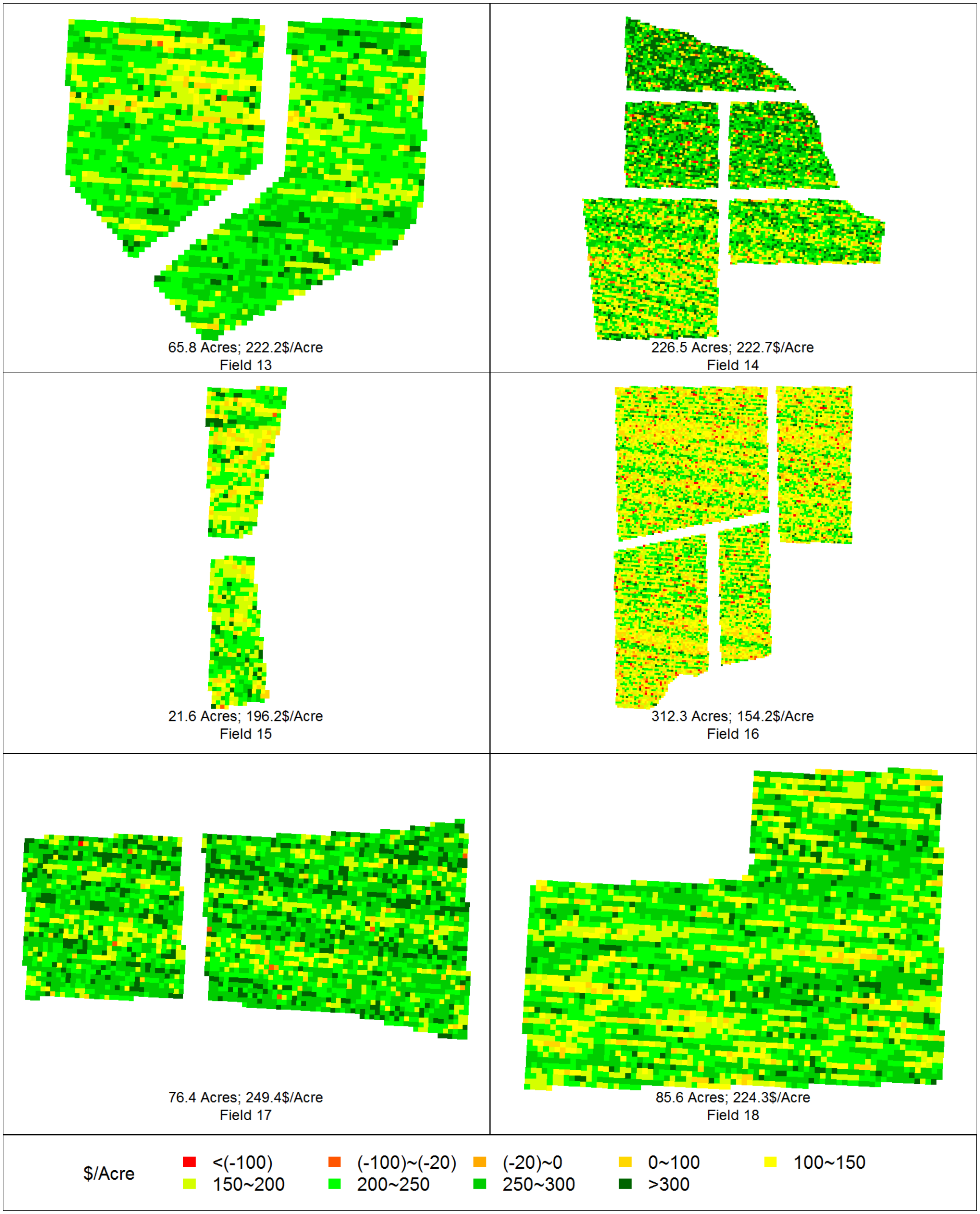

Figure 1 (cont'd). Profitability map of 21 fields in the sample farm (2012 to 2016 average, 10m grids)

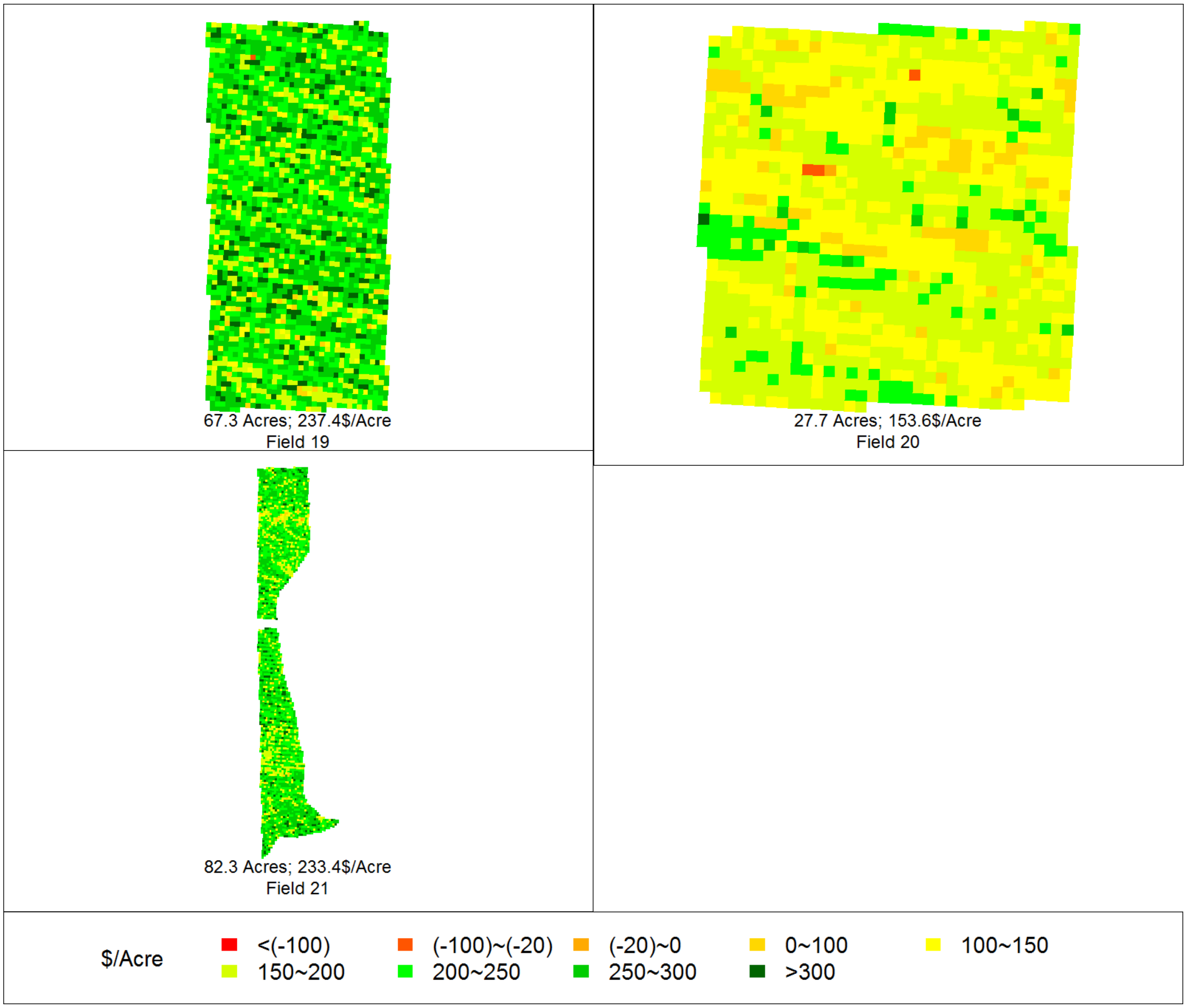

Figure 1 (cont'd). Profitability map of 21 fields in the sample farm (2012 to 2016 average, 10m grids)

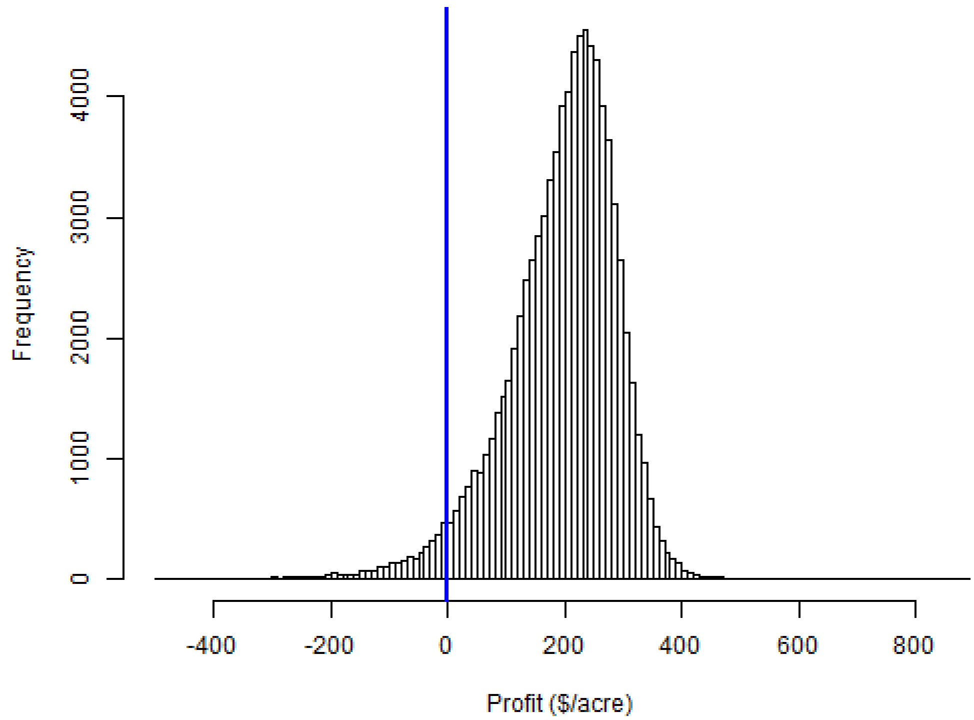

Figure 2. Distribution of grid-level profit. Grid size: 100 meter^2. Total number of grids: 88,023.

Decision-making: Retiring the unprofitable areas

A more relevant question to crop producers is how to utilize those profitability maps in improving farming management decisions. One simple method is to identify the unprofitable areas within the field and stop planting those areas. But it seems like very small portion of the farmland area is unprofitable from a five year average perspective. So the natural question a producer may ask is whether it is worthwhile to make any changes to that, and how large the potential improvement can be. Economically this is a very straightforward question to answer. We can simply calculate the total loss that are caused by those unprofitable areas. The average annual loss of those areas is $6,896 for all the 21 fields. That is 1.6% of the farm total profit ($421,592.6), and seems not very significant in size. But those loss can be easily avoided by not planting on those areas. The gains in profit is by retiring unprofitable areas are shown in Table 1 for each field.

Again, those numbers depend on the price scenarios we assume. When crop prices are higher and farming input costs are lower, the unprofitable areas will be reduced. Consequently, the strategy of retiring unprofitable areas will be less necessary. On the other hand, when crop prices are lower and farming input costs rise, which are more likely to be the current market trend, the unprofitable areas will increase. Retiring unprofitable areas will result in more benefit. For instance, if corn price falls by $0.1 per bushel from the current scenario ($3.5/bushel), the proportion of unprofitable areas will increase to 6.5%. Consequently, the total loss of those areas will increase to $14,973. If corn price falls by $0.5 per bushel, the unprofitable areas will be 41%, and the total loss will be $21,374. In those situations considering the strategy of retiring unprofitable areas will result in much greater benefit. Producers can conduct various scenario analysis based on the framework provided by this paper, and quantify the size of the unprofitable areas and total loss.

More discussions: How to retire the individual grids?

A difficulty in farming practice is how exactly to put those unprofitable grids within the field out of production. Unlike unprofitable stores in business, the unprofitable land portions are not single operational units. If the unprofitable areas are large continuous pieces of land, and are on the edge parts of the field, the operation will be simple. There will be several options the producers can choose: (1) completely abandon those parts of land and plant nothing on them; (2) plant cover crops (forages are common options); and (3) turn those areas into ponds for on-farm water storage system, especially if those areas have lower elevations in the field.

However, as shown in Figure 1, the unprofitable (as labeled in red and orange colors) 10-meter grids are distributed irregularly across the space. They scatter in all parts of the field in many small pieces rather than a few large continuous patches of land. That spatial pattern lays down a big challenge of how exactly to retire those unprofitable grids within the field in practice. Simply leaving some spots unplanted may not be a feasible idea. Even though the variable rate application devices are becoming more popular in agriculture, too many small patches requires frequent adjustment of applications or harvesting which is almost impossible in actual practice. Weed control is another major issue. The small blank spots between planted crops will cause the growth of weeds that damage the neighboring crop plants. In that case, we propose a strategy to deal with the issues of many small pieces of unprofitable areas. (1) Combine the adjacent or close small land pieces and create relatively large parts of land. The recommend size is around half to one acre. Some profitable pieces may be included if they are surrounded by unprofitable pieces. Some unprofitable pieces may also be omitted if they stand alone. This can be regarded as an approach to delineate management zones. (2) Plant a minimum amount of the same type crop in those zones. The seeding rates, fertilizers, and chemicals are kept as minimum level, or do not spay at all. The major purpose is to use those crops as cover crops to suppress the weed. Yield levels of those zones will be low, but since the inputs are also minimized, the final profit loss will be small if there not zero. It is even possible to gain a small amount of positive profit, too, depending on the yield response to various inputs. Due to the lacking of data, it is not sure how much crop yield can be achieved under the minimum planting. We plan to gather more information and work with agronomists to quantify the effects in our future study.

Conclusions

This study calculates the 10-meter resolution profitability maps for 21 corn/soybean fields in a Mississippi farm. Extensive variations of profitability across years are observed, and therefore it is not reliable to make decisions based on any single year's profitability map. Based on the assumed price scenario that is similar to the current market (corn $3.5/bushel, and soybean $10/bushel), the 5-year (over the period 2012 to 2016) average annual profit for the whole farm is $193.8 per acre. All 21 fields are profitable at the field level. Each field has some areas that are unprofitable, but the portion of those unprofitable areas is less than 1% for most fields. The unprofitable grids are mainly concentrated in a few fields. That result suggests that we should be cautious to reach any conclusions based on profitability map of a single field. The profit levels are generally higher than most existing profitability mapping studies, and it is mainly due to the different method of profit calculation used in this study. Our profit for each grid is calculated only using direct costs of farming while the fixed costs are not included. It follows the basic principle of economics that sink costs (fixed costs) should be excluded from economic decision making, and has more applicable implications for farming management.

At the whole farm level, about 4% of the total 88,023 grids are unprofitable over the period 2012 to 2016. The total amount of profit loss from those grids is $6,896, which accounts for 1.6% of total farm profit. When retiring those unprofitable grids from production, the farm can gain a profit increase of $6,896 annually. Note that this number is based on the assumed price and cost scenarios. When crop prices decrease or input costs increase, the amount of profitability gain will be higher.

This study illustrates how to utilize profitability mapping to make precision farming decisions, and quantifies the amount of profit improvement based on real world farm production data. But there are still several limitations in this study that need to be addressed in future research. First, the actual inputs data are seriously missing in the original digital data set. Therefore the profit calculation is based on published Mississippi planting budget data, which are the same for all fields. Further communication with the sample farm is required to acquire the input data information. Fortunately the sample farm in this study used uniform application, therefore only field level information is sufficient. Second, the average profitability only uses a 5-year simple average. That averaging method only uses a short period of time, and assumes each year's situation takes the same weight. In reality, whether to retire parts of the cropland (especially the permanent retiring) is a long term decision. Longer time period data should be included. If it is not feasible, an alternative solution can be using historical weather frequency weighted average to account for the long term variations in weather. Third, more price scenarios should be considered, and an interactive system can be developed to allow producers to enter the price and cost scenarios. Fourth, more analyses are required to compare different strategies to retire the unprofitable grids.

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