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# **The Value of Information in Precision Farming**

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This study examines how the value of information is measured and its role in precision farming. Two types of precision farming are discussed regarding information in use and ways of information collection. Analytical equations have been derived to link the estimation of the value of information to limited parameters available.

## The Value of Information in Precision Farming

Xuanli Liu, Mack Nelson, and Mohammed Ibrahim

Precision farming is a site-specific farming system. It is an inevitable result of escalating competition in the market of agricultural products and higher demand for less pollution from the government and the public. The competitive market makes production of higher efficiency a necessity for the survival of agricultural business, while the environmental requirements, especially the restriction on nitrogen pollution of underground water, also set a higher bar for operations in agriculture. In the foreseeable future, environmental constraints would be inevitably tighter. The day that farmers only took into account the private costs is gone. The farming system with less spillover could be a vital feature for farmers' success. Something is happening in agricultural production, and it possibly is the shift of production system towards precision farming.

Precision farming confronts farmers with both opportunity and challenge. Not doubt, Precision farming has many advantages over the conventional system. The system enables more efficient use of natural resources, and symbolizes the industrialization of agricultural production. By using contemporary technology, such as global positioning system, computer-linked yield and nutrient monitors, and variable rate chemical applicators, precision farming raises land productivity substantially and improves good land stewardship. Therefore, precision farming could be a very effective alternative to traditional agricultural production system. However, as it is always true, there is not free lunch here too. While precision farming will no doubt benefit farmers in many aspects, they are also challenged to have site-specific information about the land, have advanced knowledge and skills for managing large body of information and complex equipment

they may never be used before. In addition, collecting information is costly, and no matter how much a farm has spent on the information, it has no resale value in the market. Obviously, prior to a decision of adopting precision farming, farmers must count the value of information against costs.

Precision farming starts from information evaluation.

The objective of this study is to address the issue of information evaluation in precision farming and to provide analytical methods to measure the value of information. The paper reviews the general approach to value information, then applies the thought of information evaluation into two types of precision farming systems. The study represents an early effort to reach for an analytical solution to information evaluation under specific conditions in order to provide support in precision farming decision.

### **Theoretical Framework of Information Evaluation**

Making decisions in agricultural production, as in many other sectors, relies on relevant and available information. Two categories of information usually play a role. The first is prior information that was accumulated from farmers' experience in the past production process, based on which conventional farmers made their decision. To date, the information is still valuable though no longer a dominant element in decision. The more valuable information is related to the site-specific information, including pest patterns, nutrition level, and yields of each small unit in a large field. The information of this kind is out of the reach of experience, and gathering usually incurs substantial costs. A reasonable question raised is whether it is worth obtaining the information? How much is the information worth? This turns out to be a formidable task for farmers and researchers. Considering the ready availability of the costs involved in gathering information, the measurement of information value, or how much the application of information

could bring to farmer, is more difficult to handle. Many approaches have been addressed, and the frequently used ones are the Net Social Benefit Method discussed by Hayami and Peterson (1972), the Scoring Method, and the Statistical Decision Method by Lavalle (1968) and Marchark (1972). Among the three methods, the Statistical Decision Method showed itself the most productive one in the last two decades, and has been further developed by other scholars, such as Anderson (1977), Arrow (1970a,b), Hilo (1979), Kihlstrom (1974 a, b 1976), Gold (1974) and Winkler (1995). There is also limited discussion on applying information value into issues of agricultural economics.

Though a lot of debate continues, some common grounds have been there after years of pioneering work. It is well recognized that information value could be reasonably measured by the difference between expected payoffs of a decision maker after he receives information and expected payoff before he receives information. Specifically, four factors are involved in the measurement of information value:

- (a) Payoff function  $u(\cdot)$ , reflecting technology and environment as well as the decision maker's risk aversion attributes;
- (b) the prior probability  $h(s)$ , reflecting decision maker's uncertainty about technology and environment;
- (c) the nature of the information system, including likelihood which reflects connection between the state of nature and forecast signals, and probability density function  $f(z)$  of forecast signals; and
- (d) the decision maker's action set.

Depending on the risk attitude of decision makers, information value could be analytically expressed in the following three equations. For a typical decision maker of risk aversion, the value

$$(1) \quad EVI = [V/[ \int \int u(\pi(s, a^{*z})) - V)g(s/z)f(z)dsdz - \int u(\pi(s, a^{*o}))h(s)ds = 0]]$$

of information is measured by his willingness to pay as given in equation <sup>1</sup>:

In the case of perfect information, when the decision maker know what state of nature will happen with the support of the new obtained information, measuring information value could be simplified as:

$$(2) \quad EVI = \int \int \pi(s, a^{*z}) g(s/z) f(z) ds dz - \int \int \pi(s, a^{*o}) g(s/z) f(z) ds dz$$

If the decision maker is risk neutral, the information value would be as much simpler as expected difference between payoff functions:

$$(3) \quad EVI = \int \int \pi(s, a^{*z}) h(s) ds - \int \int \pi(s, a^{*o}) h(s) ds$$

The three cases above have a quite different level of complexity. The relaxation of risk aversion assumption makes the simplest case. To make analysis mathematically manageable, the last case will be used in the subsequent discussion. We hope that the analysis, though simpler than reality, would pave the way for more general studies of measuring the value of information.

## INFORMATION VALUE IN PRECISION FARMING

Recent studies showed that precision farming was featured with the use of site-specific information.

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1. EVI = expected value of information      EVPI = the expected value of perfect information  
 V = willingness to pay of decision maker      a<sub>j</sub> = the jth decision alternative

a<sup>\*o</sup> = the optimal action under prior probability       $\int \pi(s, a^{*o}) h(s) ds \geq \int \pi(s, a_j) h(s) ds$

a<sup>\*z</sup> = the optimal action under the posterior probability       $\int \pi(s, a^{*z}) h^z(s) ds \geq \int \pi(s, a_j) h^z(s) ds$

a<sup>\*p</sup> = the optimal action under perfect information that s happen

s = the state of nature      h(s) = The prior density function of state of nature s

h<sup>z</sup>(s) = The posterior density function of state of nature s

π(a,s) = the payoff function or profit function      u(.) = the utility function

z = the information signal      f(z) = the density function of information signal

p(z/s) = the likelihood of z given s      g(s/z) = the posterior probability of s given z

However, less discussion was documented on the role and impact of information in precision farming. This leads to our attempt to develop a few simple models to examine the decision process of precision farming through a way of information evaluation. We first distinguished two models of precision farming: the input oriented and the output oriented system. The former grows one crop variety in the field and use variable nutrient application rate according to the site-spot information. The second system grows varieties of crop and collects information from crop-based experimental design. The output-oriented precision farming costs less on collecting information, while input-oriented system may accompanied by high extra costs in information for its close relation with contemporary technologies. The two precision farming systems, although sharing some similarities, collected different information from different sources with different means. This leads to a different ways of measuring information value, and possible quite different magnitude of information value even for the same land and the same decision maker. The following section will deal with the measurements of information value for the two cases of precision farming systems.

### **Information value in input oriented precision farming**

Input oriented precision farming uses variable application rates to spread nutrients in a field. The precondition of adopting such system is awareness of information on the nutrient level at specific locations. Assuming random variable  $s$  represents the level of a needed nutrient, density function  $h(s)$  could be obtained based on the experience of farmers, and production function  $f(s)$  is available in literature. To obtain maximum profits, farmers need to keep an optimal nutrient level  $\theta^*$  at each location of the field, and the parameter  $\theta^*$  could be derived from  $p * f'(s) = w * s$  ( $p$  is the crop price and  $w$  is the cost of nutrient). In addition, farmers could buy monitoring machines to measure  $s$  in



the field. When farmers get the almost perfect information on nutrient level at each site-specific subfield, he could use variable application rate  $r$ , and make the nutrient level everywhere  $\theta^*$ . Doing this, the farmer gets profits:

$$(4) \quad \int \int \pi(r + s)h(s)dsdi = \int \int \pi(\theta^*)h(s)dsdi = \int \pi(\theta^*)di$$

Without the monitoring machine, the detailed information on specific nutrient level will not be available to the farmer. Then, the way of nutrient application is to use constant application rate, i.e.,  $r = k$ , where  $k$  is a constant. Under such condition, the profits of the decision maker are:

$$(5) \quad \int \int \pi(r + s)h(s)dsdi = \int \int \pi(k + s)h(s)dsdi$$

It would be reasonably true to believe that  $k + s \neq \theta^*$  on most of the site-specific spots. If that is true,

$$(6) \quad \begin{aligned} & \int \int (\pi(\theta^*) + \pi'(\theta^*)(k + s - \theta^*) + \frac{1}{2} * \pi''(\theta^*)(k + s - \theta^*)^2)h(s)dsdi \\ &= \int \int (\pi(\theta^*) + \frac{1}{2} * \pi''(\theta^*)(k^2 + s^2 - \theta^{*2} + 2ks - 2k\theta^* - 2s\theta^*))h(s)dsdi \\ &= \int (\pi(\theta^*) + \frac{1}{2} * \pi''(\theta^*)(k^2 + E(s^2) - \theta^{*2} + 2kE(s) - 2k\theta^* - 2\theta^*E(s)))di \\ &= \int (\pi(\theta^*) + \frac{1}{2} * \pi''(\theta^*)(k^2 + (E(s))^2 + E(s - E(s))^2 - \theta^{*2} + 2kE(s) - 2k\theta^* - 2\theta^*E(s)))di \\ &= \int (\pi(\theta^*) + \frac{1}{2} * \pi''(\theta^*)(k + E(s) - \theta^*)^2 + E(s - E(s))^2)di \\ &= \int (\pi(\theta^*) + \frac{1}{2} * \pi''(\theta^*)(k + E(s) - \theta^*)^2 + \sigma^2)di \end{aligned}$$

an approximation to equation (5) by the Taylor expansion links  $\pi(k + s)$  to  $\theta^*$ . and find payoff with no information as equation (6).

The difference between payoffs with and without information provides an estimate of information value as demonstrated in equation (7):

$$(7) \quad \int \pi(\theta^*) di - \int \left( \pi(\theta^*) + \frac{1}{2} \pi''(\theta^*) ((k + E(s) - \theta^*)^2 + \sigma^2) \right) di$$

$$= - \int \frac{1}{2} \pi''(\theta^*) ((k + E(s) - \theta^*)^2 + \sigma^2) di$$

Two major contributors are observed in the determination of information value in the analytical finding above: the difference between the optimal level of nutrients and actual levels of nutrients posterior to applying the nutrient with constant rate  $k$ , and the spatial variability in the level of the nutrient within the field. The first element, though quite complex for embedding both market influence and impact from productivity attributes of the crop planted, is relatively easy to estimate. In contrast, the other contributor of variability of nutrient to information value is costly and difficult to measure. The proper use of the three parameters would provide a strong first step support in precision decision-making. When the value of information is derived, a robust decision on adopting precision farming would be able to make if prices of the monitoring machine and other necessary equipments are also available.

### **Information value in output oriented precision farming**

Differing from input oriented precision farming that was adopted in recent years, output oriented precision farming has been used for a long time. In the system, farmers plant multiple crops in the field based on the spatial difference in a needed nutrient. The information required for arranging

crops in the field is to be gathered by way of experience and experimental designs. Farmers divide his land into an  $n \times n$  subfields and plant  $n$  varieties, and are able to have square-specific yield information  $y_{i,j,k}$  (the row  $i$ , column  $j$ , and variety  $k$ ). The farmer is supposed to make decisions on planting a specific variety at each subfield. Following the three steps, we could estimate the value of information in implementing output-oriented precision farming.

**(1) Estimating payoff in the case of no information**

If farmers have not information on the crop varieties and the sub-fields, he will randomly chooses a variety and plants it in all sub-fields. Thus, each variety will be selected with the same chance, i.e., probability  $P_k = 1/n$  ( $k=1, 2, \dots, n$ ). Doing this, the farmer will have an expected payoff from each sub-field as:

$$(8) \quad E\pi(y_{ij}) = \frac{1}{n} * \sum_{k=1}^n \pi(k, y_{ijk}) \quad k = 1, 2, \dots, n$$

Then, the expected payoff from all subfields is

$$(9) \quad TE\pi(y) = \left(\frac{1}{n}\right) * \sum_{i=1}^n \sum_{j=1}^n \sum_{k=1}^n \pi(k, y_{ijk})$$

**(2) Estimating payoff with information**

If the farmer has yield information of a variety on specific locations, he may arrange the farming in two ways.

(a). Choose a variety with the highest yields and plant it in all subfields. Then, the total payoff  $\pi(y)$  would be if the selected variety is  $k^*$ .

$$(10) \quad TE\pi(y) = \sum_{i=1}^n \sum_{j=1}^n \pi(k^*, y_{ijk^*}) = \text{Max} [ \sum_{i=1}^n \sum_{j=1}^n \pi(1, y_{ij1}), \sum_{i=1}^n \sum_{j=1}^n \pi(2, y_{ij2}), \dots, \sum_{i=1}^n \sum_{j=1}^n \pi(n, y_{ijn}) ]$$

(Here probability  $P_{k^*} = 1$ , meaning the full information about the variety  $k^*$ )

(b). Use the yield information in each sub-field and plant the best variety in each subfield. The Latin Square experimental design is assumed the default choice due to the large costs of information collection otherwise. Since the experimental design provides only a yield for one variety in each sub-field, we need to use a spatial model to predict yields of all varieties in a subfield.

$$(11) \quad \hat{y}_{i,j,k} = g(y_{1,k}, y_{2,k}, y_{3,k}, \dots, y_{n,k}, d_1, d_2, d_3, \dots, d_n)$$

Let assume that  $\hat{y}_{i,j,k}$  represents the yield of variety  $k$  in subfield of row  $i$  and column  $j$ ;  $y_{1,k}, y_{2,k}, y_{3,k}, \dots, y_{n,k}$  represent yields of variety  $k$  in row  $i$  (The column number was omitted because in each row there is only one-observed yield for a variety);  $d_1, d_2, d_3, \dots, d_n$  represent the distances from a subfield to other sub-fields that have observable yields for variety  $k$ . The farmer choose variety  $k^h$  in row  $i$  and column  $j$  will have a payoff as :

$$(12) \quad \pi(\hat{y}_{i,j,k}^h) = \max(\pi(\hat{y}_{i,j,1}^h), \pi(\hat{y}_{i,j,2}^h), \dots, \pi(\hat{y}_{i,j,n}^h))$$

The total payoff then is a sum of all site-specific payoffs which was maximized separately:

$$(13) \quad TE\pi(y) = \sum_{i=1}^n \sum_{j=1}^n \pi(k^h, y_{ijk^h})$$

### (3) Information value in output oriented precision farming

When the farmer has no perfect information as in (2) *Estimating payoff with information (a)*, the information value is the difference between expected yields with and without information, i.e.,

$$(14) \quad \begin{aligned} VPI &= \text{Equation}(10) - \text{Equation}(9) \\ &= \sum_{i=1}^n \sum_{j=1}^n \pi(y_{ijk^*}) - \left(\frac{1}{n}\right) * \sum_{i=1}^n \sum_{j=1}^n \sum_{k=1}^n \pi(y_{ijk}) \end{aligned}$$

When the farmer has full information, he will choose precision farming as (2) *Estimating payoff with information (b)*. Implementing such kind of precision farming, the needed information has an value estimated by equation (15)

$$(15) \quad VPI = \sum_{i=1}^n \sum_{j=1}^n \pi(k^h, y_{ijk^h}) - \left(\frac{1}{n}\right) * \sum_{i=1}^n \sum_{j=1}^n \sum_{k=1}^n \pi(y_{ijk})$$

## CONCLUSIONS

Evaluating information is a key step in making decision on whether to shift from conventional farming system towards precision farming system. Depending on the types of precision farming under consideration, approaches to estimate the value of information will differ. In the case of the input-oriented precision farming, the spatial variability in nutrients and conventional application rate are the two on-farm factors in the determination of information value. The larger variability in

nutrient, leads to the larger value of information, and similar impacts on information value also come from the difference between the conventional application rate and the optimal nutrient level. In the case of output oriented precision farming, two types of farming arrangements based on information available lead to the two estimates of information value.

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