AN ECONOMIC DECISION FRAMEWORK FOR PRECISION APPLICATION OF TWO INPUTS

Roland K. Roberts, Burton C. English, and James A. Larson
Department of Agricultural Economics
The University of Tennessee
2621 Morgan Circle
Knoxville, TN 37996-4518
rrobert3@utk.edu

ABSTRACT

Substantial literature exists evaluating the profitability of variable rate technology (VRT) relative to uniform rate technology (URT) for the application of a single input. This paper presents a decision-making framework for determining the relative profitability of VRT for multiple inputs and applies that framework to the application of nitrogen and water in cotton fields with three management zones. This decision-making framework can help farmers make decisions about VRT application of inputs in fields with different spatial characteristics.

INTRODUCTION

Farmers who practice precision farming use a set of technologies to gather information about the heterogeneous makeup of a farm field and use that information to assess site-specific crop needs within the field. Farmers can then make decisions about using variable rate technology (VRT) for input application. The relative profitability of VRT compared to uniform rate technology (URT) for a particular field depends on the crop, the inputs, their prices, the cost of identifying management zones and yield response functions, and the added cost of using VRT versus URT for each input. In this paper, management zones (zones hereafter) are defined as areas of the field (not necessarily contiguous) that have different yield responses to production inputs. Thus, the relative profitability of VRT versus URT depends on yield response variability and spatial variability within the field. Yield response variability refers to variability in the magnitudes of crop yield responses among zones, while spatial variability refers to the spatial distribution of zones across a field. Substantial literature exists evaluating the profitability of VRT for a single input. Little attention has been given to VRT application of multiple inputs where inputs exhibit interactions in yield response. Our objective is to present a decision-making framework for evaluating the profitability of using VRT to apply multiple inputs in fields with multiple zones.

MATERIALS AND METHODS

The general decision-making framework is presented first followed by an illustrative example of nitrogen and water applied to cotton fields with three zones. Assume optimal return above input cost per acre for VRT is $R^{*}_{VRT} = \sum \lambda_i [P_c Y_i^* (Z^*_{i1}, Z^*_{i2}, ..., Z^*_{in})]$, where λ_i is the proportion of the field in zone i ($\sum \lambda_i = 1$); P_c is the crop price; P_j is the price of input *j*; Z_{ij}^* is the optimal rate of input *j* in zone *i*, and $Y_i^* (Z_{i1}^*, Z_{i2}^*, ..., Z_{in}^*)$ is optimal crop yield in zone *i*. Further assume that optimal return above input cost using URT is $R^{*}_{URT} = P_c Y_U^* (Z^*_{U1}, Z^*_{U2}, ..., Z^*_{Un}) - \sum P_j Z^*_{Uj}$, where $Y_U = \sum \lambda_i Y_i (Z_{i1}, Z_{i2}, ..., Z_{in})$ is the weighted-average, whole-field yield response function; Z_{Uj} (j=1,…,n) are uniform input application rates; and an asterisks indicates economic optimality using Y_U as the yield response function. Note that Z_{ij}^* is found by simultaneously solving the *n* first-order conditions for profit maximization using the yield response function for zone i (i=1,…,m), and Z_{Uj}^* is found by simultaneously solving the n first-order conditions using the whole-field yield response function. Optimal return to VRT is $RVRT^* = R_{VRT}^* - R_{URT}^*$. VRT is more profitable than URT if $RVRT^* - C_1 - C_2 > 0$, where C_1 is the difference in application costs for VRT and URT and C_2 is the cost of gathering spatial information to identify zones and their yield response functions. If the zones and their response functions have already been identified, the profit-maximizing farmer will undertake VRT if $RVRT^* > C_1$, because C_2 is a sunk cost in making this decision.

Cotton fields with the following yield response functions in three zones are used as an example:

$$Y_1 = 233.72 + 0.44N_1 - 0.003N_1^2 + 23.65W_1 - 0.18W_1^2 + 0.02N_1W_1,$$

$$Y_2 = -1103.62 + 2.85N_2 - 0.004N_2^2 + 118.35W_2 - 1.63W_2^2 - 0.05N_2W_2,$$

$$Y_3 = -170.93 + 3.74N_3 - 0.01N_3^2 + 32.45W_3 - 0.02W_3^2 + 0.02N_3W_3,$$

where Y_i is cotton yield for zones 1, 2, and 3 (lb/acre); N_i is nitrogen rate for zones 1, 2, and 3 (lb/acre); W_i is irrigation water for zones 1, 2, and 3 (acre-inches); and N_iW_i is the interaction between N_i and W_i. In this example, C_2 is assumed to be known and C_1 is the difference between custom nitrogen application costs for VRT and URT plus the difference between the costs of VRT and URT irrigation. The prices of cotton lint, nitrogen, and water are assumed to be \$0.52/lb, \$0.26/lb, and \$4/acre-inch, respectively. Cost differences between VRT and URT are assumed to be \$3/acre and \$18/acre for nitrogen and water, respectively, giving C_1 = \$21/acre. $RVRT^*$ is evaluated for hypothetical cotton fields for all combinations of the $\lambda_i s$ varying between 0.0 and 0.9 in increments of 0.1.

RESULTS AND DISCUSSION

If a field has no area in zone 1, the proportion of the field in zone 2 must be between 2.2% and 86% and the proportion of the field in zone 3 must be between 97.8% (100% – 2.2%) and 14% (100% – 86%) for VRT to at least break even with URT application of the inputs. If a field has no area in zone 1 and 30% of its area in zone 2 (70% = 100% – 30% in zone 3), $RVRT^*$ is \$77/acre. Subtracting \$21/acre (C_1) from $RVRT^*$ gives a positive net return to VRT of \$56/acre, suggesting that the farmer would be \$56/acre better off using VRT than URT. As the percentage of a field in zone 1 becomes positive, the break-even proportions of the field in the other zones become narrower. For example, if the proportion of a field in zone 1 is 60%, the beak-even proportions in zone 2 are 3% and 37% and for zone 3 they are 37% (100% – 60% – 3%) and 3% (100% – 60% – 37%). Within these ranges of λ_2 and λ_3 (given λ_1 = 0.6), $RVRT^* - C_1$ is greater than or equal to zero and the farmer at least breaks even by using VRT instead of URT.

CONCLUSIONS

This paper suggests the potential for developing computerized decision aids to help farmers make choices about using precision farming technologies. One possible decision aid not mentioned above deals with the farmer's decision to gather spatial information about a field when the field's zones and yield response functions have not yet been estimated from spatial information, but educated guesses about them are available from the farmer's, or a consultant's, experience with the field. If C_2 is not known, the farmer can use conservative, educated guesses about the λ s, the corresponding yield response functions, and C_1 to estimate $RVRT^* - C_1$, which can be thought of as an education guess about the maximum amount the farmer can invest in gathering spatial information, identifying zones, and estimating yield response functions. If $RVRT^{*}–C_1 > C_2$, the farmer might decide to invest in gathering the spatial information to more accurately delineate the zones and estimate yield response functions. For example, if educated guesses suggest that $RVRT^{*}–C_1$ = \$56/acre as in one of the example in the previous section, the farmer would not invest in gathering spatial information to more accurately estimate $RVRT^{*}$ if the cost of doing so (C_2) is greater than \$56/acre. A risk averse farmer might require $RVRT^{*}–C_1$ to be substantially greater than C_2, because the estimate of $RVRT^{*}$ is uncertain.

The other case, illustrated by the example in this paper, deals with the VRT versus URT decision when the farmer has already delineated the zones and estimated their yield response functions after gathering the required spatial information. The results are still uncertain because spatial information, although better than guessing, is subject to error. Thus, a risk averse farmer might still require $RVRT^{*}–C_1$ to be somewhat greater than zero for a particular field before switching from URT to VRT. Results emphasize that definitive, general statements about the profitability of precision farming technologies are not possible because net benefits depend on the spatial characteristics of each field, and spatial information gathering technologies, methods of zone delineation, and yield response function estimation do not provide perfect information.