ECONOMICS OF FERTILIZATION UNDER SITE-SPECIFIC MANAGEMENT ZONES

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ABSTRACT

Site-specific management of crop fields using variable rate application of inputs to manage in-field variability has now been around for over 15 years. However, the degree to which site-specific management strategies increase farm profitability is not well established. The objectives of this study were: to compare uniform and variable-rate Nitrogen (N) management strategies across productivity level site-specific management zones and to identify the most profitable N management strategy. This study was conducted over three site-years on large scale irrigated corn production fields. Overall, net returns to the land and management ranged from \$76 to \$274 ac^{-1}. The variable yield goal (VYG) N management strategy had the highest net returns to the land and management in eight out of nine cases. The VYG strategy resulted in as much as \$51 ac^{-1} greater net returns to the land and management than that of the uniform strategy. Results of this study indicate that variable yield goal N management strategy utilizing productivity level site-specific management zones has the potential to increase overall farm profitability.

INTRODUCTION

Site-specific management recognizes the inherent spatial variability associated with most fields under crop production (Thrikawala et al., 1999). Nitrogen, a highly mobile nutrient in the soil system, is one of the most essential crop nutrients for optimizing grain yields. Traditional uniform N applications, in most cases, results in over- and under-application of N in various parts of the field due to in-field spatial variability (Frasier et al., 1999; Khosla et al., 1999; Thrikawala et al., 1999). Therefore uniform application of nitrogen (N) fertilizer across crop fields may not be the best N management strategy from an economic perspective. Studies have shown that variable-rate application (VRA) of N fertilizer increases N–use efficiency (NUE), grain yield, crop quality and economic returns (Prato and Kang, 1998; Thrikawala et al., 1999; Khosla et al., 2002; and Koch et al., 2004).

Intensive grid soil sampling was among the first methods used to map soil fertility levels and remains a commonly practiced means of generating VRA maps. However, grid soil sampling has been reported as expensive and time consuming and not cost-effective (Koch et al., 2004; Pilesjö et al., 2005). Additionally, the grid size used may be too large to characterize the spatial variability that exists in the field, resulting in inaccurate spatial maps. As an alternative to grid sampling, management zones have been investigated as a potential technique to describe spatial variability in fields. Doerge (1999) defined management zones as sub-regions of a field with homogeneous yield limiting factors. Using a management zone approach, a field can be separated into areas of similar productivity potential, and fertilizer can be applied variably in accordance with the productivity potential of each zone. There have been several different techniques of management zone delineation proposed in the literature. However, one commonality in all the techniques described is that they do not rely strictly on soil sampling and, therefore, have potential to be more economically feasible than the grid soil sample-based VRA.

Limited to no studies have been reported in the western Great Plains region demonstrating the economic feasibility of variable-rate N application utilizing productivity level site-specific management zones. An on-farm, enterprise-based field study was conducted in Colorado to assess the economic feasibility of variable-rate N application utilizing productivity level site-specific management zones. Specific objectives were to: (i) to compare net $ returns to the land and management achieved using variable rate N management strategies by (a) soil color-based productivity level management zones using (b) grid-soil sampling based and (c) uniform N management strategies, and objective (ii) to identify the most profitable N management strategy.

MATERIALS AND METHODS

This study was conducted over three site-years on two continuous corn (Zea Mays L.) irrigated cropping system fields in northeastern Colorado (Figure 1). Site-years I and II were located on an 18.5-ha (45.71-ac) furrow-irrigated field over two consecutive growing seasons. Site-year III was located on a 58-ha (143.3-ac) center-pivot sprinkler irrigated field. Site-years I and II were planted with Pioneer Hybrid "34H98" on a 50.8-cm (20") row spacing, while site-year III was planted with Pioneer "34K77" on a 76.2-cm (30") row spacing.

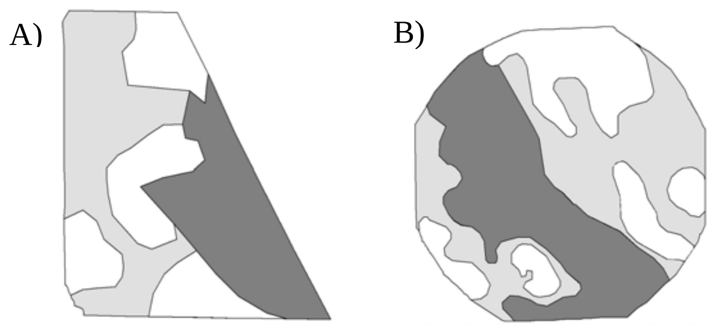

Figure 1. Maps of study sites and management zones for (A) site years I and II, and (B) site-year III. Management zones are: high = dark gray, medium = light gray, and low = white.

Prior to planting soil color-based management zones (SCMZs) were delineated in each field. Details of the SCMZ delineation technique are provided in Fleming et al. (2004), Khosla et al. (2002), Koch et al. (2004), and Inman et al. (2005). Nitrogen application rates for each N management strategy were calculated using an N recommendation algorithm for irrigated corn (Mortvedt et al., 1996) (Eq. 1)

N rate = 35 + (1.2 X EY) – (8 X soil NO_3-N ppm) – (0.14 X EY X OM) – other N credits
Where: EY = expected corn grain yield, OM = organic matter [Eq.1]

Four N management strategies evaluated in this study were:

1. Uniform N application with a constant yield goal.

2. Variable N application based on grid soil sampling with a constant yield goal. Soil samples were collected using a 0.4-ha (1-ac) grid and analyzed for soil NO_3 and organic matter (OM). The variable-rate N was determined, for each grid cell (i.e., 0.4-ha area) using Eq. [1], as driven by the residual soil NO_3 and OM content obtained at each grid soil-sampling location.
3. Variable N application based on SCMZ using a constant yield goal (CYG). Soil NO_3 and OM levels were determined for each management zone by averaging soil NO_3 and OM values at all grid points that fell within a management zone. Eq.[1] was used to determine N-rate using a constant yield goal across the management zones.
4. Variable N application based on SCMZ using a variable yield goal (VYG). Soil N rates were determined similar to Strategy no. 3 above, except that a different yield goal was assigned for each management zone.

A constant yield goal of 12.54 Mg ha^{-1} (200 bu ac^{-1}) was used for the uniform, grid-based, and CYG N management strategies. For the VYG N management strategy, expected yields were 13.80, 11.91, and 10.03 Mg ha^{-1} (220, 190, 160 ac^{-1}) in the high, medium, and low productive level management zone, respectively, over all three site-years. Yield goals were determined through consultation with cooperating farmers (Koch et al., 2004).

A randomized strip-plot design was used with experimental strips that spanned the entire length of the field and traversed each of the three SCMZ. Each N management strategy was replicated four times for site-years I and II, site-year III had only one experimental strip for each N management strategy. Urea ammonium nitrate (UAN 32–0–0), was applied using a cultivator at the V6 crop growth stage. Grain yield was recorded using a Green Star™ (Deere and Co., Moline, IL) instantaneous yield-monitoring system. Analysis of variance (ANOVA) was performed on weighted grain yields observed for the four N management strategies to test the significance difference ($P<0.05$).

ECONOMIC ANALYSIS

To compare the profitability of each N management strategy, the proportions of management zones were standardized to the proportion of management zones across the entire field (Koch et al., 2004). Enterprise budgets were created with Profit and Loss Enterprise Budget software (v.1.2) (Hoag and Vandenberg, 2003). Enterprise budgets were created for all site-years and N management strategies. Gross revenue was calculated based on \$3.5 bu^{-1} corn grain and \$0.55 lb^{-1} nitrogen. Net returns to the land and management were calculated as the difference between total operating costs (including ownership costs) and gross revenue. Weighted mean net returns were a function of management zone proportion across the entire field. In addition to calculating net returns for each experimental strip and management zone, net returns were calculated for each yield monitor pixel.

RESULTS AND DISCUSSION

Weighted net returns to the land and management across management zones for all N management strategies and site-years are presented in Table 1. All N management strategies evaluated in this study were profitable at the current corn grain price of \$3.5 bu^{-1}. The profitability of each N management strategy, however, depends greatly on prices paid for grain and the price of N fertilizer, both of which can fluctuate widely. Net returns to the land and management ranged ranged from \$76 to \$282 ac^{-1}. Across all N management strategies, the VYG strategy resulted in the highest net return to the land and management in two out of three site-years (Table 1). For site-year III, there was only $4/ac difference between VYG and CYG, so VYG performed equal to or better at all three site years. The profitability of the VYG strategy can be attributed, in part, to optimizing the N fertilizer input for each zone. Koch et al. (2004) found that the low zone, managed using the VYG strategy, cost as much as 16% less than other N management strategies. Applying optimum amounts of N fertilizer to the low zone, as in the VYG strategy, significantly reduces one of the primary factors that drive net returns to the land and management. Koch et al. (2004) conducted a sensitivity analysis of various N management strategies and found that the VYG N management strategy was consistently more profitable across a wide range of corn grain and N fertilizer prices than uniform, grid, and CYG N management strategies.

Table 1. Weighted net returns per acre to the land and management for each N management strategy across site years.

	N Management Strategy			
	Uniform	CYG†	VYG‡	Grid§
Site Year	----------------------- $ ac^{-1}	-----------------------		
I	165	160	183	76
II	255	234	282	263
III	234	250	247	122

† CYG = Constant yield goal variable-rate N management strategy
‡ VYG = Variable yield goal variable-rate N management strategy
§ The Grid strategy used a 0.4-ha soil sampling grid to determine N rate irrespective of management zones.

Net returns to the land and management across N management strategies, management zones and site-years are presented in Table 2. Net returns ranged from \$119 to \$280 ac^{-1} across management zones, N management strategies and site-years. In general, the low zone was the least profitable, with net returns between \$119 and \$265 ac^{-1}. The low zone has been shown in other studies to have soil properties that adversely affect crop productivity potential (Inman et al., 2004; Mzuku et al., 2005, Hornung et al., 2006). In contrast, the high zone was the most profitable in six out of nine comparisons, with net returns ranging from \$136 to 320 ac^{-1}. Comparing N management strategies, the grid strategy was the least profitable in two out of three site-years (Table 2) because of the additional costs associated with intensive grid soil sampling (i.e., labor and analysis costs) (Koch et al., 2004). It should be noted, however, that in this study the grid strategy utilized a constant yield goal for all grid cells. Snyder et al. (1999) found that grid-based N application, using a differential yield goal (i.e., a different yield goal for each grid cell) could reduce total N applied without reducing grain yield. Perhaps studies that incorporate a variable yield goal for each grid cell as a part of grid-based N management study may increase the overall profitability of using a grid soil sampling-based N management strategy. Comparing the uniform N management strategy to the CYG strategy, the CYG strategy was less profitable in five out of nine comparisons (Table 2). These results were not surprising because the CYG strategy resulted in more N being applied to the low zone. Grain yields realized in the low zone under the CYG strategy were not significantly higher than yields realized under the uniform N management strategy.

Table 2. Net returns per hectare to the land and management for each N management strategy across management zones and site years.

		Management Zone		
		High	Medium	Low
Site Year	N Strategy	------------------- \$ ac^{-1} -------------------		
	Uniform	136	225	133
I	CYG[†]	196	170	119
	VYG[‡]	195	189	167
	Grid[§]		----------------------- 123 -----------------------	
	Uniform	266	259	231
II	CYG	258	232	210
	VYG	320	252	265
	Grid		----------------------- 227 -----------------------	
	Uniform	239	244	210
III	CYG	250	258	239
	VYG	280	238	218
	Grid		----------------------- 123 -----------------------	

[†] CYG = Constant yield goal variable-rate N management strategy
[‡] VYG = Variable yield goal variable-rate N management strategy
[§] The Grid strategy used a 0.4-ha (1-ac) soil sampling grid to determine N rate irrespective of management zones.

CONCLUSION

The net returns from four N management strategies were compared across irrigated corn production fields and soil color-based management zones over three site-years. Variable rate N management strategies that were based on SCMZs were most profitable across all site years, with the VYG strategy being most profitable in two out of three site years. Net returns across management zones followed the productivity potential of the zones. Generally, higher returns were realized in the high production potential management zones with lower returns in the low zone. This study clearly demonstrates that variable-rate N management is more profitable than uniform N management. Of the variable-rate N management strategies, the VYG N management strategy was consistently more profitable than both the grid and CYG. The variable yield goal N management strategy has the potential to increase overall farm profitability.

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