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A microeconomic perspective on the value of OFPE data in management zone delineation

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Abstract

Precision agriculture researchers began investigating "management zone" (MZ) delineation as variable-rate technology emerged in commercial markets in the 1990s. A large part of that research has focused pm questions about what clustering or delineation methods should be used on past yield data and spatial field and soil characteristics data to delineate MZs. The literature's MZ delineation methods have grown in complexity over the years, but several widespread flaws in this literature persist. Using microeconomic theory to define MZs, we show that creating MZs for a generic input is suboptimal as the input type, management decisions, and zones are fundamentally connected. Specifically, a profitable MZ delineation requires a selected managed input and sufficient knowledge about site-specific yield response functions, and in particular marginal yield response to input application rates, which can only be estimated with data from on-farm precision experiments (OFPEs). Thus, OFPE is vital for the proper establishment of MZs.

Keywords

management zones, on-farm precision experimentation.

Presenter Profile

David S. Bullock is a Professor in the Department of Agricultural and Consumer Economics at the University of Illinois. He studies the economics of agricultural technology and information and has published research on precision agriculture technology since 1998. He is the Principal Investigator of the eight-year USDA-sponsored Data-Intensive Farm Management project, which uses precision agriculture technology to conduct large-scale, on farm agronomic experiments which generate data to aid farmers' management of nitrogen fertilizer and other inputs. He teaches graduate courses in microeconomic theory. He received his Ph.D. from the Department of Economics at the University of Chicago in 1989.

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Introduction

Precision agriculture researchers began investigating "management zone" (MZ) delineation as variable-rate technology emerged in commercial markets in the 1990s. A large part of that research has focused on questions about what clustering or delineation methods should be used on past yield data and spatial field and soil characteristics data to delineate MZs. The literature's MZ delineation methods have grown in complexity over the years, but several widespread flaws in this literature persist. Using microeconomic theory to define MZs, we show that creating MZs for a generic input is suboptimal as the input type, management decisions, and zones are fundamentally connected. Specifically, a profitable MZ delineation requires a selected managed input and sufficient knowledge about site-specific yield response functions, and in particular marginal yield response to input application rates, which can only be estimated with data from on-farm precision experiments (OFPEs). Thus, OFPE is vital for the proper establishment of MZs. We maintain that the methods used to delineate MZs over the past generation are a product of the data-*extensive* methods of input management guidelines that were developed in an era of expensive data generation. But increased employment of OFPE methods are creating a world of inexpensive field trial data generation. The obvious implication is that management zones can now be determined empirically, using copious data analysed in the context of meaningful, rigorous microeconomic theory.

Brief Literature Review

There are several limitations and gaps in the existing management zone literature. First, it is exceedingly common for studies to declare *determination of management zones without specifying how the zones should be managed*. They make no attempt to estimate economically optimal input rates for each zone or evaluate the profitability of the rates compared to the optimal uniform input rate for a field. Rather, they tend to claim validity of their management zone determinations on the variations of soil and field characteristics or yield within and across zones (Cillis et al. 2018; Colaco and Bramley 2018; Kayad et al. 2021; Velasco 2020).

Yield-based MZ research has typically taken three steps in MZ determination: identifying variables associated with yield, choosing the number of zones, and then using cluster analysis to define those zones. Several methods are available for each step of this process. Principal component analysis is commonly used to choose the relevant variables (Gustaferro et al. 2010; King 2005; Peralta et al. 2014; Tagarkis et al. 2013; Yan et al. 2007). Other studies have used normalized classification entropy to determine the optimal number of management zones through balancing the variation within a zone and the variation across zones, but alternative methods have been proposed by Zhang et al. (2010) and Vendrusculo and Kaleita (2011). Similarly, fuzzy c-means and k-means clustering are common methods to delineate management zones with the chosen numbers of zones and characteristics variables, but Velandia et al. (2008) proposed a new method to account for spatial correlation. By using Moran's I scatter plots, these zones account for the spatial structure of the field or soil characteristics.

A Microeconomics-based Definition of Management Zones

Consider a field partitioned into some number of sites, where a site is defined as a piece of the field on which vector of *characteristic* variables **c** = (c_1, …, c_M) takes on some value. For example, on some site *A*, the levels of those characteristics variables may be represented by the vector value $\mathbf{c}^A = (c_1^A, \dots, c_L^A)$, where, c_1^A = 23% may be soil clay content, c_2^A = 3.7 may be terrain slope in degrees, etc. Similarly, let $\mathbf{c}^B = (c_1^B, \dots, c_L^B)$, where maybe clay content on site B is c_1^B = 12%, terrain slope on site B is c_2^B = 1.7, etc. Characteristics values for sites C and D, $\mathbf{c}^C = (c_1^C, \dots, c_L^C)$ and $\mathbf{c}^D = (c_1^D, \dots, c_L^D)$, are defined similarly. Now define a per-acre yield response function dependent on the input choice variable *N* and the characteristics variable **c**: $y = f(N, \mathbf{c})$.

It seems natural that a management zone should be defined as a part of crop production field in which the input or inputs being considered are best managed with the same management strategy. Here the word "should" is normative, and implicitly requires that the strategist have an objective. In managing a field, many farmer objectives are plausible: the farmer may wish to maximize profits, maximize expected profits if the decision involves uncertainty, or maximize some function of the higher moments of the profit distribution. For the purposes of the current discussion, we maintain simplicity by modelling farm management conducted under conditions of certainty and perfect information, and we assume a risk-neutral neutral farmer whose objective is to maximize profits. Continuing to keep things simple, assume that the producer wants to site-specifically manage the input *N*, to maximize per-acre net revenues on the field. Let s^j represent the area of site *j*, in acres. Indexing sites by *j* = 1, 2, 3, …, *J*, let N_J be a variable representing the producer's choice of the input on a site *j*, the farmer's net revenues maximization problem is to solve the following:

$$\max_{N_1, \dots, N_J} \left\{ \sum_{j=1}^{J} s_j \left[pf\left(N_j, \mathbf{c}^j\right) - wN_j \right] \right\}. \quad (1)$$

Equivalently, we can say that the producer wants to maximize net revenues by maximizing net revenues on each site, thus solving *J* different problems:

$$\max_{N_j} \left[pf\left(N_j, \mathbf{c}^j\right) - wN_j \right], \ j = 1, \dots J. \quad (2)$$

For some generic $j \in \{1, \dots, J\}$, let N_j^* be the solution to the problem above. N_j^* must depend on the maximization problem's parameters, which are *p*, *w*, and $\mathbf{c}^j$, so we can write $N_j^*\left(p, w, \mathbf{c}^j\right)$ This function is implicitly defined by the necessary condition for profit maximization, solved using ordinary calculus:

$$p \frac{\partial f\left(N_j^*(p,w,\mathbf{c}^j),\mathbf{c}^j\right)}{\partial N} - w = 0, \quad (3)$$

or equivalently,

$$\frac{\partial f\left(N_j^*(p,w,\mathbf{c}^j),\mathbf{c}^j\right)}{\partial N} = \frac{w}{p}. \quad (4)$$

Using the Theoretical Framework to Critique the Literature

Equation (4) above makes clear that a management zone is a part of the field in which the marginal product schedule is invariant. Figure 1 illustrates this point. The top panel of Figure 1 shows the yield response functions specific to some field section A and specific to some field section B. The two areas have different values, $\mathbf{c}^A$ and $\mathbf{c}^B$, of the vector of field characteristics variables, which results in each site having its own yield response function, shown as $f(N, \mathbf{c}^A)$ and $f(N, \mathbf{c}^B)$. In is assumed that the two yield response curves are vertically parallel. Two (input price, output price) situations are shown in the illustration. In the first situation, the output price is p = 10 and w =5, making w/p = 0.5. In the second situation, the output price is p = 10 and the input price is w = 3, making w/p = 0.3. The profit-maximization condition shown in equation (4) is illustrated in the top panel of Figure 1. Because the yield response curves are vertically parallel, their slopes equal 0.5 at the same input application rate, which is shown as $N^*(10{,}5,\mathbf{c}^A)$ = $N^*(10{,}5,\mathbf{c}^B)$. In the same way, their slopes equal 0.3 at the same input application rate $N^*(10{,}3,\mathbf{c}^A)$ = $N^*(10{,}3,\mathbf{c}^B)$. The bottom panel of Figure 1 presents an alternative diagram that makes the same point was is made in the top panel. Because the two yield response curves are parallel, then their partial derivatives with respect to N are the same. This partial derivative is often called the marginal product of N, and putting the price ratio w/p on the panel's vertical axis shows that no matter the value of the price ratio w/p, the economically optimal input application rate is the same for site A as for site B. That is, these two sections are in the same management zone, even though site A is "more productive" than site B.

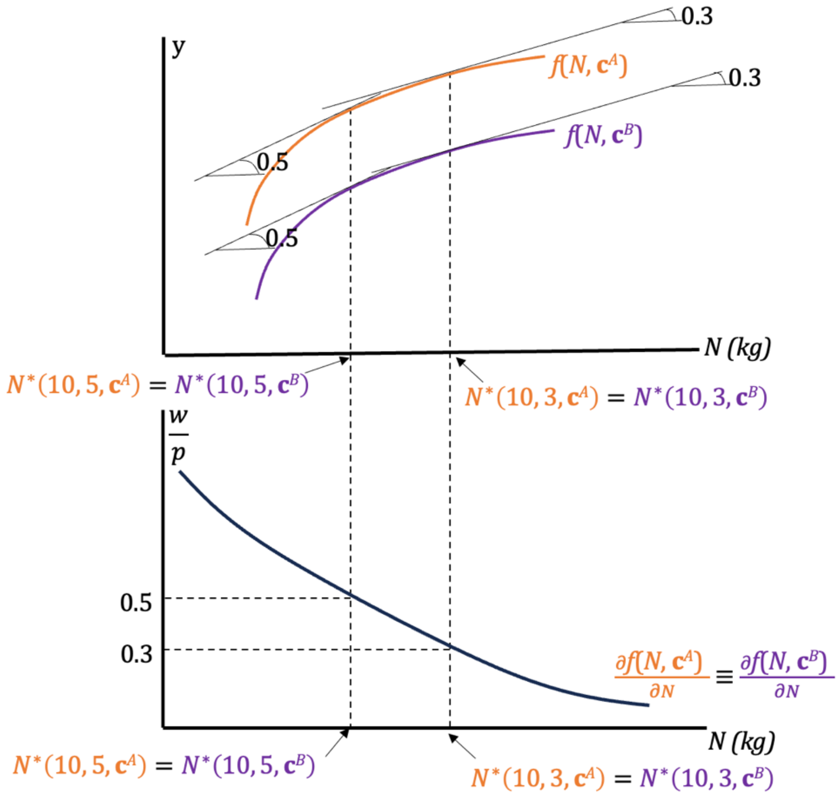

Figure 1. Management zones are determined by the input price, the output price, and the marginal yield response to the input application rate.

Figure 2 is another depiction of why finding sites that have different levels of yield productivity need not be helpful for delineating management zones. Rather, you gathered data on past yields. Assuming that MZs are determined using past yield data from a field that was managed uniformly in the past, the data would show a yield of 250 at sites A and B, and a yield of 125 at sites C and D. If site A with site B were grouped because they have similar yields, and similarly site C with site D were grouped because they have similar yields., then the management zones have badly created. Sites can have similar yields without having similar economically optimal input application rates. The two management zones that should come out of Figure 1 are one that combines site A with site C, since their optimal N rate is 100, and one that combines site *B* with site *D*, since their optimal N rate is 200. Grouping sites with similar yields into management zones does not maximize profits.

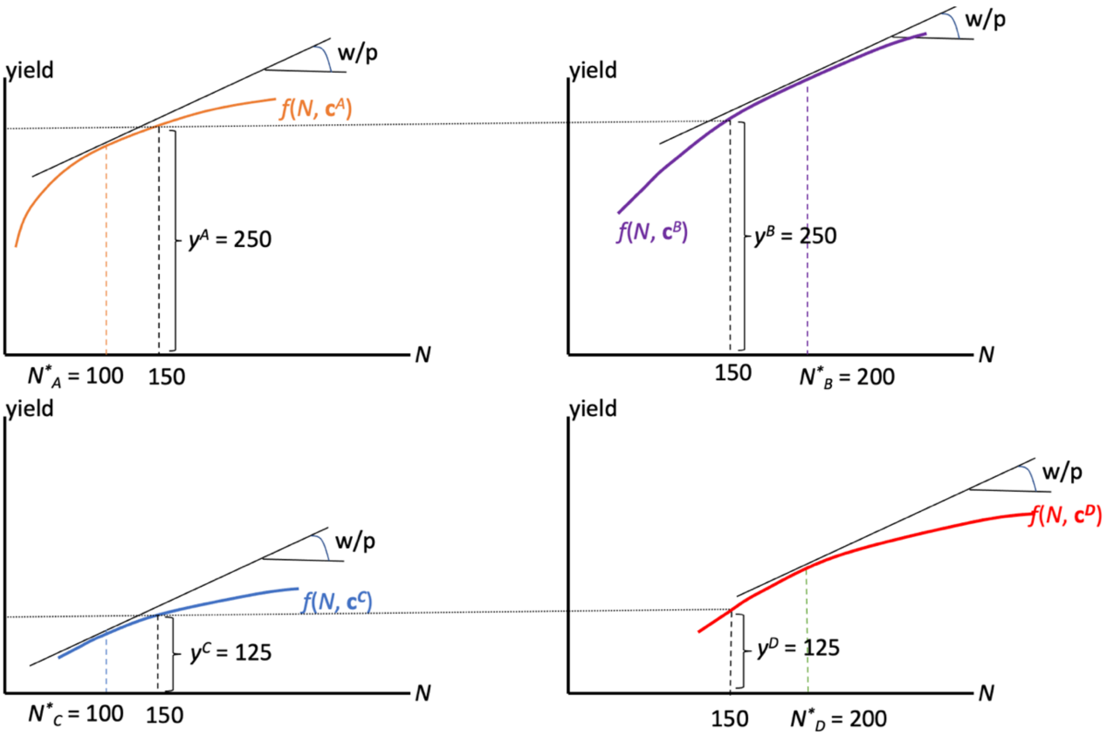

Figure 2. Similar yield values do no imply similar optimal management strategies

Conclusion

The discussion above shows that management zones should be delineated by marginal yield response functions. Knowing a site's yield response function is sufficient for knowing it marginal yield response function. Agricultural scientists have been running field trials for hundreds of years to generate the (input rate, yield) data needed to estimate yield response functions, and in many ways estimation of yield response functions was the principal motivation behind R.E. Fisher's development of modern statistical methods. The problem with the types of "small plot" field trials that Fisher and many others ran to generate data useful for crop input management is that running them has traditionally been labour-intensive and therefore *expensive*. This led Stanford (1966, 1973) and others to attempt to come up with data-*extensive* methods of recommending input application strategies (Rodriguez, et al., 2019). Trying to use yield maps or field characteristics maps to determine input management zones is a continuation of this pattern of data-extensive strategies. Basic microeconomic theory makes it clear that field trial data are needed to obtain empirically-identified management zones. Relatively recently, on-farm precision experimentation (OFPE) has been greatly lowering the costs of running very large agronomic field trials (Bullock, et al. 2019; LaCoste, et al. 2022). OFPE has to potential of generating just the kinds of data needed for empirically-determined input management zones.

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References

Bullock, D.S. et al. (2019) ‘The data-Intensive Farm Management Project: Changing Agronomic Research Through on-Farm Precision Experimentation’, Agronomy Journal, 111(6), pp. 2736–2746. doi:10.2134/agronj2019.03.0165.

Cillis, D. et al. (2018) ‘Field-scale electrical resistivity profiling mapping for delineating soil condition in a nitrate vulnerable zone’, Applied Soil Ecology, 123, pp. 780–786. doi:10.1016/j.apsoil.2017.06.025.

Colaço, A.F. and Bramley, R.G.V. (2018) ‘Do crop sensors promote improved nitrogen management in grain crops?’, Field Crops Research, 218, pp. 126–140. doi:10.1016/j.fcr.2018.01.007.

Guastaferro, F. et al. (2010) ‘A comparison of different algorithms for the delineation of management zones’, Precision Agriculture, 11(6), pp. 600–620. doi:10.1007/s11119-010-9183-4.

Kayad, A. et al. (2021) ‘Ten years of corn yield dynamics at field scale under Digital Agriculture Solutions: A case study from North Italy’, Computers and Electronics in Agriculture, 185, p. 106126. doi:10.1016/j.compag.2021.106126.

King, J.A. et al. (2005) ‘Mapping potential crop management zones within fields: Use of yield-map series and patterns of soil physical properties identified by electromagnetic induction sensing’, Precision Agriculture, 6(2), pp. 167–181. doi:10.1007/s11119-005-1033-4.

Lacoste, M. et al. (2021) ‘On-farm experimentation to transform Global Agriculture’, Nature Food, 3(1), pp. 11–18. doi:10.1038/s43016-021-00424-4.

Peralta, N.R. et al. (2013) ‘Delineation of management zones with measurements of soil apparent electrical conductivity in the Southeastern Pampas’, Canadian Journal of Soil Science, 93(2), pp. 205–218. doi:10.4141/cjss2012-022.

Rodriguez, D.G., Bullock, D.S. and Boerngen, M.A. (2019) ‘The origins, implications, and consequences of yield-based Nitrogen Fertilizer Management’, Agronomy Journal, 111(2), pp. 725–735. doi:10.2134/agronj2018.07.0479.

Stanford, G. (1966) ‘Nitrogen requirements of crops for maximum yield’, Agricultural Anhydrous Ammonia Technology and Use, pp. 237–257. doi:10.2134/1966.nh3agricultural.c13.

Stanford, G. (1973) ‘Rationale for optimum nitrogen fertilization in corn production’, Journal of Environmental Quality, 2(2), pp. 159–166. doi:10.2134/jeq1973.00472425000200020001x.

Tagarakis, A. et al. (2012) ‘Management zones delineation using fuzzy clustering techniques in grapevines’, Precision Agriculture, 14(1), pp. 18–39. doi:10.1007/s11119-012-9275-4.

Laurimar G Vendrusculo and Amy F Kaleita (2011) ‘Modeling zone management in precision agriculture through Fuzzy C-means technique at spatial database’, 2011 Louisville, Kentucky, August 7 - August 10, 2011 [Preprint]. doi:10.13031/2013.38168.

Li, Y. et al. (2008) ‘Determination of potential management zones from soil electrical conductivity, yield and crop data’, Journal of Zhejiang University SCIENCE B, 9(1), pp. 68–76. doi:10.1631/jzus.b071379.

Stanford, G. (1966) ‘Nitrogen requirements of crops for maximum yield’, Agricultural Anhydrous Ammonia Technology and Use, pp. 237–257. doi:10.2134/1966.nh3agricultural.c13.

Stanford, G. (1973) ‘Rationale for optimum nitrogen fertilization in corn production’, Journal of Environmental Quality, 2(2), pp. 159–166. doi:10.2134/jeq1973.00472425000200020001x.

Tagarakis, A. et al. (2012) ‘Management zones delineation using fuzzy clustering techniques in grapevines’,

Precision Agriculture, 14(1), pp. 18–39. doi:10.1007/s11119-012-9275-4.

Velandia, M.M. et al. (2008) 'Economics of Management Zone Delineation in Cotton Precision Agriculture', The Journal of Cotton Science, 12, pp. 210–227.

Velasco, J. et al. (2021) 'Delineation of site-specific management zones using estimation of distribution algorithms', International Transactions in Operational Research, 30(4), pp. 1703–1729. doi:10.1111/itor.12970.

Zhang, X. et al. (2009) 'Zone mapping application for precision-farming: A decision support tool for Variable Rate Application', Precision Agriculture, 11(2), pp. 103–114. doi:10.1007/s11119-009-9130-4.