

# DETERMINATION OF OPTIMAL NUMBER OF MANAGEMENT ZONES

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## ABSTRACT

There were numerous research carried out to determine the optimal number of management zones for variable rate application of fertilizer. It was shown that the number of zones is usually determined by field size and spatial variability of soil properties or crop conditions. However, in real industry it is necessary to consider characteristics of field equipment that will be used to apply fertilizer, and also the economics of variable rate technology. In this study, we investigated the relationship between within-field variability, number of management zones and feasibility of product application using variable rate maps with the different number of zones ranging from 3 to 12. It was found that in many cases the increase of the number of zones did not improve the accuracy of variable rate application of fertilizer. In most cases, the optimal number of management zones varied from 3 to 7. Based on the natural variability, creation of 10-12 zones was not economically efficient and caused major difficulties for the application of fertilizer in the field.

**Keywords:** Precision agriculture, satellite imagery, variable rate technology, management zones.

## INTRODUCTION

There are many different concepts and methods of delineating management zones for variable rate application of fertilizer. They are based on utilizing grid soil sampling, soil electrical conductivity (EC) measurements, yield mapping, analysis of aerial and satellite imagery, field topography etc. Regardless to the base method used, there are always two conceptual questions: how to classify the data, and how many zones to delineate.

The question about the number of management zones was studied by different research groups. In most cases, they tried to find the best solution for explaining within-field variability. In particular, Fridgen et al. (2000, 2004) developed an automated procedure for creating zones and testing the number of zones to create.

This procedure was implemented in the software program called Management Zone Analyst. Another aspect of the problem was studied by Chang et al. (2004). They examined four management zone delineation approaches: (i) sample areas impacted by old homesteads separately from the rest of the field; (ii) separate the field into grid cells; (iii) use geographic information systems or cluster analysis of apparent electrical conductivity, elevation, aspect, and connectedness to identify zones; and (iv) use the Order 1 soil survey. Based on a six-year study, they suggested using both nutrient and yield variability for delineation of zones. Pelcat et al. (2004) analyzed the optimum number of management zones created from normalized difference vegetation index (NDVI) using the Fuzziness Partition Index (FPI) and Modified Partition Entropy (MPE). They found that based on the FPI and MPE plots, the greatest improvement in classification and organization between classes occurred at three (3) zones, with additional improvement up to 9-10 zones, depending on within-field variability.

All these results take into account various layers of information and their spatial variability. However, when it comes to the practical application of precision Ag technologies on real farms, there are many other factors coming into play, such as accuracy of GPS, swath of field equipment, speed of field equipment etc. In precision agriculture industry, there are various opinions about the optimal number of zones to create, and suggest number often ranges from 3 to 12 for the same field.

## **MATERIALS AND METHODS**

Our experiments were carried out in a real farmer's fields near Calgary, AB, Canada. We tried to analyze the number of management zones in comparison to the natural within-field variability and quality of fertilizer application. The main aim of our study was to determine, what information must be taken into account to make decisions about the optimal number of management zones, and how feasible is the accurate application of fertilizer depending on the number of management zones and field equipment.

For delineation of management zones, we used over 25 years of multispectral satellite imagery, yield data and field relief. Based on the concept that variable rate application of fertilizers is aimed to optimize the balance of nutrients in soil for best development of field crops, the natural within-field variability was estimated as variability of green biomass and yield within field boundaries.

For each field used in the analysis, we calculated variable fertility index, i.e. an average potential of land to produce yield. Based on the fertility index, in each field we delineated from 3 to 12 management zones. Composite soil samples were collected from each zone and analyzed for the main characteristics including soil organic matter, pH, concentrations of nitrogen, phosphorus, potassium, calcium, magnesium, and micronutrients. For each zone, site-specific fertilizer rates were created. Fertilizers were applied using grower's field equipment. After the application, as-applied files were collected from the equipment and overlaid with fertilizer recommendations for further analysis.

## RESULTS AND DISCUSSION

Our results obtained from several years of field tests indicate that the number of five management zones is the most realistic number that fits both spatial variability of most fields, and technical characteristics of field equipment.

Visual comparison of our zone maps with as-applied data indicated relative accuracy of the field operation (Fig. 1). However, on the edges of each zone we can clearly see dents related to the errors of field application. The average length of the dents was approximately 30 m. In this particular field, carbamide was applied by an air seeder, and look-ahead time was set up to 2 seconds. Even in this case, the seeder was unable to ensure 100%-accurate application of the product. If we compare the size of the dents and area covered by them with the total size of management zones and whole field, we can state that five management zones in this case was a realistic number fitting both within-field variability and functionality of field equipment.

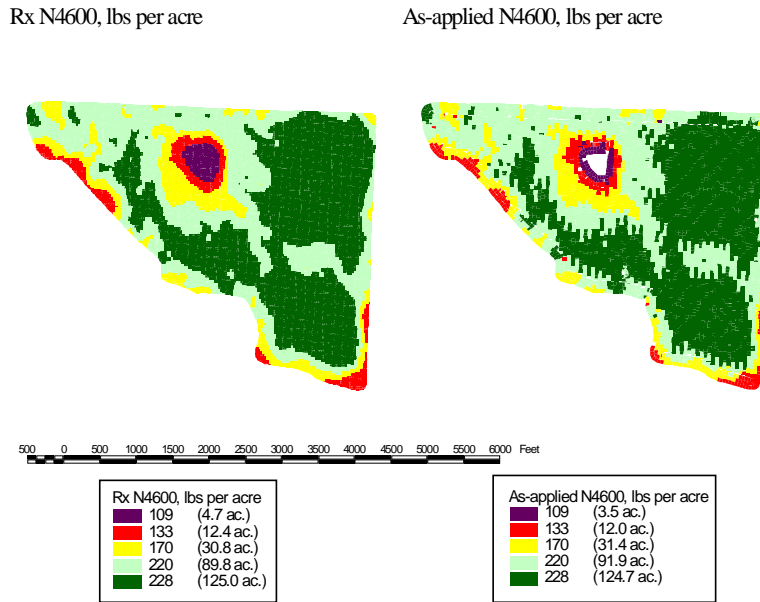


Fig. 1. Comparison of fertilizer recommendations and as-applied data.

Increase of the number of zones to from 5 to 10 creates serious difficulties for the application of fertilizer in this field. It is easy to see that the size of dents on the edges of management zones exceeds the width of the zones (Fig. 2).

Analysis of fitted variogram for fertility index in this field indicated it reached the sill at approximately 30 m (Fig. 3). It gives a good idea about the smallest details that we need to take into account when managing this field on a site-specific basis.

Rx N4600

As-applied N4600, lbs per acre

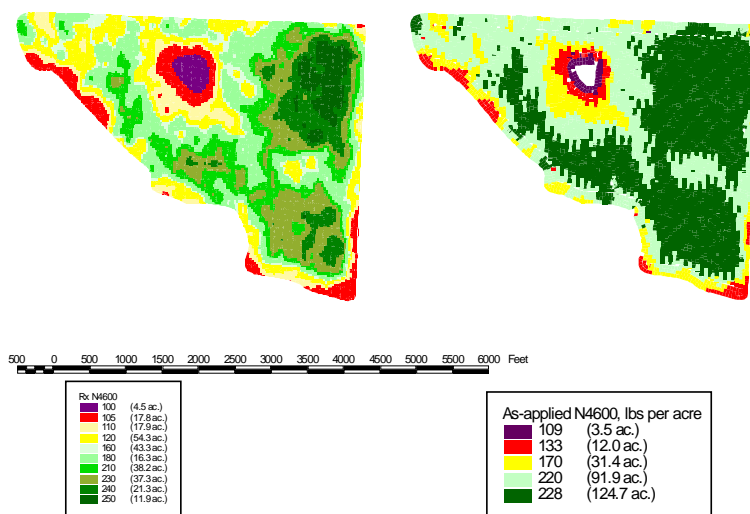


Fig. 2. Comparison of fertilizer recommendations with the increased number of zones and as-applied data.

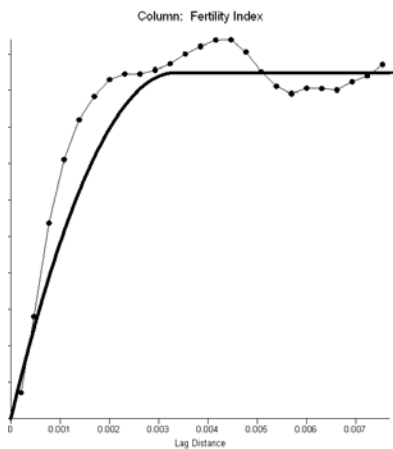


Fig. 3. Fertility index variogram analysis.

There is a point of view in the industry that contemporary equipment can manage over ten zones within one field. However, our analysis demonstrates that it can be done in large fields with low variability. Fig. 4 shows the field, where the equipment has to pass through eight zones within 70-80 meters. In practice, field equipment cannot ensure such precision, especially without RTK and sectional control. In addition, increasing the number of management zones in the fields from 5 to 10 will double cost of soil analysis and considerably increase labor expenses for soil sampling, if zone method is used. This is particularly important in Canadian Prairies with high percent of low value crops, such as wheat and barley.

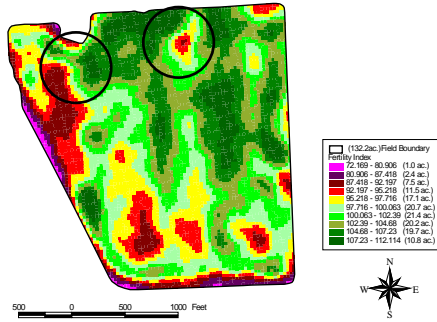


Fig. 4. Increased number of zones.

In some cases, operators of field equipment try to increase speed in order to increase the total area applied per day. In practice, it leads to unpredictable results (Fig. 5). Excessive speed coupled with incorrect look-ahead time increases the lengths of dents on the edges of management zones to 50-70 m, and it makes the whole idea of variable rate application useless.

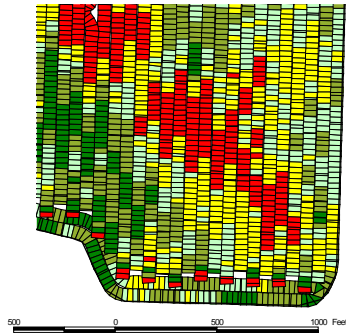


Fig. 5. Example of very low accuracy of variable rate fertilizer application.

Among the most important characteristics influencing the optimal number of zones are the factors considered for the analysis and method of zone delineation. For example, Fridgen et al. (2000, 2004) using principal component analysis showed that 6-7 principal components explained over 90% of the cumulative variance. In their experiments, principal component 1 was dominated by soil EC, organic matter, Mg and K. The second one was related to elevation, slope, pH and P. The optimal number of management zones delineated from yield data in their experiments was 4-6, depending on the field variability. These numbers were based on fuzziness performance index (FPI) and modified partition entropy (MPE). However, it is important to remember that the goal of management zones is not to find areas within the field with different properties. The main aim is to explain, why some areas in the field produce above or below average, and provide solutions for the most efficient way to manage soil fertility and crop production, i.e. the most important factor for delineation of zones is variability of grain yield or green biomass.

Our experiments and practical experience show that when using yield data or satellite imagery, the average of five management zones give good results for both explaining within-field variability, cost efficiency and applying fertilizer in the field.

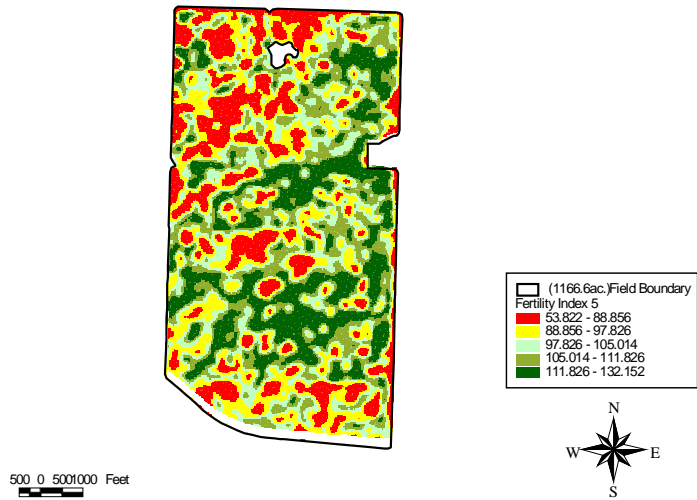


Fig. 6. Variability of green biomass, five zones.

Fig. 6 illustrates variability of green biomass in 472-hectare field in Southern Alberta. Delineation of five zones gives a good picture of within-field variability and helps to adjust fertilizer rates according to the yield goals and soil characteristics. At the same time, it makes both soil sampling and application of fertilizer in this field feasible from the technical point of view.

Increasing the number of zones from 5 to 6, and then to 8, add some additional details to the map, but does not make the application map more manageable (Fig. 7 and 8).

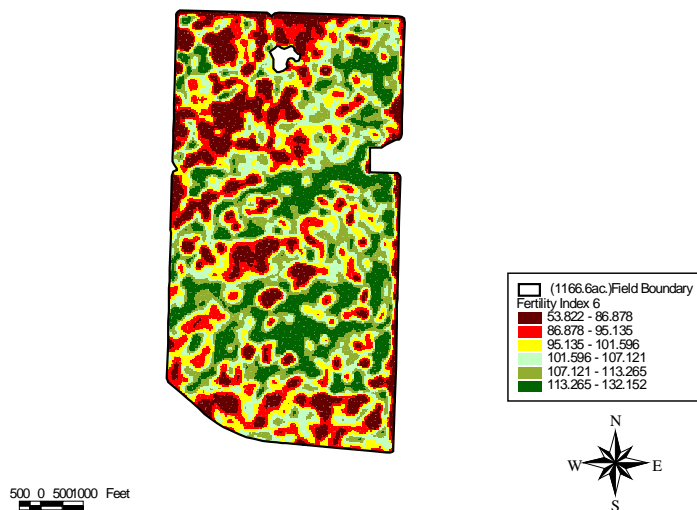


Fig. 7. Variability of green biomass, six zones.

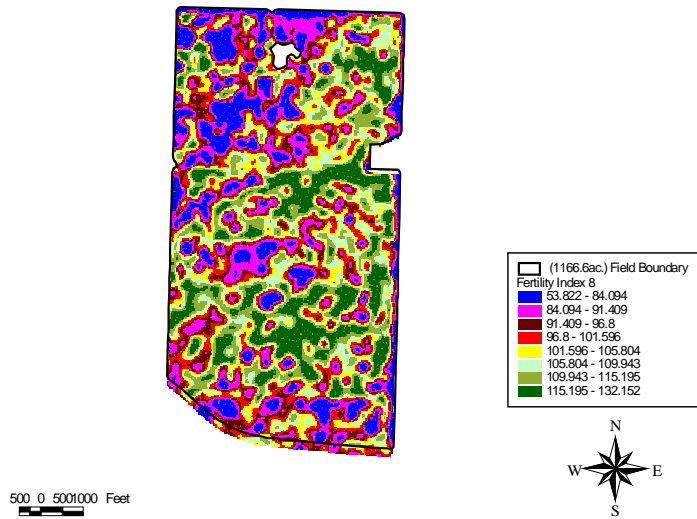


Fig. 8. Variability of green biomass, eight zones.

The areas with the medium yielding potential become very narrow and, therefore, very problematic for successful application of fertilizer in the field. Width of the zones in transitional areas decreases to 5-10 m. At the same time, analysis of variogram for this field indicates that spatial variability of this large field is very similar to the one shown in Fig. 1, with the range just over 30 m (Fig. 9).

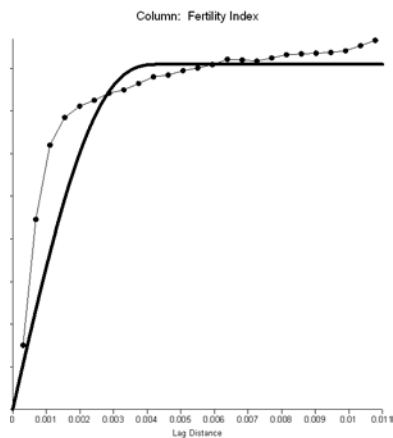


Fig. 9. Fertility index variogram analysis.

It supports the statement that in the conditions of Southern Alberta details of within-field variability smaller than approximately 30 m in size are not important for delineation of management zones for variable rate application of fertilizer. Increasing number of management zones often leads to creation of maps, which cannot be applied in real conditions using existing field equipment, increased cost of zone soil sampling and reduction of net profit from the application of variable rate technology.

## **CONCLUSION**

The optimal number of management zones for variable application of fertilizer depends on both within-field variability and technical characteristics of field equipment. Another important factor is related to the economics of variable rate technology, i.e. comparison of expenses related to delineation of zones and soil analysis, and net profit obtained as a result of variable rate technology application.

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