A segmentation approach to delineate zones for differential Nitrogen intervention

R.P. de Oliveira[1], B. Whelan[2] and A. McBratney[2]
[1] *Embrapa Solos – Rio de Janeiro, Brazil*
[2] *Precison Agriculture Laboratory – Sydney, Austrália*
ronaldo@cnps.embrapa.br

Abstract

Multi-source and -temporal data integration is expected to support the delineation of within-field management zones that may better conform to unique combinations of crop yield variations. This work addresses the evaluation of zone delineation approaches based on image classification and segmentation methods. An object based segmentation is introduced using ancillary data from multivariate analysis of yield maps. A simple economic evaluation is conducted to compare delineation methods aiming variable-rate Nitrogen applications. Advantages and penalties are suggested for 2, 3, and 4 management zones. Results show that a procedure combining multiresolution, watershed and region grow segmentation algorithms has systematically resulted in greater net worth. It is suggested that segmentation methods have potential application for zone management delineations supporting contiguous patterns.

Keywords: Crop Management Zones, Yield Variation, Object Based Segmentation

Introduction

The analysis of several years of yield mapping can minimize the risk associated with strong temporal yield variations (Schepers *et al.*, 2005). However, methods using multiple inputs are still maturing while considering economic evaluations on the opportunity for site-specific crop management (SSCM). Approaches for optimal delineation of management zones (MZs) have considered multi-source and -temporal data integration from production factors. Technological approaches have considered image processing (Mulla *et al.*, 2000), landform segmentation (Martin & Timmer, 2006), crop models (Miao *et al.*, 2006), data mining (Shaerer *et al.*, 2000); and attribute space clustering (Li *et al.*, 2007). Still, a few studies have been undertaken to systematically compare the diverse range of results (Whelan *et al.*, 2007). Pixel based processes have mostly used high resolution inputs for unsupervised clustering (Vrindts *et al.* 2005) and fuzzy thresholding (García-Pérez *et al.*, 2001). Classification procedures have used *k*-means (Shatar & McBratney, 2001) or fuzzy *k*- means (Van Alphen & Stoorvogel, 2000) clustering methods, commonly applied to single field-season decision support based on crop yield averages (Jaynes *et al.*, 2005). Although computational performance analysis have been introduced (Zaït & Messatfa, 1997), Hartigan (1975) recognizes that clustering methods very often yield different results, making their classification and evaluation a difficult task.
Whether to search for the optimal number of cluster classes (Vrindts *et al.* 2005) or for the number of contiguously manageable polygons (Khosla *et al.*, 2002) is still a great matter of investigation. According to Fraisse *et al.* (1999), the optimal number of zones sub-dividing a field may vary from year to year as a function of weather and crop type.

Results in Schelde *et al.* (2007) reinforce the lack of benefits from increasing the number of management classes beyond four. Moreover, Shatar & McBratney (2001) have argued that clustering methods often produce non contiguous subdivisions, increasing the number of small, random zones in contrast to the optimal use of variable-rate technology. Recent developments have shown growing attention given to object-based image analysis (Wang, 2008). Based on objects composed as a group of neighbour pixels, this concept offers the opportunity to extract information from spectral (attribute space) and shape feature (physical space) constraints. Experiments using object based segmentation for SSCM are not new in field robotics.
This contribution aims to evaluate the performance of MZ delineation methods using object-based image segmentation techniques and standard classification procedures. A segmentation process is introduced using multiple-year yield maps, that considers multiresolution segmentation, watershed transformation, and grow region algorithms. Common used k-means clustering techniques are computed as previously proposed for SSCM investigations, and also combined with object-based grow region algorithm.
An economic evaluation is conducted considering operational advantages and penalties to different numbers of management classes. Financial advantages are based on different values per zone area and the occurrence, or not, of a class area predominance.

Material and methods

Rainfed broad-acre fields have been selected from a historical set (1997-2006) of available grain-crop yield monitor data from three Australian non-profit grower's organizations involved in PA technology. Data selection considered one field from each different agronomic region where non-stationary spatial and temporal crop variation could be observed, being: a) field Road (112 ha) with seven seasons (1999-2005); b) field WA (81 ha) with six seasons (1999-2004); and c) field BT (135 ha) with five seasons (1998, 2001, 2003, 2005, 2006).
Multiple-year maps are here considered as better characterizing more stable spatial and temporal crop production variations. Input maps for zone delineation are median yield, first PCA component (PC1), and second PCA component (PC2). These multi-year yield maps were computed by raster calculations of yield averages by pixel and multivariate analysis, as suggested in Jaynes *et al.* (2005). The use of PCA is suggested as a technique showing the significance of the temporal variation altering yield spatial variations. Components are calculated only for yield data to match average yield inputs.
Zone management delineation methods are based on three approaches, thus: a) *k*-means clustering classification; b) *k*-means clustering classification with grow region algorithm; and c) object based segmentation algorithms. A procedure combining multiresolution segmentation, watershed transformation and grow region algorithms is evaluated.
The *k*-means cluster classification was first conducted as a pixel based process whereby a set of entities is divided into several clusters of similar class membership values to each other and different from the members of other clusters. A second procedure for zone delineation combines histogram thresholding and region grow algorithms. It is a simple extension of the previous classification process, with additional reshaping technique for splitting and merging operations into sub-objects in the image object domain and allows growing image objects into a larger space. The third process has focused on a new method of application using object-based image segmentation, which proposes an

composite segmentation approach combining multiresolution segmentation with watershed transformation and grow region algorithms.

The use of the multiresolution segmentation was taken as the first step in the composite process for image information extraction, which would avoid over-segmentation issues as reported when using the standard watershed transformation algorithm to zone management partitioning (Roudier *et al.*, 2008). Unsupervised multiresolution object segmentation (Baatz & Schäpe, 2000) was executed with process parameters that could generate small size objects preserving general patterns on the input. This process provides different scale parameters and segment homogeneity criterion (i.e. shape and compactness). The idea in this process was to generate primitive objects as related to the agronomic process involved, approximately 100 m^2. The watershed transformation algorithm (Beucher & Lantuejoul, 1979) has been introduced for PA applications in Roudier *et al.* (2008). Settings for the watershed algorithm have considered the minimum length factor that could further split sub-objects already generated by the multiresolution process, as generating sub-watersheds within broader image objects. Finally, the grow region algorithm is applied to generalize and produce the final object segmentation results for zone managements considering 2, 3, and 4 classes.

A net worth assessment is proposed to estimate single field intervention for variable-rate Nitrogen application, as a simple way of looking at comparing zone delineation methods for operational matters. Economic advantages and penalties to zone management of Nitrogen are suggested in Australian dollars per hectare ($/ha) by class for procedures with 2, 3, and 4 management classes. A criterion of different benefit values by management class follows the concepts in Robertson *et al.* (2008). Robertson *et al.* (2008) suggest that the economic advantage to zone over uniform management can be expressed as a continuous function of yield differences between lowest and highest yielding zones in a field. Benefits were considered according to different classes, as shown in Tables 1, 2, and 3, using market prices as given in Robertson *et al.* (2008) for the significance of the variation in yield potential of wheat crops in Western Australia. Penalties are estimated using the cost of variable rate-services as given by Bongiovanni *et al.* (2007) as a function of machinery footprints crossing boundaries between different management classes. They were estimated using the cost of variable-rate services as per meter ($/m) based on the required change in application rates when the machinery footprint crosses boundaries between different zone classes. Therefore, the overall penalty for a single field operation of variable Nitrogen application accounts for the number of machinery crosses over the total length of borders between management zones. The cost of US$ 6.00/ha for experiment in Argentina is converted to Australian dollars (AU$). A resulting penalty of AU$ 0.25 is assumed per border crossing. Finally, the net worth of variable Nitrogen application is simply calculated as the difference between total advantage and penalty cost of Nitrogen interventions.

Table 1. The advantage to zone management considering 2 management classes.

Class	No predominance (AU$/ha)	Low yield predominance (AU$/ha)	High yield predominance (AU$/ha)
Higher yield (ZH)	8	5	6
Lower yield (ZL)	0	2	0

Table 2. The advantage to zone management considering 3 management classes.

Class	No predominance (AU$/ha)	Low yield predominance (AU$/ha)	High yield predominance (AU$/ha)
Zone 1 (higher yield)	8	5	6
Zone 2 (average yield)	4	3	3
Zone 3 (lower yield)	0	2	0

Table 3. The advantage to zone management considering 4 management classes.

Class	No predominance (AU$/ha)	Low yield predominance (AU$/ha)	High yield predominance (AU$/ha)
Very High	8	5	6
High	6	4	4
Low	2	3	1
Very Low	0	2	0

Results

Preprocessing outputs from multiple-year yield maps have shown that PCA components for the three selected fields have accounted for PC1 and PC2 respectively as follows: 41% and 19% in field Road, 60% and 16% in field WA, and 64% and 20% in field BT. This preliminary evaluation has shown that PC2 appears to respond more to machinery footprints or historical changes in management. Therefore, no further economic evaluation considering the PC2 as input was carried out. Multiple-year crop information was considered as an effective source of strong spatial and temporal variations in crop yield, considering median yield and first principal component maps as reflecting different aspects of crop production factors and spatial crop variation patterns. Although preliminary in nature, the proposed objective function characterizing the net worth of variable-rate Nitrogen interventions has proved robust across different segmentation approaches and price assumptions. Outcomes from the three delineation procedures are shown for 2, 3, and 4 classes by individual fields, as for: a) field Road, in Figure 1 for median yield and PC1; b) field WA, in Figure 2 for median yield and in Figure 3 for PC1; and c) field BT, in Figure 4 for median yield, and PC1.

The net balance model which considers financial advantages, in relation to the contrast between yield means and the relative size of each zone management classes, against penalties for an increased number of times in which variable-rate equipment is activated to change application rates has proved effective.

Segmentation methods have brought some improvement in generating contiguous within-field zone segmentations. Overall results for the economic evaluation using the composite segmentation approach, multi-resolution segmentation grow region with watershed transformation, have shown a greater opportunity for the delineation of management zones using the first principal component (PC1) as input (Figures 1 to 4). Median yield inputs have systematically responded with less lengthy zone borders than inputs of PC1 for the same segmentation process of each field.

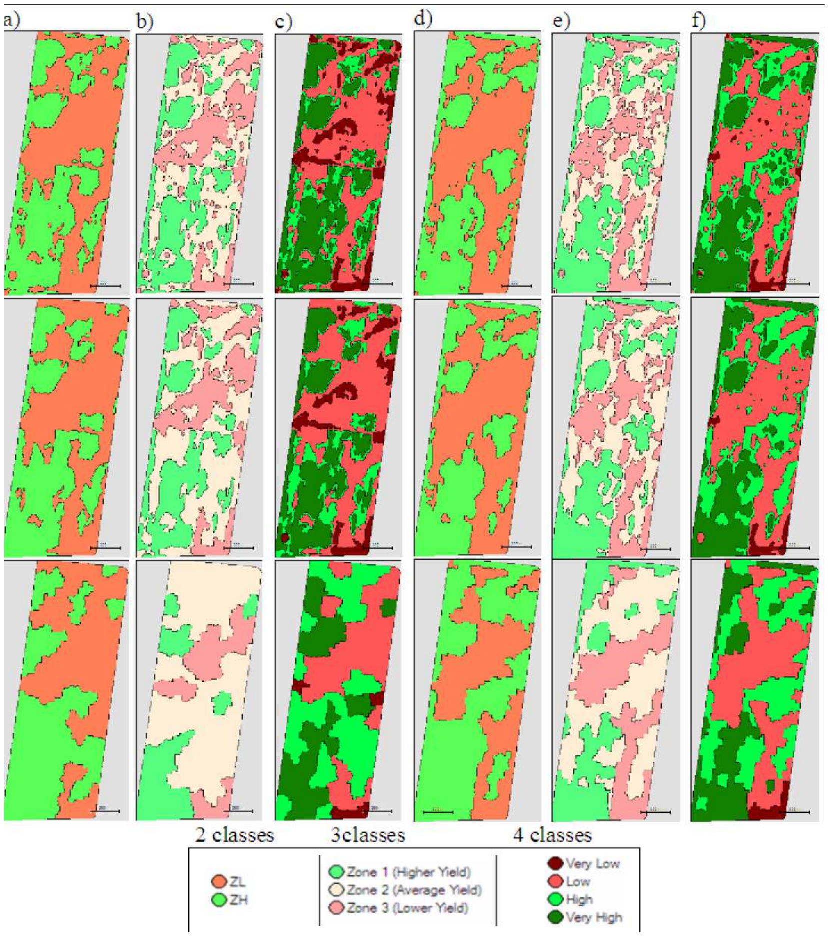

Figure 1. Management zones for field Road using k-means (first row), k-means with region grow (second row), and hybrid segmentation (third row) with 2, 3, and 4 classes, respectively using the median yield input map (columns a, b, and c) and the PC1 input map (columns d, e, and f).

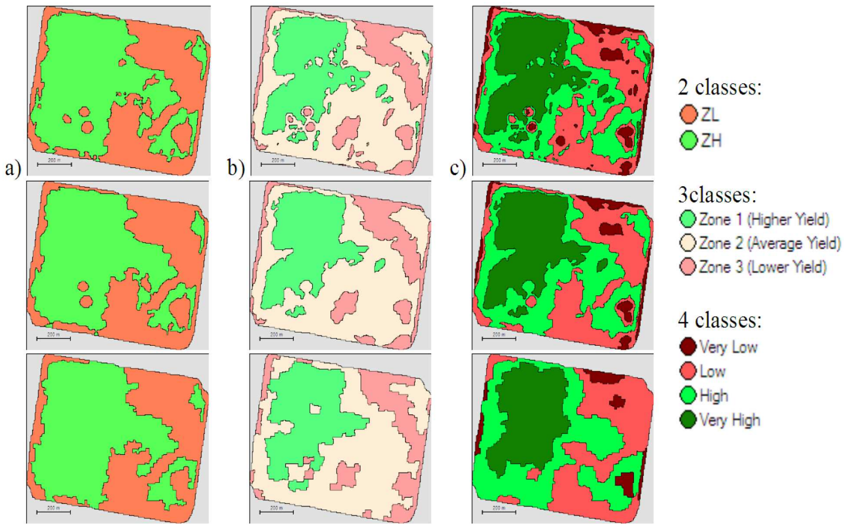

Figure 2. Management zones for field WA using k-means (first row), k-means with region grow (second row), and hybrid segmentation (third row) with 2, 3, and 4 classes (columns a, b, and c respectively) using median yield map input.

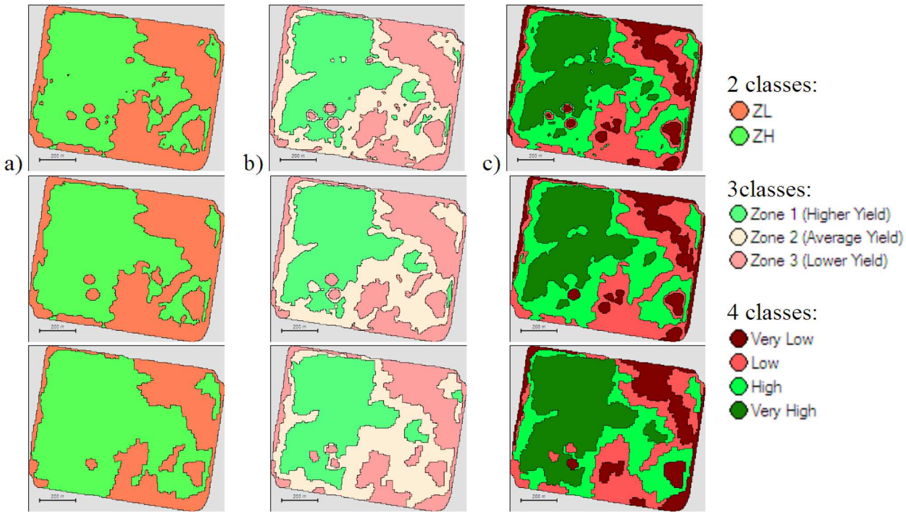

Figure 3. Management zones for field WA using k-means (first row), k-means with region grow (second row), and hybrid segmentation (third row) with 2, 3, and 4 classes (columns a, b, and c respectively) using PC1 map input.

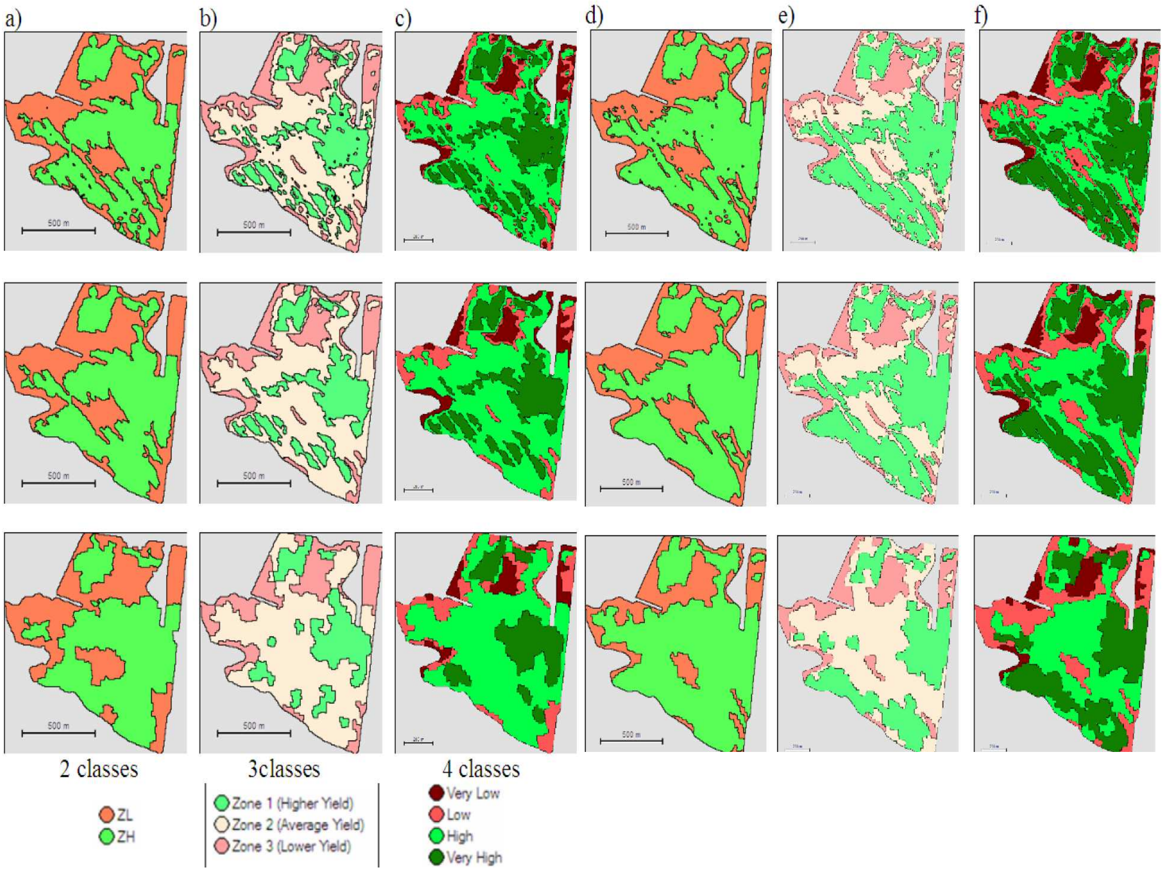

Figure 4. Management zones for field BT using k-means (first row), k-means with region grow (second row), and hybrid segmentation (third row) with 2, 3, and 4 classes, respectively using the median yield input map (columns a, b, and c) and the PC1 input map (columns d, e, and f).

In contrast, the more heterogeneous character of PC1 inputs has supported segmentation of zones in which the advantage to zone management has been maximized for two class segmentations, mostly promoting the best economic net worth for fields of strong spatial and temporal variation such as field BT.
Finally, the multiresolution with the watershed and grow region segmentation has provided better net worth across all fields for all class numbers according to net worth results shown in Table 4.

Table 4. Best net worth from all delineation processes of selected fields.

Field	Classes	Delineation Method	Input	Net Worth ($/ha)
Road	2	Segmentation	Median Yield	**$ 3.10**
	3	Segmentation	Median Yield	$ 2.38
	4	Segmentation	Median Yield	$ 2.46
WA	2	Segmentation	PC1	**$ 3.16**
	3	Segmentation	Median Yield	$ 1.64
	4	Segmentation	Median Yield	$ 2.10
BT	2	Segmentation	PC1	**$ 4.92**
	3	Segmentation	PC1	$ 2.31
	4	Segmentation	PC1	$ 0.65

General discussion and conclusion

Results suggest that scenarios considering advantages with differences in starting soil fertility status between zones are worth investigation. Maximum and minimum values given by Robertson *et al.* (2008), from 21 to 44 ($/ha) in Western Australia (WA), contrast a lot with figures previously used, from 0 to 8 ($/ha), as a reference for the advantage to zone management (Tables 1 to 3). Penalty prices given to the cost of variable-rate services, as associated with a larger total border length between different zones, were easy to compute and could be directly related to a greater number of non-contiguous zone segments and/or an increased shape contours.
Results show a great potential for the use of new segmentation algorithms for delineation of MZs, in particular to fields with strongly segmented spatial patterns as in the case of field BT in this investigation. The multiresolution watershed segmentation has systematically resulted in greater net worth for differential zone management, with the PC1 input and 2 zone class outputs likely to characterize greater net advantages for single intervention for variable-rate Nitrogen application.
An empirical study on object-based image segmentation algorithms has been conduced. A simple economic objective function has been proposed and applied as a mean to evaluate different approaches for the delineation of management zones for SSCM. The hybrid segmentation process has shown potential to support decisions on the opportunity for the adoption of site-specific zone management in a semi-automated fashion. For the compounded segmentation workflow no over-segmentation issues were observed when using solo watershed transformation or training seed-objects for grow region algorithm.

References

Baatz, M., & Schäpe, A. (2000). Multiresolution segmentation: an optimization approach for high quality multi-scale image segmentation. In J. Strobl, T. Blaschke, & G. Greisebener (Eds.), *Angewandte Geographische Informationsverarbeitung, Vol. XII* (pp. 12-23).

Beucher, B., & Lantuejoul, C. (1979). Use of watersheds in contour detection. In *Proceedings of the International Workshop on Image Processing: Real-time and motion detection/estimation* (pp. 2.1-2.12). Rennes, France, 17-21 September.

Bongiovanni, R. G., Robledo, C. W., & Lambert, D. M. (2007). Economics of site-specific nitrogen management for protein content in wheat. *Computers and Electronics in Agriculture, 58,* 13–24.

García-Pérez, L., García-Alegre M.C., Marchant, J., & Hague, T. (2001). Dynamic threshold selection for image segmentation of natural structures based upon a performance criterion. In S. Blackmore, & G. Grenier (Eds.), *Proceedings of the 3rd European Conference on Precision Agriculture* (pp. 193-198). Montpellier.

Hartigan, J. A. (1975). *Clustering Algorithms*, Wiley, New York.

Jaynes, D. B., Colvin, T. S., & Kaspar, T. C. (2005). Identifying potential soybean management zones from multi-year yield data. *Computers and Electronics in Agriculture, 46*, 309-327.

Khosla, R., Fleming, K. L., Delgado, J. A., Shaver, T. M., & Westfall, D. G. (2002). Use of site-specific management zones to improve nitrogen management for precision agriculture. *Journal of Soil and Water Conservation, 57*, 513–518.

Li, Y., Shi, Z., Li, F., & Li, H. (2007). Delineation of site-specific management zones using fuzzy clustering analysis in a coastal saline land. *Comp. and Electronics and Agriculture, 56*(2), 174–186.

Martin, W. K. E. and Timmer, V. R. (2006). Capturing spatial variability of soil and litter properties in a forest stand by landform segmentation procedures. *Geoderma 132,* 169–181.

Miao, Y., Mulla, D. J., Batchelor, W. D., Paz, J. O., Robert, P. C., & Wiebers, M. (2006). Evaluating management zone optimal nitrogen rates with a crop growth model. *Ag. Journal, 98*(3), 545-553.

Mulla, D. J., Sekely, A. C., & Beatty, M. (2000). Evaluation of remote sensing and targeted soil sampling for variable rate application of lime. In P. C. Robert, R. H. Rust, & W. E. Larson (Eds.), *Proceedings of the 5th International Conference on Precision Agriculture, CD-ROM* (142.pdf). ASA-CSSA-SSSA, Madison, Wisconsin, USA.

Robertson, M. J., Lyle, G., & Bowden, J. W. (2008). Within-field variability of wheat yield and economic implications for spatially variable nutrient management. *Field Crops Res., 105*, 211-220.

Roudier, P., Tisseyre, B., Poilvé, H., & Roger, J. M. (2008). Management zone delineation using a modified watershed algorithm. *Precision Agriculture, 9*(5), 233-250.

Schepers, A. R., Shanahan, J. F., Liebig, M. A., Schepers, J. S., Johnson, S. H., & Luchiari, A. (2005). Appropriateness of management zones for characterizing spatial variability of soil properties and irrigated corn yields across years. *Agronomy Journal, 96*, 195–203.

Shatar, T. M., & McBratney, A. (2001). Subdividing a field into contiguous management zones using a k-zones algorithm. In G. Grenier, & S. Blackmore (Eds.), *Proceedings of the 3rd European Conference on Precision Agriculture* (pp. 115–120). Agro-Montpellier ENSAM, France.

Van Alphen, B. J., & Stoorvogel, J. J. (2000). A Functional Approach to Soil Characterization in Support of Precision Agriculture. *Soil Science Society of America Journal, 64*, 1706-1713.

Vrindts, E., Mouazen, A., Reyniers, M., Maertens, K., Maleki, M. R., Ramon, H., & De Baerdemaeker, J. (2005). Management zones based on correlation between soil compaction, yield and crop data. *Biosystems Engineering, 92*(4), 419–428.

Wang, M. (2008). A multiresolution remotely sensed image segmentation method combining rainfalling watershed algorithm and fast region merging. *The International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences, XXXVII* (Part B4). Beijing.

Whelan, B. M., Taylor, J. A., & McBratney, A. B. (2007). Potential Management Classes: Is there value in their delineation? In *Proceedings of the 2007 Australasian Precision Agriculture Symposium* (15-21). Australian Centre for Precision Agriculture, The University of Sydney, NSW.