Soil suitability and crop versatility assessment using fuzzy analysis at a farm scale

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Abstract
There is the need to explore simultaneous soil suitability analysis for several viable crops to determine the overall suitability or versatility of a given area or a farm. The main objectives of this paper are to: fit fuzzy membership functions (FMFs) to determine soil suitability for multiple crops; determine the diversity of multiple suitability at each location using the Shannon's Index and equitability equation; and determine the overall versatility at the farm scale, and establish a new versatility equation by combining the previous versatility methodology with a diversity index. To understand the overall versatility of the study area suitability analysis was carried out for each of the several crops- canola, barley, field pea, Lucerne and wheat. The multiple suitability analysis demonstrated subtle differences in the trend or patterns of the individual crop maps. The development of the improved versatility map, incorporating Shannon's index, yielded important information for management decisions. The results indicate that the Northern and Southern paddocks of the study area exhibited higher versatility than the rest of the farm and would be highly suited for multiple crop rotations. Another pertinent point is that the areas of low versatility could be studied further to determine which of the crops are better suited to the soil.

Key Words
Soil suitability analysis; soil versatility; crop suitability, soil evaluation, land evaluation.

Introduction

With fluctuating rainfall patterns or higher frequency of dry periods, efficient land utilisation for agricultural production systems is required for the survival of most farms in Australia. Therefore land evaluation techniques and their resulting soil or land suitability maps must address the economic viability and provide information for management decisions at field or farm scale. Modern precision agricultural practices require across-farm and/or within-field soil variability which should be accounted for in the suitability assessment for it to be an effective tool for management decisions. Soil function under a number of land uses should also be assessed as it provides different options to the farmer and thus reduces the farmer's dependency on a single land use. There is therefore the need to explore simultaneous soil suitability analysis for several viable crops to determine the overall suitability or versatility. The main objectives of this paper are to i) fit fuzzy membership functions (FMFs) to determine soil suitability for multiple crops; ii) determine the diversity of multiple suitability at each location using the Shannon's Index and equitability equation; iii) determine the overall versatility at the farm scale, and establish a new versatility equation by combining the previous versatility methodology with a diversity index.

Methods

Derivation of soil suitability for crops

The study area is located in the southern region of New South Wales (NSW), Australia, within the Riverina bioregion in SW NSW. It is about 20kms NW of Corowa, which is situated on the Murray River. In deriving the soil suitability for a number of crops a set of rules and suitability scores were based on range of values of each soil quality indicator for the different crop varieties (Table 4.1). Literature and expert opinions on each crop were the main guides for devising the rules. The crops considered in this study were wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), canola (*Brassicaceae* family), peas (*Pisum sativum*), and lucerne (*Medicago sativa*) were predominantly differentially sensitive to soil pH ranges and salt tolerance before loss of yield. They were included in the versatility analysis as they represented the range of crops grown in the district. A few of the soil quality indicators such as CEC, ESP, OC and Ca/Mg ratio, are broadly non-limiting to cropping production across regions.

Creation of continuous soil suitability map for multiple crops for the derivation of soil versatility

In creating the continuous soil suitability maps for each crop, we followed the more efficient procedure of soil suitability analysis prior to interpolation (Figure 1). We then used the resulting crop suitability maps to derive the overall versatility for the multiple crops at each grid location of the continuous maps.

Figure 1. Flow diagram illustrating the method used for determining the suitability maps for individual crop.

In previous studies (Triantafilis and McBratney 1993; Triantafilis *et al*. 2001) versatility was derived through some form of aggregation of soil suitability for multiple crops were derived by arithmetic mean. However, this approach can be limiting because soil versatility is not efficiently accounted for. It also lacks the ability to take into consideration the interaction among the suitability criteria, i.e., the soil quality indicators. By incorporating the diversity measure the overreaching interactions among different uses reinforce the overall versatility. For example when diversity measure is incorporated into versatility analysis based on suitability at two points for each crop are 0.9, 0.8, 0.7, 0.6, 0.5, and 0.7, 0.7, 0.7, 0.7, 0.7 respectively both would have a mean of 0.7 but are characterised by vastly different diversity in terms of suitability for different uses. This may not be appropriate for matching management decisions, as the full understanding versatility is not accounted for. For this reason we combined the classical arithmetic mean versatility (Eq 1) and diversity index or Shannon Index ((Eq 2) at each grid point to create a new versatility.

$$Z = \frac{X_i}{\sum_{i=1}^{n} X_i} \tag{1}$$

where Z is the standardized proportion score for aggregated suitability for each individual crop, X_i is the suitability score of each individual crop;

$$H = -\sum_{i=1}^{n} z_i * \ln z_i \tag{2}$$

where H is Shannon's diversity index, n is the total number of crops, z_i is the proportion of n made up of the ith crops.

Results

Overall the patterns of the soil suitability maps for each crop are quite similar, which was to be expected, as the farm lies in the Wheat Belt of Eastern Australia, mostly invariably suitable for most grain crops. However, there are subtle differences among the various crops. By focusing on a paddock in Figure 2 the subtle differences are obvious. This is demonstrated in the Middle Eastern section of the Figure 2a which map depicts a higher range of suitability for Lucerne than that of Field Pea (Figure 2b), even though the differences are smaller for Lucerne than Field Pea, with more area falling within the 0.78-0.84. Other areas depicting subtle differences in suitability range was the Northern section of the paddock with Lucerne again showing higher values. These subtle differences are further reinforced by statistical analysis. Table 1 presents the overall mean, maximum, minimum and standard deviation of suitability grades for each crop.

Table 1. Statistical breakdown of suitability grades for each crop

Crop	Max	Min	Mean	S.D
Wheat	0.97	0.64	0.83	0.06
Canola	0.95	0.60	0.81	0.06
Barley	0.99	0.59	0.82	0.07
Field Pea	0.98	0.61	0.82	0.06
Lucerne	0.97	0.62	0.83	0.05

The statistical parameters are remarkably similar, indicating little difference among the suitability for the selected crops. However, what the statistical breakdown demonstrates is that all the crops selected for suitability analysis were found to be highly amenable to the soils in the farm with suitability mean values ranging from 0.81-0.83. Even though the statistical analysis does not pick up the subtle differences in the spatial patterns of suitability values (Figure 2), even though the methodology developed could be part of a larger scale analysis such as regional or national to provide a sufficient base for managerial decisions.

Another key objective of this paper was to compare classical versatility analysis reported by Triantafilis and McBratney (1993) and Triantafilis *et al*. (2001) at the farm scale. The result is illustrated in Figure 3a. As this versatility was derived by the summation of the mean suitability values for the five crops, we would expect the versatility to mirror the suitability maps. As such, and like the suitability maps for each crop, the map shows relatively low variability across the study area. Thus the spatial variation in the versatility map epitomizes those of individual suitability maps.

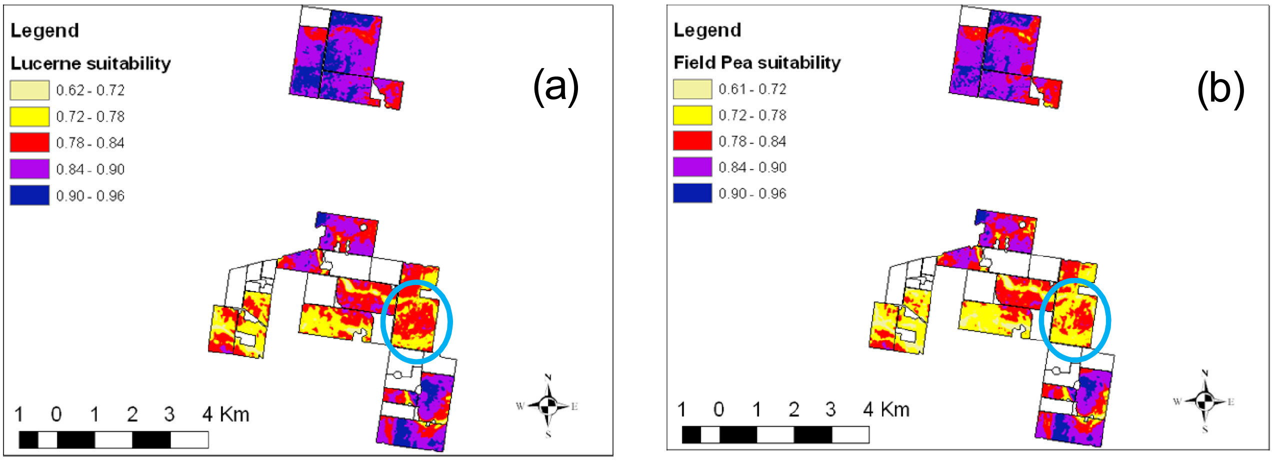

Figure 2. Suitability map for a) Lucerne and b) Field Pea (circle paddock illustrates where subtle differences)

An obvious finding is that relatively high versatility coincides with incidence of large suitability for most of the crops, and vice versa. This is illustrated by the areas with high versatility values >0.83 located in the Northern and Southern paddocks and the mid to low versatility values depicted in the middle paddocks (compare Figure 3b). We opined that this approach does not wholly account for versatility and diversity of suitability for different crops at a given location with respect to adaptability to a variety of crops. Therefore to improve the output and to account for the diversity of suitability, the Shannon diversity index was introduced and the results are discussed in the next section.

As the diversity index was derived using a function equivalent to the one used for species (bio)diversity analysis it is prudent to interpret the results carefully. Firstly, traditionally Shannon's index accounts for both different species and their evenness within a community. It must also be noted that traditionally the results of diversity indices are compared with other communities; for example, diversity of species present in rainforests and grasslands communities could be compared.

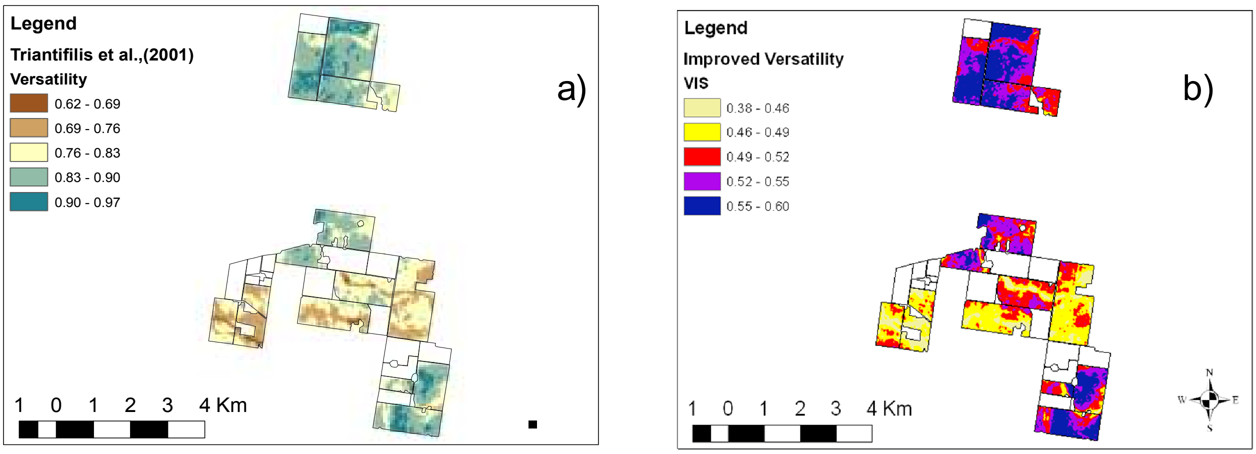

Figure 3. a) Classical versatility map versus b) Improver versatility map

The resulting versatility based on suitability scores, incorporating Shannon's index, assumes a value between 0 and 1, with 1 being the soil is completely versatile; i.e. handle any crop rotation, and 0 meaning the soil is unsuited for multiple crop rotations. The result of this combined versatility-Shannon index is shown in Figure 3b. The map illustrates versatility values that are more diverse than the traditional versatility (Figure 3a) of Triantafilis and McBratney (1993). Both the northern and southern areas depict a mid to versatility range high (0.49-0.60) while the mid areas are portrayed as unsuitable for multiple crop rotations. This information can be vastly beneficial to the landholder when deciding long-term crop rotation and crop selection; it also provides information as to which areas that can be subject to possibly land use change, i.e. revert from cropping to grazing pasture. This point is also emphasised in Triantafilis *et al*. (2001) in which they showed distinct areas as having high potential for different land use.

Conclusion

In this paper the development of an improved versatility analysis for farm scale management decisions was the main objective. Previous methodology was extended by the inclusion of a diversity index. The initial results of soil suitability for individual crops, as illustrated by suitability maps, exhibit equitable means ranging between 0.81 - 0.83. However, the multiple suitability analysis demonstrated subtle differences in the trend or patterns of the individual crop maps. The development of the improved versatility map yielded important information for management decisions. The results indicate that the Northern and Southern paddocks of the study area exhibited higher versatility range than the rest of the farm and would be highly suited for multiple crop rotations. Another pertinent point is that the areas of low versatility had been identified through this process and could then be subjected to further detailed land use assessment to determine alternative land uses best suited for the areas. Both of these points are vastly important in an era of economic uncertainty when efficiency in relation to productivity is essential to the survival of the farm business. As stated earlier the methodology for versatility analysis has not been greatly covered in the literature since the early work of Triantafilis and McBratney (1993) and not at the farm extent and this research would reignite further research in this area.

References

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