Delineation of Site-Specific Management Zones using sensor-based data for Precision N management

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Abstract

Nitrogen is a critical nutrient influencing crop yield, however, the common practice of uniform application of nitrogen fertilizer across a field often results in spatially variable nitrogen availability for the crop, leading to over-application in some areas and under-application in others. This imbalance can cause agronomic and economic losses and significant environmental issues. Precision nitrogen application involves application of N fertilizers based on soil conditions and crop requirements. One approach for precision N application is the delineation of agricultural fields into site-specific management zones (SSMZs) based on soil and crop properties. Integrating macro-scale soil data with micro-scale crop data allows characterizing patterns not observable through either technique alone. With the accessibility and availability of sensors and technologies which could quantify variability in soil and crop properties at different spatial and temporal scales, it is possible to generate maps without the need of destructive soil and crop sampling, and their laboratory analyses. Therefore, this study involves delineating SSMZs in a winter wheat field by characterizing both macro and micro-scale variability in soil and crop. The methodology involves analyzing proximal sensor-derived soil data (soil EC_a*, OM, CEC and slope) and remote sensing-derived (Planet* Labs*) crop vegetative indices at different growth stages to develop SSMZs. The MZs were delineated with Management Zone Analyst (MZA) software which uses fuzzy c-means clustering algorithm. Based on the calculations in MZA, optimum number of zones with lowest Fuzziness Performance Index (FPI) and Normalized Classification Entropy (NCE) were 2. Yields were compared for validating the delineated zones, where zone 1 obtained an average yield of 33.8 bushels per acre, which was statistically different from zone 2*, which obtained *an average yield of 25.6 bushels per acre. These observations suggest that delineating field into zones may provide opportunity for optimizing N management strategies in wheat production.*

Keywords.

Site specific management zones, soil, crop, remote sensing, MZA

Introduction

Nitrogen (N) is a critical nutrient for healthy crop growth and high yields, but uniform application of N fertilizer across fields often results in uneven nitrogen availability to plants, leading to over-application in some areas and under-application in others. This practice is not only uneconomical for farmers but also poses environmental risks. Precision nitrogen application, which involves N fertilizer application to specific soil conditions and crop needs, offers a solution. One effective method for precision N application is the delineation of agricultural fields into site-specific management zones (SSMZs). Previous studies have demonstrated the potential of SSMZs to analyze the spatial variability in yield and differences in crop N uptake across zones in the field (Inman et al., 2005). The SSMZs have been traditionally developed utilizing soil-based properties and historical crop yield data (Hornung et al., 2006), as well as remote sensing-based crop vegetative indices to monitor crop nitrogen variability (Cao et al., 2015). Integrating both macro-scale soil data and micro-scale crop data provides a comprehensive view of variability patterns that single techniques cannot capture alone. With advancements and availability in sensor technologies and remote sensing, it is now feasible to quantify soil and crop variability at different spatial and temporal scales, allowing for the generation of detailed maps without the need for destructive sampling and laboratory analyses. This study aims to delineate a winter wheat field into site-specific management zones by incorporating both macro and micro-scale variability in soil and crop properties. By identifying areas with varied productivity potential, this approach enables the development of tailored nitrogen management strategies based on the specific needs of each productivity zone.

Materials and methods

The study was conducted on a 6.5-acre dryland winter wheat field in Hutchinson, Kansas. The methodology involved collection of proximal sensor-derived soil data, including soil electrical conductivity (ECa) at shallow (30 cm) and deep (90 cm) depths, organic matter (OM), cation exchange capacity (CEC) and slope. Soil data were collected using Veris MSP-3 (Veris Technology, Kansas, USA) on a conventionally tilled field before planting. Crop remote sensing data were obtained at different wheat growth stages (Feekes 4, 6, 8, 10.5 and 11.2) from Planet Labs (Planet Labs PBC, California, USA) satellite imagery with a spatial resolution of 3m. The vegetative indices derived from satellite data included normalized difference vegetation index (NDVI) and normalized difference rededge index (NDRE).

The collected data were uploaded in ArcGIS Pro (ESRI, California, USA), and were processed, and resampled to point data at same spatial scale. Processed data were analyzed using the Management Zone Analyst (MZA) software, which uses fuzzy c-means clustering algorithm to delineate zones in the field. Optimum number of zones were determined by calculating Fuzziness Performance Index (FPI) and Normalized Classification Entropy (NCE), with the lowest values indicating the best clustering solution.

Spatial interpolation technique "Kriging" was used to transform point-clusters to raster-zones in ArcGIS Pro. Crop yield was measured using a Kincaid plot-combine harvester, where the quantity of grain obtained in each plot was used to determine yield in kilograms per hectare (kg/ha).

Results

Analysis of sensor-derived soil and crop reflectance data were analyzed in MZA yielded optimum number of zones as 2. These were based on the minimum values for normal classification entropy (NCE) and fuzziness performance index (FPI) (Fig. 1 & 2, respectively). Crop yield data were used to compare the two management zones. It was observed that Zone 1 obtained an average yield of 2271.4 kg/ha, whereas Zone 2 obtained an average yield of 1719.6 kg/ha. The yields were significantly different, with a p-value of 0.0001. This significant difference in yield between the zones attested to the effectiveness of delineated zones.

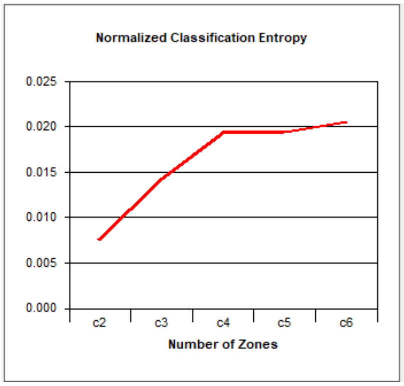

Fig. 1: Normalized Classification Entropy (NCE)

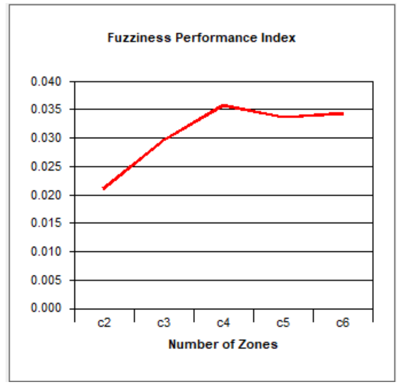

Fig. 2: Fuzziness Performance Index (FPI)

Conclusion

Delineating agricultural fields into site-specific management zones using proximal sensor-derived soil data and crop vegetation indices from remote sensing provides an effective method of classifying field into areas of different productivity potential. The significant yield difference between the zones implies that there are different productivity potential areas in the field, where different N fertilizer application strategies need to be followed. These strategies can help in improving nitrogen use efficiency (NUE) and reducing environmental impacts.

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