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Delineation of nutrient management zones in Chunian using soil attributes database developed by soil fertility research institute, Punjab, Pakistan

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Abstract

A significant increase in food production, approximately 70%, is needed to feed the estimated 9.1 billion world population by 2050. Site-specific nutrient management through adoption of Precision Agriculture (PA) technologies can potentially increase crop productivity while keeping the use of chemical fertilizers at its minimum required level. In this study, agricultural land of tehsil Chunian was delineated into management zones using georeferenced soil attributes database developed by Soil Fertility Research Institute (SFRI), Punjab. Appropriate number of zones was determined after conducting fuzzy c-means unsupervised clustering analysis by using Management Zone Analyst (MZA) software and finally Quantum Geographic Information System (QGIS) was used to differentiate study area into five zones. Analysis of variance was performed to verify whether these defined zones reflect soil attributes. We concluded that tehsil Chunian could be categorized into five statistically different management zones based on soil electrical conductivity (EC), pH, soil organic matter (SOM), available potassium and available phosphorus levels. The highest crop yield was predicted in southeastern parts of tehsil Chunian represented by management zone-2 (4.4 t ha^{-1}) followed by zone-1 (4.3 t ha^{-1}). Whereas, northern and northwest areas were predicted with decreasing trend of wheat yield (zone-5, 3.7 t ha^{-1}; zone-4, 4.0 t ha^{-1}), respectively. We found that MZA and QGIS software could be used as supportive tools for making informed-decisions and the database of soil attributes developed by SFRI would serve as primary source of information for adoption of PA technology in coming years.

Introduction

An approximate 70% increase in food production is needed to feed the 9.1 billion world population by 2050 (FAO, 2009). This significant increase is not possible without the use of fertilizers. It is assumed that 50% of the world's food could be produced by using Haber-Bosh reactive nitrogen (Jensen *et al.*, 2011). Considering the important role of N to achieve high crop yield potentials; global use of N fertilizers have increased up to 9 folds since 1960s and further increase of 50% is expected by 2050 (Sutton *et al.*, 2013). If this increase is considered as inevitable, it should be site-specific keeping in view the temporal and spatial variability within the field. Uniform-rate application of agricultural inputs besides being expensive has potential environmental and agronomical limitations (Maleki *et al.*, 2007). It is estimated that injudicious use of fertilizers is causing an approximate damage cost of $170 billion annually to global ecosystem (Sutton *et al.*, 2013). Therefore, site-specific nutrient management by utilizing PA technology could manage over or under-application of agricultural inputs which would not only increase production but also reduce input costs (Maleki *et al.*, 2007).

In addition to negative climatic impacts of overdose application of fertilizers, the energy issues related to their production are also worth considering. The energy consumption starting from manufacturing, transportation and soil-application of these fertilizers is substantial and significantly contribute to production cost of agricultural produce. Almost 37% of total input cost is spent on fertilizers (NFDC, 2018). Global energy crisis is limiting the access to nutrient inputs particularly N fertilizers which are primary agricultural inputs (Liska and Perrin, 2011).

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Challenges such as enhancing crop productivity and related issues of boosting energy cost for plant nutrient production, and its potential negative impact on climate necessitates the judicious use of chemical fertilizers. It is also imperative to reconsider the nutrient use efficiency of fertilizer inputs (Liska and Perrin, 2011).

Adoption of PA technology has potential to increase crop productivity while keeping the use of chemical fertilizers at its minimum required level. Fertilizer application rates can be adjusted using GIS-technology after precise estimation of site-specific crop needs. This will potentially increase resource use efficiency.

The first step towards adoption of PA in Punjab, Pakistan is the development of digital maps representing fertility related attributes of agricultural land. Different information sources such as aerial photography and remote sensing etc. are used for categorization of field into homogeneous subplots. However, soil attributes estimated after soil sampling and chemical analysis give detailed, precise and accurate description of field as compared to other sources (Franzen, 2007).

Soil Fertility Research Institute (SFRI), Punjab, Lahore, under the leadership of Dr. Shahzada Munawar Mehdi, took an initiative step and developed a web-based database which is freely accessible to farming community. Farmers and researchers can visualize and explore the soil attributes of their farm area to make appropriate management decisions (Mehdi *et al.*, 2013). Continuing the process of development, SFRI is further expanding and updating the previously developed digital map of soil attributes of agricultural land in Punjab. To make the digital database more precise, the sampling grid cell size has now reduced to 10-acres (40469 m^2). Estimated 2.8 million soil samples from 24000 villages of Province Punjab will be collected and 5.2 million farmers will get benefit in a stipulated period of 5 years (GOP, 2018).

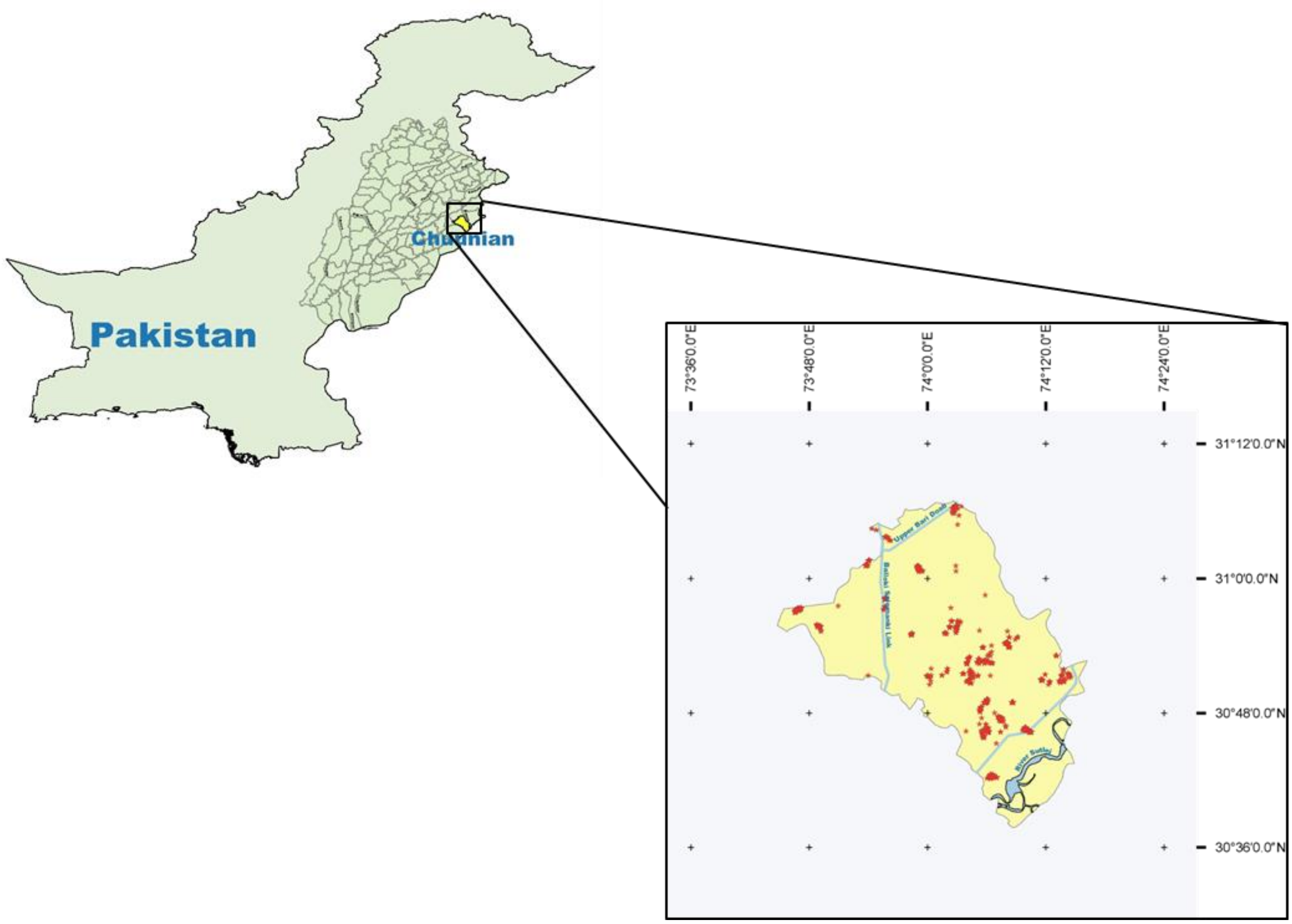

Figure 1: Location of the study area. Solid circles represent the georeferenced soil sampling points. River Sutlej and Upper Bari Doab canal are represented in blue color.

This study was undertaken with the hypothesis that soil attributes such as EC, soil pH, SOM, plant available phosphorous and potassium of tehsil Chunian contribute to crop yield and could be used to delineate field into nutrient management zones.

Materials and Methods

A total of 546 georeferenced soil samples were collected, air-dried, passed through 2mm sieve, labelled and stored in plastic bottles. Standard procedures were followed for estimation of EC, soil pH, SOM, plant available potassium and phosphorous described in Richard (1954) and (Ryan *et al.*, 2007).

Use of MZA and QGIS as an example

Different software packages of GIS are available to delineate field into management zones. However, these are cumbersome and need proper training to use them. Conversely,

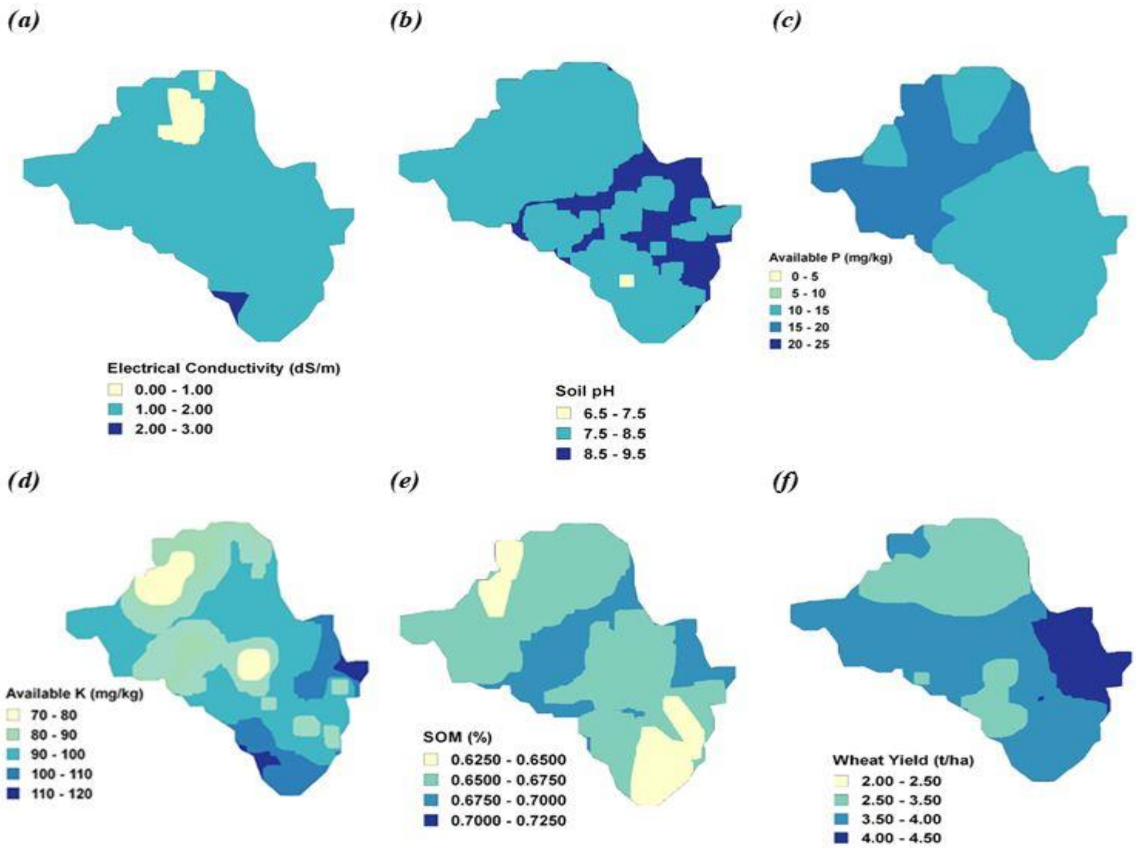

Figure 2: Kriged maps of soil attributes used for fuzziness c-means clustering analysis in Management Zone Analyst (MZA) computer program; (a), (b), (c), (d), (e), and (f) show the maps of electrical conductivity, soil pH, available phosphorous, available potassium, soil organic matter and wheat yield, respectively.

Table 1: Descriptive statistics of soil attributes and wheat yield in study area

	Predicted values				
Variable	**Minimum**	**Maximum**	**Mean**	**S. D.**	**CV (%)**
EC (dSm^{-1})	0.94	2.12	1.49	0.339	22.68
pH	7.33	9.36	8.48	0.097	1.15
SOM (%)	0.629	0.707	0.670	0.015	2.24
Avail. P (mg kg^{-1} soil)	13.3	16.1	14.9	0.510	3.42
Avail. K (mg kg^{-1} soil)	64.9	126.2	94.2	7.917	8.41
Yield (t ha^{-1})	2.90	4.40	3.71	0.320	8.61

EC, electrical conductivity; SOM, soil organic matter; Avail. P, available phosphorous; Avail. K, ammonium acetate extractable potassium.

Management Zone Analyst (MZA) is an easy-to use software program which helps to determine the appropriate number of homogeneous zones in a field. The MZA divides a field mathematically into natural clusters or subplots by using quantitative and georeferenced soil attributes. The software (MZA) is freely available at official website of United States Department of Agriculture (USDA, 2000).

Fuzzy *c*-means unsupervised clustering algorithm is used in MZA for data clustering. Observations close to the cluster center are grouped in same cluster. Generally, three methodologies namely Euclidean, Diagonal and Mahalanobis are available in MZA program to measure the similarity of an observation to a cluster center. The Euclidean distance methodology identifies similarity based on correlation between attributes, however, it generates spherical clusters which generally do not exist. This issue is compensated by diagonal-distance measurement of similarity which assumes the shape of cluster after weighting the variances of measured attributes. The Euclidean distance is suitable when attributes are independent and show equal variance whereas diagonal distance deals with independent attributes having unequal variances. The Mahalanobis distance measures similarities when attributes are correlated and variances are unequal (Fridgen *et al.*, 2004).

index (FPI) to determine the appropriate number of zones of a field. The FPI value ranges from 0 to 1 and represents the degree of membership sharing among clusters. Values close to 1 indicate larger degree of sharing and non-distinct classes whereas values close to 0 represents distinct classes with less membership sharing (Fridgen *et al.*, 2004). Georeferenced values of soil EC, pH, SOM, P and K were used as classification variables. These values were gridded to 100-m cell and then kriged. Data files were saved as comma-delimited text file and imported to QGIS and MZA for development of kriged maps and descriptive statistics, respectively, (Figure 2 and Table 1). Projected Coordinated System WGS 1984 UTM: Zone 43 was used to georeferenced the base map and sampling points.

Statistical analysis

A post-hoc Tukey's test was performed using RStudio, computer program, to determine which predicted zones were statistically different in wheat yield.

Results

Statistical analysis of predicted soil pH of study area showed an increasing trend of alkalinity with mean value of 8.48. The mean EC value is 1.49 dSm^{-1}. The higher coefficient of variations (CV, 22.68%) of EC due to real difference

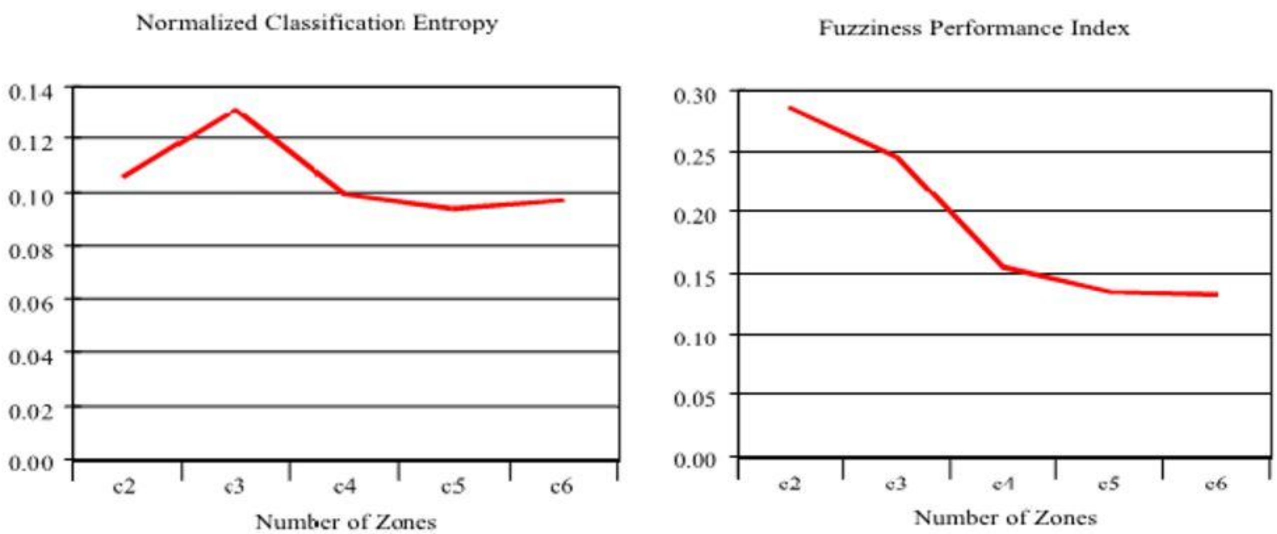

Figure 1: Fuzziness Performance Index (FPI) and Normalized Classification Entropy (NCE) of soil attributes. The lowest number of clusters produced by FPI and NCE are five.

MZA settings used in this study were as follows: Mahalanobis measure of similarity was used for clustering, fuzziness exponent was 1.3 with maximum numbers of iteration of 300. Convergence criterion was 0.0001. Management Zone Analyst provides fuzziness performance

between samples shows heterogenity in topsoil salinity. The soil fertility level fall in medium category regarding available P, available K status when compared with criteria set by SFRI (Malik *et al.*, 1984). Soil organic matter status of study area was in poor category (Table 1).

The smallest number of clusters suggested by FPI and NCE after fuzzy c-means analysis in MZA could be used to subplot the field into management zones (Fridgen *et al.*, 2004). The MZA suggested five management zones for area under study as the FPI and NCE values were lowest for five clusters. Hence, we categorized agricultural land of tehsil Chunian into five management zones using soil EC, pH, SOM, P and K as input variables for Fuzzy c-means clustering analysis (Figure 3). Analysis of variance (n=546) verified that soil attributes in each of defined zone were statistically different from others (Table 2).

Management zones

The five management zones map was finally developed using the MZA output data. The names of villages in each defined zone are also presented in map (Figure 4).

Discussion

Delineation of agricultural land into management zones would provide useful information to producers and policymakers to make informed decisions for sustainable

Table 2: Analysis of variance of soil attributes in defined zones

Management zones	Soil attributes					
	EC (dS m-1)	pH	SOM (%)	avail. K (mg kg-1)	avail. P (mg kg-1)	Yield (t ha-1)
Zone-1	1.76	8.54	0.65	99.5	14.4	4.3
Zone-2	1.73	8.53	0.67	101.4	14.6	4.4
Zone-3	1.78	8.52	0.68	94.0	14.7	4.1
Zone-4	1.15	8.41	0.66	88.4	15.4	4.0
Zone-5	1.11	8.39	0.67	91.8	15.3	3.7
P value (zones)	0.001	0.001	0.001	0.001	0.001	0.001

EC: electrical conductivity; SOM: soil organic matter; avail K: plant available potassium; avail P: plant available phosphorous.

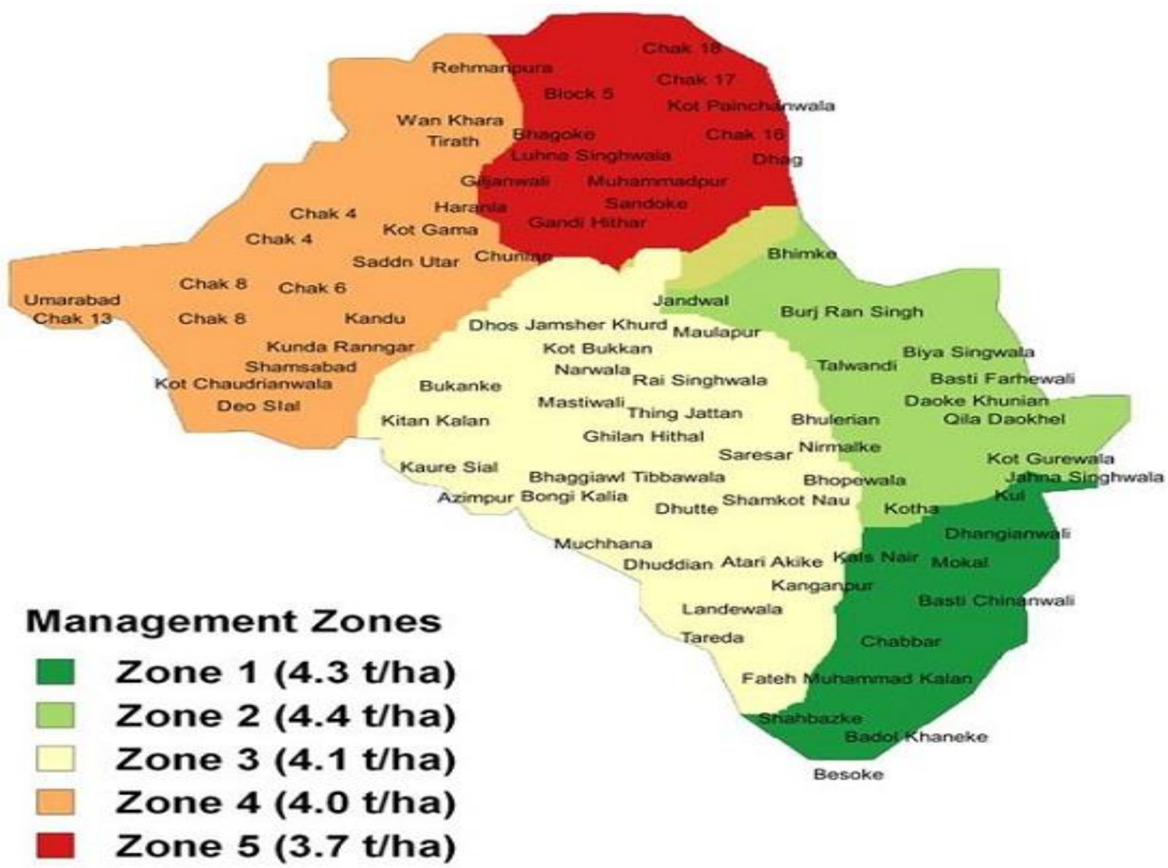

Figure 4: Five distinct management zones with names of villages

use of land resources. Scientific land-use plan after proper validation can be suggested for defined zones to protect cultivated land from potential degradation due to inappropriate land management practices. The highest crop yield was predicted in southeastern parts of tehsil Chunian represented by management zone-2 (4.4 t ha^{-1}) followed by zone-1 (4.3 t ha^{-1}). The mean EC values for zone 1 and 2 were 1.76 and 1.73 dS m^{-1}, respectively, (Table 2). The highest value for available potassium (101.4 mg kg^{-1}) was found in zone 2. These management zones (1 & 2) are situated in proximity to river Sutlej which could be the one reason for higher value of plant available potassium. MZA has predicted significantly higher yield in these zones in comparison to other zones. Northern and northwest areas were predicted with decreasing trend of wheat yield (zone-5, 3.7 t ha^{-1}; zone-4, 4.0 t ha^{-1}), respectively. Minimum wheat yield (3.7 t ha^{-1}) was predicted in zone-5 (Table-2, Figure. 4).

Management zone maps were developed using correlation between soil fertility attributes and wheat yield. These correlations could be used to set the fertilizer recommendations at village-level. It is reported that besides reducing sampling density, zone-based fertilizer recommendations has produced significantly higher yield when compared with farmer practice and State recommended fertilization in India (Iftikar *et al.*, 2009). The zone-based fertilizer recommendations can be readjusted by conducting field trials in defined management zones.

Management zone could help farmers to adopt variable rate application (VRA) technology intuitively. It would potentially increase resource use efficiency by apply agricultural inputs in zones according to the need. Wittry and Mallarino (2004) has reported higher productivity due to VRA of phosphorous fertilizers in comparison to uniform fertilization. Similarly, VRA of nitrogen fertilizers (e.g. Urea) across different nutrient management zones could give better response of wheat yield while reduced fertilizer dose from 12 to 41% when compared with conventional uniform-rate application method (Farid *et al.*, 2013). Computer guided variable rate applicator can be used to control the application-rate of agricultural inputs considering within field spatial variability.

Conclusions

Digital map of soil attributes of a region has utmost importance for efficient resource management and making sustainable management policies. The digital map developed by Soil Fertility Research Institute, Punjab, would serve as primary source of information for adoption of PA technologies in coming years. We conclude that categorization of tehsil Chunian into five management zones based on soil attributes could help to make better nutrient management decisions. Zones with lower predicted yield should be focused to improve soil fertility status. The Management Zone Analyst software (MZA) can be used to determine the appropriate number of zones for management of plant nutrients. However, more research is needed to precisely delineate the agricultural land of Punjab into management zones.

Acknowledgements

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