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Correlation of Spatial Variability of Soil Macronutrients with Crop Performance by Using Satellite and Remote Sensing Indices for Site Specific Agriculture: Chakwal Region

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Abstract

Site-specific agriculture includes the application of soil on variable areas rather than the whole field and requires the knowledge of spatial variability of soil nutrients in the area. A survey was conducted to find out the spatial variation of soil macronutrient, to prepare the soil fertility maps and to correlate soil nutrients with NDVI values, at University Research Farm, Koont, Chakwal. Soil samples were collected and analyzed for soil macronutrient (NO_3-N, P, K, SO_4-S and $CaCO_3$) concentration through standard procedures. Obtained data were analyzed by using GIS and ordinary statistics to predict the spatial variability and preparation of digital maps of the soil macronutrients. NDVI values were calculated by acquiring the cloud free landsat images of study area to correlate with soil macronutrients. The results showed that, NO_3-N and Available P were deficient in study area and were having the mean value of 7.54 mg kg^{-1} and 6.64 mg kg^{-1} respectively. K and SO_4-S were in satisfactory ranges and were having average values of 130.3 mg kg^{-1} and 8.69 mg kg^{-1} respectively. Study area was classified as moderately calcareous soil and lime content were having the mean value of 7.88%. Geostatistical analysis showed that NO_3-N and available P were strongly spatial dependent while K, SO_4-S and $CaCO_3$ were moderately spatial dependent. Pearson correlation analysis among NDVI values and soil parameters showed that NO_3-N, P, K and $CaCO_3$ were significantly positively correlated with NDVI values whereas SO_4-S showed non-significant positive correlation with NDVI values. Study recommended that spatial variability of soil properties should be taken in account in decision making processes regarding farm operations such as fertilizer application, more studies on different spatial scale should be conducted and use of such techniques in profitable and sustainable site-specific agriculture should be promoted.

Keywords: Site-specific farming; GIS; Spatial variation; Digital maps; NDVI

Introduction

Blind and uniform application of fertilizer, without knowledge of farm fertility status and spatial variability of nutrients is a common problem in this era that lead to the reduction of farmer profit. It has been observed in several studies that soil nutrients vary spatially in the fields [1]. Site specific agriculture is based on the management of spatial variation of soil nutrients by the application of amendments according to the specific site and crop [2]. Quantification and awareness of spatial variability of soil properties is a key for such type of management practices [3].

Different technologies have been developed that make us enable to improve the application of different amendments in accordance to their need [4]. Geostatistical approach is very supportive for the assessment of spatial varability as well as to predict the values at unsampled location of the study area [5]. Spatial variation and digital mapping of OM content were studied by many workers to develop the site specific agriculture technology for different areas [6-8]. Geostatistics is a statistical method that can be successfully used in soil science for preparation of maps and to estimate the soil properties at unsampled location [9]. Geostatistics has been proven a suitable technique for the evaluation and description of spatial pattern of soil properties and wheat yield. Identified spatial pattern and wheat yield by geostatistical and semivariogram analysis has been found helpful for the division of fields into different management zones such as fertilizer management, as well as gypsum application for reclamation of salt affected areas. Krigging and semivariogram was found helpful for the prediction of soil properties at unsampled locations [10].

Krigging is a technique that is used for the interpolation of unknown sites from measure sites to study the spatially variable processes. The term krigging is a generic name that has been adopted to appreciate the pioneer work of Daniel Krige. Kriging is the one-sided average that is based on the known spatial dependence as shown by the semivariogram. It is able to provide more reliable description of spatial pattern for the soil characteristics than all other interpolators as observed in many comparative studies [11]. Noor et al. [12] in 2013 conducted a research trial for the estimation of spatial variability of micronutrients in citrus orchards by using krigging technique. The results revealed that almost all maps shown that micronutrients varies spatially in the field.

The Normalized Difference Vegetation Index (NDVI) shows patterns of vegetative growth from green-up to senescence by indicating the quantity of actively 4 photosynthesizing biomass on a landscape [13]. Verhulst et al. [14] demonstrated that the spatial variability of soil properties influence the crop performance and is correlated with the NDVI values by affecting the spectral characteristics of vegetation. Ma et al. [15] showed that higher the nitrogen contents increase the chlorophyll content and leading to increased NDVI values.

Keeping in view the above scenario a study was designed with the aim to examine the spatial variation of soil nutrients at farm level, to prepare the soil fertility maps and to correlate NDVI values and soil macronutrient status of University research farm Koont, Chakwal.

Materials and Methods

Study area and soil sampling

Study was conducted at University Research Farm Koont, Chakwal, Pakistan (N33° 6' 42.54" to N33° 7' 16.98"and E73° 0' 24.3" to E73° 1' 15.54") with an altitude of 1645 m to 1703 m above from sea level. The study area was about 100 hectors. Mainly parent material of the soil is derived from shale and sandstone, with humid t sub-humid climate and annual average rainfall is 350-500 mm. the mean annual monthly temperature is 5.9-38.4°C. Soil sampling was done at depth of 0-20 cm with 30 × 30 m grid spacing and location was recorded by global positioning system (GPS) receiver.

Soil analysis

All samples were analyzed for NO_3-N [16], Available P [17], Extractable K [18], SO_4-S [19] and $CaCO_3$ [20].

Statistical and geostatisical analysis

ArcGIS 10.1 software was used for statistical and geostatistical analysis of the data. Semivariogram analysis was done to calculate the nugget to sill ratio, which indicates the degree of spatial dependence by using uniform interval to establish the range of spatiality. According to criteria given by Attar et al. [21] spatial dependence is classified in to weak (ratio >75%), moderate (ratio 25-75%) and strongly spatial dependent (ratio <25%). Other statistical parameters of data such as mean, minimum, maximum and standard deviation (S.D) were also calculated. Co-efficient of variance (CV) was calculated to check the variation of soil nutrients in soil. Soil nutrients with CV<15% were grouped as least variable, nutrients with CV value 15-35% were moderately variable while nutrients with CV value >35% were grouped as highly variable Wilding [22]. Co-efficient of skewness and kurtosis were calculated to check the normality of distribution of data and our data did not show the normal distribution, so the data was log-transformed. Log transformed data made it clear that data was normally distributed. Data was cross validated by plotting a graph between the measured values on X-axis and predicted values on Y-axis which lead to the plotting a QQ plot between standardized error on Y axis and Normal value on X-axis to show the quantiles of difference between estimated and predicted values and relating quantiles from a standard normal distribution.

Digital mapping

Soil fertility maps of study area were prepared by using ArcGIS 10.1 software indicating the concentration of macronutrients at different locations of the area. GPS points of each sample were used to prepare the maps.

NDVI mapping and Correlation of NDVI and soil macronutrients

NDVI maps of studied area were prepared by obtaining cloud free landsat images for one year duration to calculate the NDVI values by using formula given by Chaudhury [23]. Pearson correlation analysis was done to find the co-efficient of correlation among NDVI values and soil macronutrients. To minimize the error NDVI values of fallow fields were excluded in correlation analysis.

NDVI=(pNIR-pR)/pNIR+pR

Results and Discussion

Basic soil analysis of study area

According to the results pH was ranging from 7-8.5 with mean value of 7.72. Study area was free from salinity hazards and EC was ranging from 0.06 dsm^{-1}-0.47 dsm^{-1} with mean value of 0.246 dsm^{-1}. Overall there was deficiency of OM content in study area and OM contents were ranging from 0.1-1.6% with average value of 0.63%. Most of the samples were falling in sandy loam textural class whereas silt clay loam and sand clay loam classes were also observed in some samples. Sand contents were ranging from 18%-77% with average value of 57.6%, silt contents were falling in the range of 3%-70% with mean value of 30.1%,while clay contents were observed in the range of 3%-33% with mean value of 12.16%. All results are enlisted in Table 1.

Soil properties	Minimum	Maximum	Mean
pH	7	8.5	7.72
EC (dsm^{-1})	0.06	0.47	0.246
OM content (%)	0.1	1.6	0.63
Sand content (%)	18	77	57.6
Silt content (%)	3	70	30.1
Clay content (%)	3	33	12.16

Table 1: Basic soil analysis of studied area.

Status of soil nutrients in study area

Nitrate nitrogen content were ranging from 1.053 mg kg^{-1} to 16.18 mg kg^{1} with the average value of 7.54 ± 2.21. About 95% samples were found deficient in NO_3-N while 5% samples were marginal according to the criteria suggested by Malik et al. Deficiency of nitrogen in these areas is due to less organic matter contents in these soils due to climatic conditions and less use of organic amendments. Rizwan et al. [24] described almost similar results, Nitrate nitrogen was varying from 1.37 to 18.74 mg kg^{-1} with the average value of 7.89 mg kg^{1} while they were working on same study area. About eighty five percent samples were found deficient and the difference in the results might be due to the temporal and seasonal variation in concentration of nitrate nitrogen in the area. The available P was ranging from 1.29 mg kg^{-1} to 23.6 mg kg^{-1} with the mean value of 6.64 ± 3.17. About 78% samples were deficient in available P, 19% samples were in satisfactory ranges while 3% samples shown adequate level of available P. Ahmad and Khan [25] declared almost similar results, that 70-95% soils have deficiency of available P. The reason of low available P is pH factor as most of soils were alkaline in study area which lead to the fixation of P

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with basic cations. Potassium was ranging from 81.98 mg $kg^{-1}$to 256.78 mg kg^{-1} in surveyed area with the mean value of 130.3 ± 30.47. It was found that 86% samples were in satisfactory range, 13% samples showed sufficient K contents while the rest of 1% were having adequate K level. Khalid et al. [26] found the similar results and 62% samples were in satisfactory ranges. The reason of presence of adequate K concentration is most of the soils are dominant in mica minerals that is able to supply K to soil solution and plants. SO_4-S was ranging from 3.3 mg kg^{-1} to 20.23 mg kg^{-1} with the mean value of 8.69 ± 3.15. About 95% samples were marginal in S, 4% samples were deficient while rest of samples shown adequate level of S contents. Deficiency of sulfur is due to less OM contents in these soils. Ahmad et al. [27] claimed that well drained and light textured soils with higher rainfall in pothowar region are generally deficient in S content. While $CaCO_3$ contents were ranging from 4.77% to 11% with mean value of 7.88 ± 1.57 and soil were classified under weakly to moderately calcareous due to calcareous nature parent material. Shaheen et al. [28] also observed almost similar results and $CaCO_3$ were ranging from 5.1 to 17.5% and soils of pothowar region were classified as moderately to strongly calcareous. All results are enlisted in Table 2.

Nutrient	Min.	Max	Mean	S.D[1]	C.V%[2]	Kurtosis	Skewness
NO_3-N	1.053	16.18	7.54	2.21	29.31	4.23	-0.077
Available P	1.29	23.5	6.64	3.17	47.74	9.85	1.99
Available K	81.98	256.78	130.3	30.71	23.56	3.84	1.2
Sulfate sulfur	3.3	20.23	8.69	3.15	36.25	4.63	1.28
$CaCO_3$%	4.77	11	7.88	1.57	19.92	2.04	-0.043

Table 2: Assessment of macronutrient contents (mg kg^{-1}) of studied area. [1]Standard Deviation, [2]Co-efficient of variance.

Geostatistical analysis of the data

QQ plot assured the normal distribution of the data (Figures 1,3,5,7 and 9) and semivarience curve was obtained to check the degree of spatial dependence of data (Figures 2,4,6,8 and 10). And spherical model was best fitted for all nutrients. Nitrate nitrogen was found moderately variable with CV% 29.31 (Table 1). Non Log transformed data of Nitrate nitrogen showed the range of 1.23855Ao, data was strongly spatial variable as indicated by and nugget to sill ratio which was 13.784%. Available phosphorus was found highly variable within the study area with higher CV% of 47.74 (Table 1). Log-transformed data of available P contents and the range was 1.23855Ao. Nugget to sill ratio was 23.64% indicating strong spatial dependence of available P within the field. Extractable Potassium contents exhibited a weak variability with in the field with CV% 23.56 as listed in (Table 1). Extractable K was having the range of 1.23855Ao and Nugget to sill ratio was 38.23% pointing out the moderate spatial variability of K concentration with in the fields. Sulfate sulfur showed that there was a high variation in its concentration within the field CV% of 36.65 with as listed in (Table 1). Sulfate sulfur was having rang of 8.6691 Ao while Nugget to sill ratio was 38.90% giving an indication of moderate spatial variation of the sulfur. A weak variation in concentration of Calcium was reported with CV% of 19.92 as shown in (Table 1). Lime was having the range of 6.52826 Ao. Semivariogram analysis of lime contents showed nugget to sill ratio was 32.73%, indicated the moderate spatial variability of lime contents. All the geostatistical data is summarized in (Table 3).

Parameter	Model	Range(A_0)	Ratio[1](%)
Nitrate-Nitrogen	Spherical	1.23855	13.78
Available P	Spherical	1.23855	23.64
Extractable K	Spherical	1.23855	38.23
Sulfate sulfure	Spherical	8.6691	38.9
Calcium carbonate	Spherical	6.52826	32.73

Table 3: Semivariogram of the macronutrients in studied area. [1]Nugget to sill ratio.

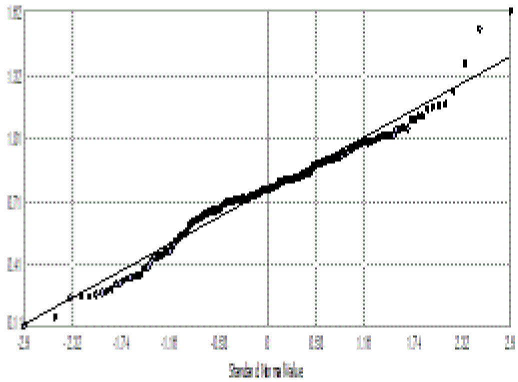

Figure 1: QQ plot of NO_3-N.

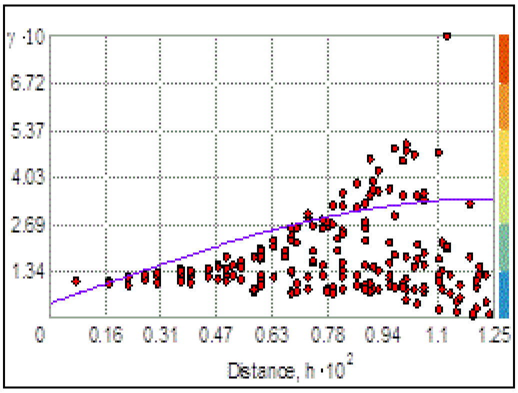

Figure 2: Semivariogram of NO_3-N.

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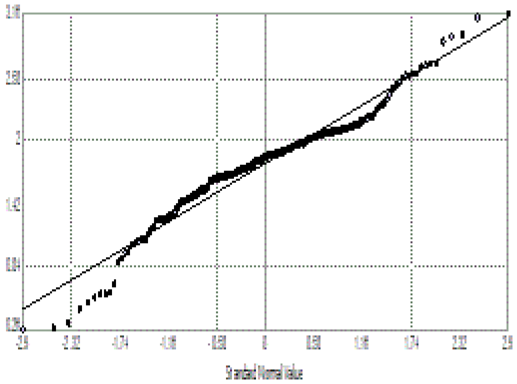

Figure 3: QQ plot of available P.

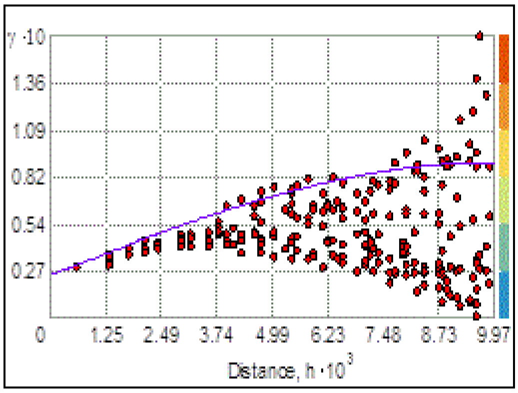

Figure 6: Semivariogram of extractable K.

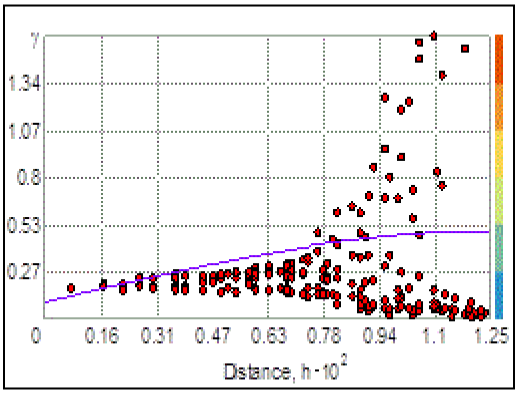

Figure 4: Semivariogram of available p.

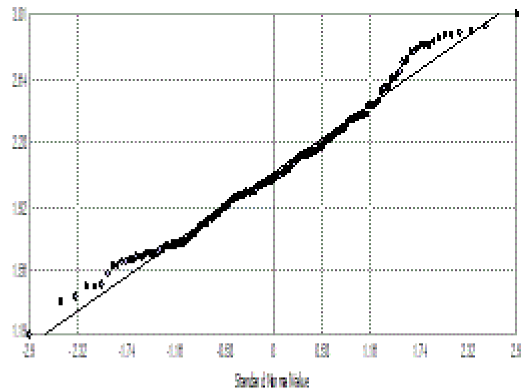

Figure 7: QQ plot of SO_4-S.

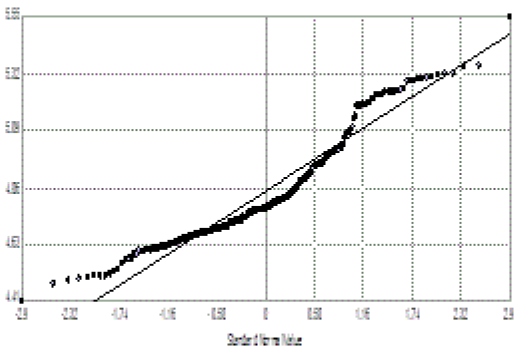

Figure 5: QQ plot of extractable K.

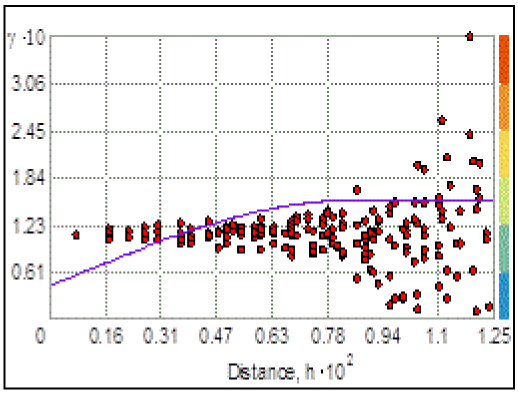

Figure 8: Semivariogram of SO_4-S.

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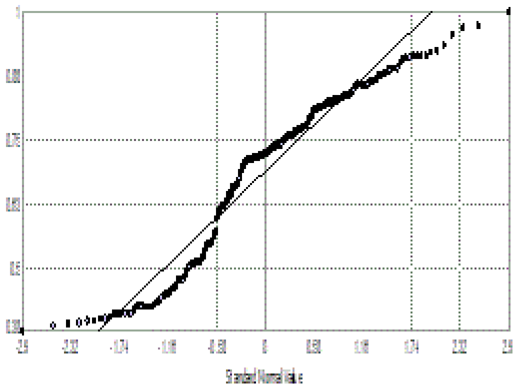

Figure 9: QQ plot of $CaCO_3$.

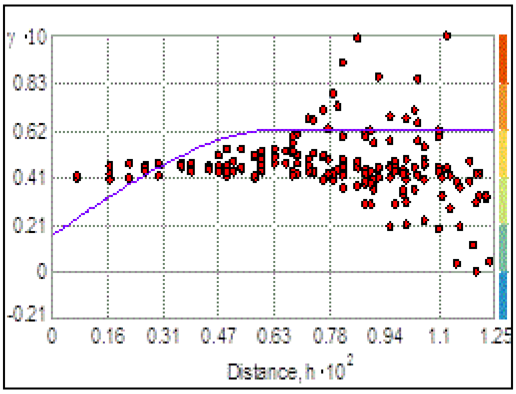

Figure 10: Semivariogram of $CaCO_3$.

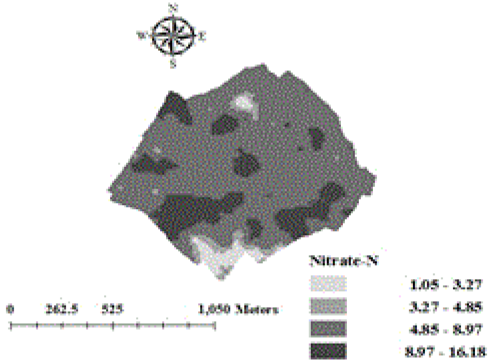

Figure 11: Digital map of NO_3-N.

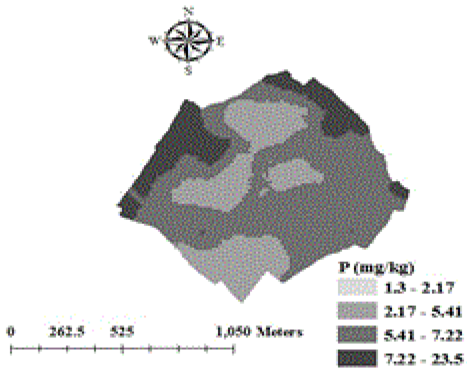

Figure 12: Digital map of available P.

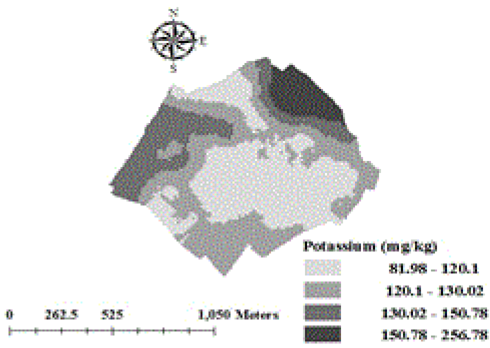

Figure 13: Digital map of extractable K.

Digital mapping

According to the prepared maps, it has been indicated that there was severe deficiency of NO_3-N in over all study area however, some southern parts of studied area were containing moderate concentration of available N. Overall in the studied area there were patches having higher N contents. Keeping in view the map, the area was categorized as low in N although some area was in moderate ranges (Figure 11). The map showed that northern and western edges of studied area were containing higher available P contents while some southern and central parts of the studied area were containing lower contents of available P. Moreover, rest of the area was deficient available P contents (Figure 12). Available K contents were in satisfactory ranges in most parts of surveyed area, however it as found marginal in central parts of the studied area. The map showed that northeastern and southwestern parts of the area were containing higher amount of extractable K (Figure 13). Sulfate S contents were falling in moderate ranges in area while northeastern boundaries and southwestern parts of the surveyed area were lower in S concentration (Figure 14). Southern parts were containing lower concentration of lime and it was observed that some patches in central parts with lower lime contents, while the eastern parts were containing higher contents of lime as shown in Figure 15.

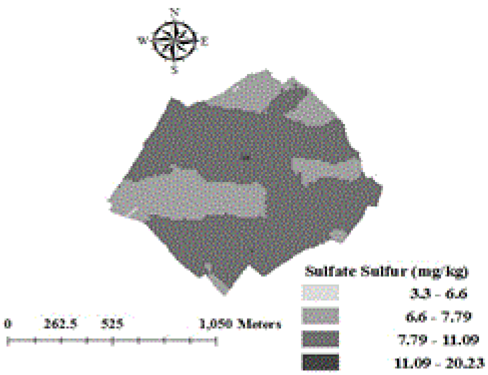

Figure 14: Digital map of SO_4-S.

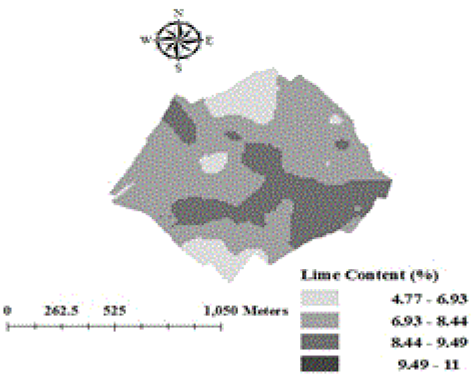

Figure 15: Digital map of $CaCO_3$.

NDVI mapping

The Normalized Difference Vegetation Index (NDVI) shows patterns of vegetative growth from green-up to senescence by indicating the quantity of actively 4 photosynthesizing biomass on a landscape [13]. Landsat images of study area were acquired for one year duration. Cloud free images were used for NDVI calculation according to the prescribed procedures. Figures 16-24 show the NDVI maps of the study area for different dates. A large temporal as well as spatial variation was observed in the NDVI of the study area. The diversity of crops sown and their low density resulted in the relatively smaller NDVI values. Other reasons of lower NDVI values might be the irregular cropping pattern and the difference in sowing time of the crops.

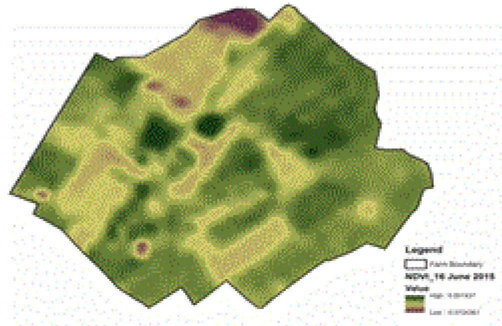

Figure 16: NDVI of 16 June 2015.

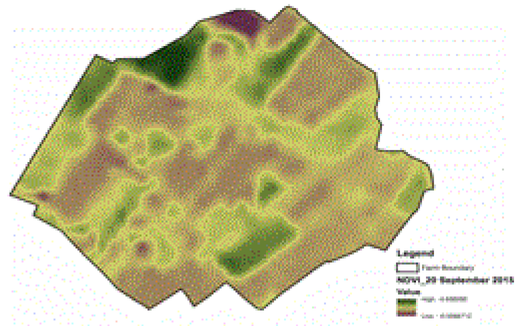

Figure 17: NDVI of 20 Sep. 2015.

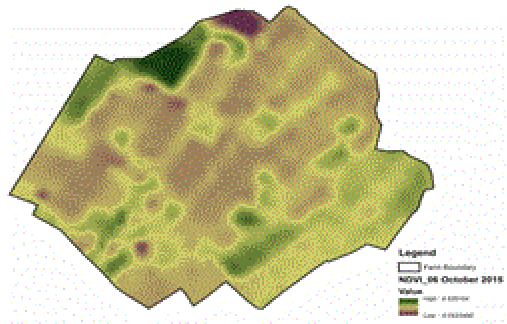

Figure 18: NDVI of 06 Oct. 2015.

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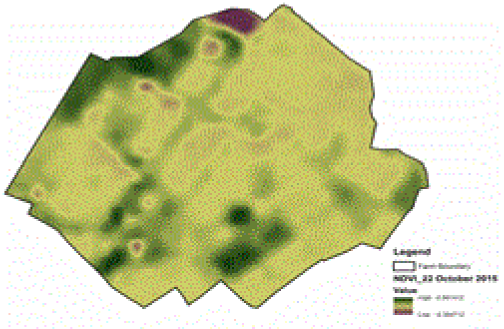

Figure 19: NDVI of 22 Oct. 2015.

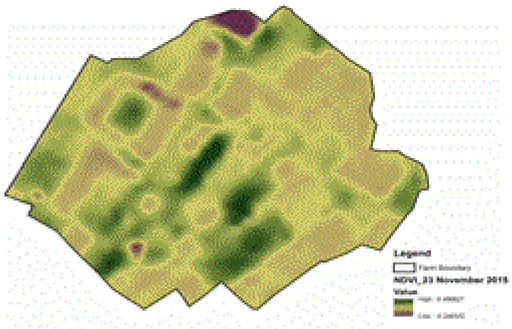

Figure 20: NDVI of 23 Nov. 2016.

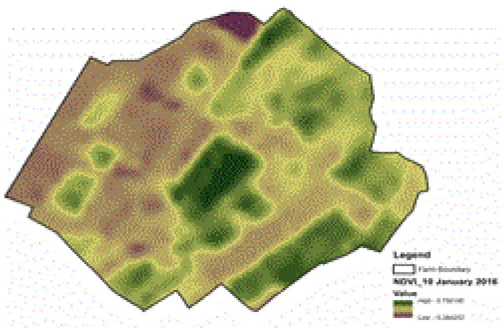

Figure 21: NDVI of 10 Jan. 2016.

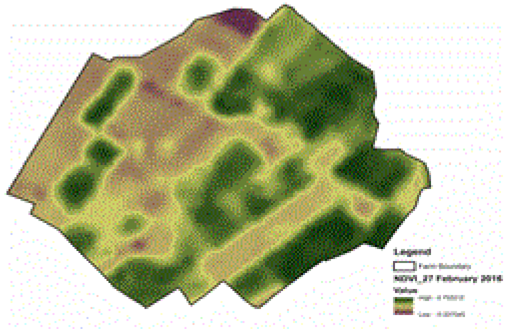

Figure 22: NDVI of 27 Feb. 2016.

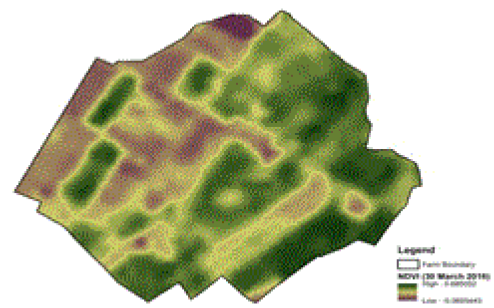

Figure 23: NDVI of 30 March 2016.

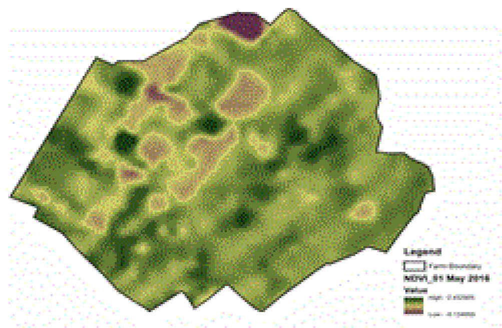

Figure 24: NDVI of 01 May 2016.

Correlation among NDVI and soil macronutrients

Pearson correlation co-efficient among NDVI values and macronutrient contents are presented in Table 4. It was found that NDVI values of 16-June-2015 was showing the best relationship with soil fertility status, while the relation is lost with the NDVI values of image beyond this period, because it was the sowing period just after the sampling. It was found that K, P, NO_3 and $CaCO_3$ were having significant positive correlation with NDVI values. Similar results has been described by Ma et al. [15] higher the nitrogen contents increase the chlorophyll content and leading to increased NDVI values. Whereas SO_4 was having non-significant positive correlation.

NDVI values of 20-September 2015 were having significant negative correlation with soil macronutrients in case of K, NO_3 and $CaCO_3$ because at that time most of the crops were going toward maturity leading in lower values of NDVI. NDVI values of 6-October 2015 and 22-October 2015 were showing significant negative correlation with macronutrients because green color of crops was detached. Obtained values of NDVI of 10-Janruary when correlated with soil fertility status it was observed that $CaCO_3$ was having significant positive correlation with crop growth because most of the crops were on their initial stages at that time. Landsat NDVI of 27-Februaury 2016 showed significant positive correlation with K and $CaCO_3$. Whereas NDVI values of 30-March 2016 were having significant positive correlation with $CaCO_3$

content. Zhao et al. [29] showed almost similar result when he was working on Corn crop. According to his result deficiency of N reduced the NDVI values by reducing the reflectance. Masoni et al. [30] evaluated that decrease in sulfur concentration decrease the NDVI values by inhibiting the physiological process in plants. Belay et al. [31] exclaimed that soil fertility status and use of inorganic amendments are positively correlated with NDVI values by affecting the spectral properties of pants. Verhulst et al., [14] demonstrated that the spatial variability of soil properties influence the crop performance and is correlated with the NDVI values by affecting the spectral characteristics of vegetation.

Date	16-Jun-15	20-Sep-15	06-Oct-15	22-Oct-15	23-Nov-15	10-Jan-16	27-Feb-16	30-Mar-16	01-May-16
Variables	NDVI_167	NDVI_263	NDVI_279	NDVI_295	NDVI_327	NDVI_010	NDVI_058	NDVI_090	NDVI_122
NO_3 (mg kg^{-1}	0.183*	-0.176*	-0.117	-0.103	0.081	0.102	0.12	0.145	0.148
P (mg kg^{-1})	0.279*	-0.095	-0.129	-0.138	-0.118	0.038	0.108	0.103	0.032
K (mg kg^{-1})	0.220*	-0.182*	-0.246*	-0.228*	-0.13	0.142	0.194*	0.119	-0.013
SO_4 (mg kg^{-1})	0.152	-0.025	0.013	0.045	-0.003	0.083	0.132	0.097	0.072
$CaCO_3$%	0.190*	-0.238*	-0.155	-0.139	0.045	0.283*	0.254*	0.275*	0.122

Table 4: Correlation of NDVI and macronutrients in study area. *Significant correlation co-efficient.

Conclusion

Nitrogen and Phosphorus were strongly spatial dependent while Potassium, sulfure and Lime content were moderately spatial dependent. N and P was deficient in 95% and 78% samples respectively while K and S were in satisfactory ranges in 86% and 95% samples respectively. Most of the samples were moderately calcareous. Soil macronutrients were significantly positive correlated with NDVI values of studied area.

Recommendation

Spatial variability of soil macronutrients should be taken into account during decision making related to the farm interventions like application of fertilizer/soil amendments and other farming operations. More studies on different spatial scales are required for further recommendations and use of such techniques in profitable and sustainable site-specific agriculture.

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