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MAPPING NITROGEN STATUS IN SOIL AND FOLIAGE OF COTTON PRODUCING AREA OF SOUTHERN PUNJAB, PAKISTAN

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Abstract

Nitrogen (N) is deficient in more than ninety percent soils of Pakistan. Nitrogen deficiency and poor management causes yield losses in most of the crops in Pakistan therefore its efficient management is vital for ensuring optimum crop production. A field survey was conducted for mapping NO_3-N content in soils and total N content in the foliage of cotton producing area using geo-statistics and GIS as diagnostic tools. Seventy geo-referenced soil samples were collected from the surface soil (0-15cm depth) along with associated foliage samples. Our results indicated that bioavailable NO_3-N content in soil ranged from 3.43-14.24 µg g^{-1} with the mean of 8.47 µg g^{-1}. Thirteen out of 16 soil series were categorized as deficient (< 11 µg g^{-1}) in plant available NO_3-N. Nitrogen content in the foliage ranged from 2.44–4.55%, with a mean of 3.52%. Forty-three percent of total analyzed plant samples were categorized as N deficient. Moderate to strong spatial dependence of NO_3-N in the soil and foliage provided an opportunity to prepare digital maps for classifying the whole area into various zones. Generated maps indicating differential nutrient status of cotton producing area provide regional scale information. This information will be helpful for future studies on site-specific nutrient management.

Key words: GIS, Geo-statistics, Nitrate-N, Environment, Fertility, Site-specific.

Introduction

Specific Nutrient Management (SSNM) in is necessary in the intensive farming systems, because of various factors affecting its availability to plants which include its kinetics, uptake, mineralization, immobilization, and other factors like denitrification and leaching. Furthermore, condition of prevailing weather and soil, tillage operations being carried out in the soils and the crop growth stages during a growing season also affect various components of N-cycle, which makes it more difficult to control and manage nitrogen content in the soils (Hirel, 2011). Nitrogen (N) is an important plant nutrient, and necessary input to maintain economical agricultural production worldwide. Predetermination of appropriate nutrient doses with special reference to space and time is a pre-requisite for site specific nutrient management. Application of site-specific N prescriptions is necessary for increasing N use efficiency and to thwart adverse environmental effects (Ferguson *et al*., 2002).

Nitrogen is one of the main nutrient being used for crops as fertilizer and is considered the most yield limiting nutrient because most of agricultural soils are deficient in N (Ledgard *et al*., 2014). Consumption of N is more in the country as compared to other nutrients. Farmers apply large quantities of N to crops. Moreover, soil- nutrient- plant system inefficiencies prevent efficient utilization of N, leaving it in soil or lost through volatilization, which results in wastage of resources and is of great concern for environmental pollution.

In Pakistan fertilizers such as urea and diammonium phosphate (DAP) are primarily used as N fertilizer. According to Agricultural Statistics 2014-15 on an average 3.3 million tons N containing fertilizer was used in the country mainly focusing wheat, Maize and cotton crops as it shows a N:P ratio of 3.39:1. Despite the higher use of N fertilizer the average N recovery efficiency (NRE) for cereals stands $\simeq$35% in N fertilizer consumption keeping the use of N fertilizer on higher side. The low NRE emphasis the need for looking into remaining 65% of the applied N and understanding its fate (Arain *et al*., 2000).

In upper 15 cm of alkaline calcareous soils there exists 0.1%-0.6% N (Cameron *et al*., 2013). Such stored N converted into two N species viz., NH_4^+ and NO_3^- both directly utilized by plant. Besides losing through volatilization NO_3^- is mobile and is potentially leached to aquifer contributing human health hazards of high byNO_3^- in drinking water (Boyer *et al*., 2002; Ledgard *et al*., 2014).It therefore seems imperative to quantify how much of the applied N actually leads to plant uptake and effectively utilized in ecosystem.

One of the crucial components of SSNM is spatial analysis or digital mapping of N in soil through the use of Geographic information system (GIS) tools, which leads to know the nutrient status of soil at a single glance (Attar *et al*., 2012; Ahmed *et al*., 2017). Application of nutrient fertilizer doses where and when needed using digital maps leads to decrease in yield losses due to over or under-fertilization (Ahmed *et al*., 2014). Soils that have a high degree of spatial variability in N content can be better managed using site-specific management zones.

Rahim Yar Khan is the main district of cotton growing area in Pakistan. The use of nitrogenous fertilizer is increasing in the area. Soil series being a basic unit of soil classification has an immense importance. Soil series provides the basis for studying soil characteristics as it includes soils similar in most of the characteristics (Nabi *et al*., 2018). Although considerable work has been done on nutrient management in cotton crop, but a meager information is available on site-specific nutrient status and its management.

Keeping in view the importance of N in the crop production, its losses and use of site specific nutrient management technology for efficient nutrient management for crop production, this research work was carried out to prepare the digitals maps indicating the N content in the cotton fields of the district.

Materials and Methods

Soil sampling, processing and analysis: Rahim Yar Khan Area is located between the 28.4212° N, 70.2989° E in the Punjab province of Pakistan (Fig. 1). Climatic conditions are congenial for growing cotton. Seventy soil and associated foliage samples were collected from the representative soil series to cover the whole cotton producing area. Precise locations were recorded with the help of GPS (Garmin e-trex) coordinates are given in (Table 1). Sampling frequency from representative soil series is manifested in (Table 2). Associated foliage samples were also collected to examine the N content. Soil samples were air dried; ground; passed through a 2 mm sieve, labeled to process for further analysis. The samples were analyzed for soil properties such as texture (Gee & Bauder, 1982), pH by 1:2 soil water suspension (Mclean, 1982), $CaCO_3$ contents (Leoppert *et al.*,1984), organic matter (Nelson & Sommers, 1983), and plant available NO_3-N content by Ammonium bicarbonate diethylene triamine penta acetic acid (ABDTPA) method (Soltanpor & Workman, 1979). Critical values described by Soltanpour, (1985) were used to classify the soil in to low (<11 µg g^{-1}), medium (11-20 µg g^{-1}) and high (>20 µg g^{-1}) in plant avaialable NO_3-N content.

Statistical and Geo-statistical analyses: Descriptive statistical measure like mean, standard deviation, kurtosis and skewness were applied to the data sets obtained for plant available NO_3-N content in the soil and total N content in the foliage to examine the central tendency. Effect of various physico-chemical properties availability of N was examined by applying correlation analysis (Steel & Torrie, 1980). Normal distribution of NO_3-N content in the soils and total N content in the foliage was characterized using the Kolmogrov-Smirnov (K-S) test for goodness-of-fit (Sokal & Rohlf, 1981). Heterogeneity of dataset regarding plant available NO_3-N content and total N content in the foliage was quantified by applying co-efficient of variance (CV%). Variables having CV% values < 15%, 15 to 35%, and >35% were categorized as least, moderate and highly variable respectively (Wilding, 1985). Geostatistical analyses and digital mapping was carried out using ArcGIS 10.5 software. Semivariogram modeling was performed to quantify the spatial variability of plant available NO_3-N in the soils and total N content in the foliage (Ahmed *et al.*, 2017; Bhatti *et al.*, 1991). Ordinary kriging (Equation 1) was applied to prepare digital maps (Isaaks & Srivastava, 1989). Nugget value enumerates the errors and uncertainty due to sampling and small scale variability. Changes in prediction due to parent material, and vegetation are summarized in sill value. Semivariance is measure of scattering of all observations below target value. Separation distance over which spatial dependence is more apparent is called range (Aishah *et al.*, 2010). Extent of spatial dependence for various attribute data is quantified by using an indicator spatial ratio. A ratio value of <25, 25-75, and >75 percent represents highest, medium and weak spatial dependence respectively (Cambardella, 1994; Attar *et al.*, 2012). Ordinary kriging was adopted for interpolation of attribute data owing to its higher flexibility. Average standardized error (ASE) (Equation 2) and root mean square error (RMSE) (Equation 3) were used examining the simulation accuracy (Robinson & Metternicht, 2006). Closer values of average standardized error and root mean square error were taken as criterion examining prediction accuracy (Hani *et al.*, 2010).

$$Z_K(X_0) = \sum_{i=1}^{n(h)} \lambda_i Z(X_i) \qquad \text{Equation 1}$$

$$ASE = \frac{1}{n}\sum_{i=0}^{n}[Z^*x_i - Zx_i] \qquad \text{Equation 2}$$

$$RMSE = [\sum_{i=0}^{n}(Z^*x_i - Zx_i)^2/N]^{\frac{1}{2}} \qquad \text{Equation 3}$$

where $Z^*(x_i)$ and $Z(x_i)$ reperesents the observed and predicted values respectively.The ME and RMSE values are in the range of [0, ∞].

The whole area was classified into five nutrient variability zones on the basis of differential P content in the soils.

Results and Discussion

Physico-chemical properties of the soils: The basic descriptive statistics of soil physico-chemical properties is summarized in Table 3. Our data indicated that sand, silt, clay and EC were highly heterogeneous as the CV was more than 35%. Contrastingly, data regarding CaCO3 and pH indicated the least heterogeneity with CV less than 15%. Soils of all the surveyed cotton fields contained 6.1-12.0% CaCO3. Considering a minimum of 1% CaCO3 content for a soil to be calcareous, all the sampled soils in Rahim Yar Khan District were classified as calcareous. However, there was variation in $CaCO_3$ content of different soil series.

The soils of Rahim Yar Khan District were generally low in organic matter as its content ranged from 0.42 to 1.72% with a mean of 0.86%. In fact, 57% fields contained less than 0.86% organic matter, which is considered minimum requirement for good plant growth (Cottenie, 1980). Only three soil series, out of a total of 16 (Bahalike, Missan, and Sultanpur) had adequate organic matter content. Electrical conductivity (1:1) of the surveyed soils ranged from 0.26 to 1.40 dS m^{-1} with a mean value of 0.59 dS m^{-1} in soils (Table 3). Harunabad soil series had the lowest (0.30 dS m^{-1}) while Missan soil series had the highest (1.25 dS m^{-1}) mean EC. Thus, all the surveyed soils were not salt affected. The soils of Rahim Yar Khan district were alkaline in reaction with pH varying from 8.15 to 8.80. Mean pH value for the soils was 8.34 (Table 3).

Silty clay and silt loam were the dominant textural classes found in the surveyed area as 44 % of the total analyzed samples were categorized as silty clay and 22% as silt loam. Other textural classes found in the surveyed area were clay, loam, loamy sand, sandy loam, and silty clay loam (Table 4).

Textural classes of all collected soil samples demonstrated their suitability to grow cotton as well as other agronomic crops. On an average, soils contained 25.77% clay, 39.28% silt and 34.43% sand.

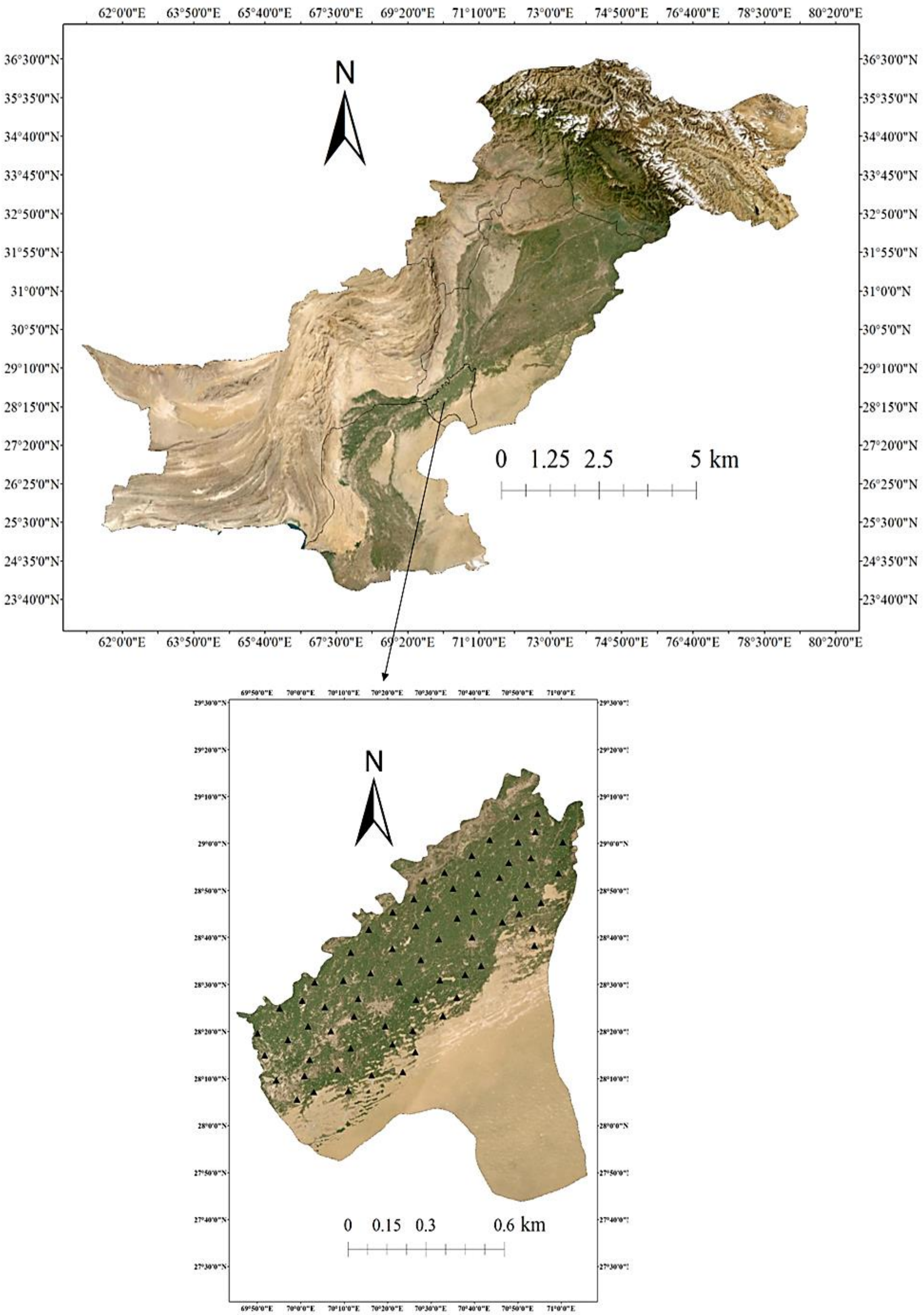

Fig. 1.Geographical location of the surveyed areashowing sampling points.

Table 1. Precise location (coordinates) of sampling sites in district Rahim Yar khan.

S. No.	Latitude (N)	Longitude (E)	S. No.	Latitude (N)	Longitude (E)	S.No.	Latitude (N)	Longitude (E)
1.	28° 09′37"	69° 54′20"	25.	28° 35′11"	70° 27′37"	48.	28° 50′27"	70° 35′4"
2.	28° 14′57"	69° 51′42"	26.	28° 30′56"	70° 32′1"	49.	28° 53′49"	70° 33′5"
3.	28° 19′36"	69° 50′0"	27.	28° 39′37"	70° 31′45"	50.	28° 52′2"	70° 28′29"
4.	28° 18′14"	69° 56′59"	28.	28° 39′37"	70° 31′45"	51.	28° 48′11"	70° 26′3"
5.	28° 21′7"	70° 01′37"	29.	28° 44′7"	70° 36′2"	52.	28° 45′21"	70° 21′8"
6.	28° 24′55"	69° 55′5"	30.	28° 40′2"	70° 39′28"	53.	28° 41′42"	70° 15′38"
7.	28° 26′33"	70° 00′18"	31.	28° 33′57"	70° 41′33"	54.	28° 36′46"	70° 11′30"
8.	28° 25′89"	70° 05′33"	32.	28° 32′6"	70° 37′51"	55.	28° 30′49"	70° 09′48"
9.	28° 30′27"	70° 03′9"	33.	28° 27′14"	70° 35′56"	56.	28° 32′23"	70° 16′4"
10.	28° 13′58"	70° 02′1"	34.	28° 23′19"	70° 32′42"	57.	28° 30′35"	70° 22′40"
11.	28° 10′31"	70° 00′48"	35.	28° 20′10"	70° 25′47"	58.	28° 26′44"	70° 26′32"
12.	28° 07′7"	70° 02′59"	36.	28° 15′39"	70° 26′21"	59.	28° 52′43"	70° 45′45"
13.	28° 05′31"	69° 59′7"	37.	28° 11′24"	70° 23′29"	60.	28° 43′15"	70° 46′26"
14.	28° 11′56"	70° 08′30"	38.	28° 17′18"	70° 21′6"	61.	28° 45′28"	70° 39′55"
15.	28° 07′21"	70° 10′55"	39.	28° 21′8"	70° 19′26"	62.	28° 49′17"	70° 40′38"
16.	28° 10′40"	70° 16′20"	40.	28° 57′28"	70° 39′23"	63.	28° 53′39"	70° 40′49"
17.	28° 16′23"	70° 11′31"	41.	29° 00′47"	70° 43′33"	64.	28° 45′3"	70° 50′20"
18.	28° 20′6"	70° 06′56	42.	29° 05′41"	70° 49′45"	65.	28° 41′55"	70° 53′17"
19.	28° 23′11"	70° 12′15"	43.	29° 00′15"	70° 50′4"	66.	28° 38′16"	70° 53′47"
20.	28° 26′55"	70° 13′14"	44.	29° 06′21"	70° 54′31"	67.	28° 47′23"	70° 55′22"
21.	28° 37′36"	70° 21′6"	45.	29° 02′33"	70° 54′1"	68.	28° 48′25"	70° 49′25"
22.	28° 42′27"	70° 26′28"	46.	28° 56′55"	70° 52′58"	69.	28° 51′13"	70° 52′8"
23.	28° 45′72"	70° 29′14"	47.	28° 55′56"	70° 47′56"	70.	28° 53′41"	70° 59′21"
24.	29° 00′17"	71° 00′22"						

Table 2.Sampling frequency in the representative soil series of the surveyed area.

Soil series	Sub-group	No of sites	Soil series	Sub-group	No of sites
Awagat	Fluventic Camborthid	2	Missan	Halic Camborthid	4
Bagh	Fluventic Camborthid	6	Nabipur	Typic Camborthid	7
Bahalike	Fluventic Camborthid	2	Pacca	Typic Camborthid	10
Dungi	Halic Camborthid	2	Rustam	Typic Torrifluvent	1
Harunabad	Fluventic Camborthid	2	Shahdara	Typic Torrifluvent	1
Jhakkar	Halic Camborthid	3	Sodhra	Typic Torripsamment	1
Malti	Typic Camborthid	5	Sultanpur	Fluventic Camborthid	13
Miani	Typic Camborthid	5	Yazman	Typic Torripsamment	6

Table 3. Descriptivestatistics of physico-chemical properties of soils of the surveyed area.

Soil property	Mean	SD[a]	Minimum	Maximum	[b]CV %
Sand	34.42	22.95	6	83	66.67
Silt	39.28	15.71	10	63	39.99
Clay	25.77	12.19	6	46	47.30
$CaCO_3$ (%)	8.45	1.11	6.1	12	13.13
pH	8.34	0.13	8.15	8.8	1.55
EC	0.59	0.22	0.26	1.4	37.28
Organic matter (%)	0.86	0.30	0.42	1.72	33.72

[a]Standard deviation, [b]Co-efficient of variation

Table 4. Textural class distribution in the surveyed area.

Textural class	No of samples	Percent samples
Clay	6	08.33
Loam	10	13.89
Loamy sand	7	09.72
Sandy loam	11	15.28
Silt loam	15	20.83
Silty clay	16	22.22
Silty clay loam	7	09.72

Plant available NO_3-N and cotton foliage-N indexing: NO_3-N content in soils ranged from 3.43-14.24 µg g^{-1} with the mean value of 8.47µg g^{-1} (Table 5). Thirteen out of 16 soil series exhibited mean NO_3-N content less than 11 µg g^{-1}. Considering 11 µg g^{-1} of NO_3-N content in soil as critical level for plant growth (Soltanpour, 1985), our results indicated that hundred percent of the sites sampled from Awagat, Dungi, Missan, Rustam, Sodhra were classified as NO_3-N deficient. Fifty to seventy percent of the sampled sites of soil series Bagh, Harunabad, Pacca, Yazman and Sultanpur were categorized as deficient in

NO_3-N content, while 30 to 40% sampled sites of soil series Jhakkar, Malti, Miani and Nabipur were considered as deficient in plant available NO_3-N content (Table 6). Foliage N content in cotton ranged from 2.44–4.55%, with a mean of 3.52% (Table 5). Considering 3.5% of foliage N as threshold for healthy cotton growth (Jones *et al*., 1991; Reuter *et al*., 1997a) 43% of cotton plants suffered from N deficiency in the District.

Nitrogen sources in the soil include rainfall, organic and inorganic fertilizers and nitrogen fixation. It is removed from the soil through crop harvest, leaching, erosion, denitrification and volatilization (Maqsood *et al*., 2016). The deficiency of plant available nitrogen and foliage N in soil might be due to low organic matter content. It is because of lack of incorporation of crop residues in most of Pakistani soils. According to an estimate that soil organic matter contains around 90 kg of N per ton (Subbarao *et al*., 2006) secondly crop residues contains 1 to 6% N content (Mahmood, 2000). Another reason for deficiency of total N content in the foliage of cotton plant might be prevailing high temperature in the cotton producing area which leads to rapid hydrolysis of urea forming ammonium ions loosely bound to water molecules leading to conversion of ammonium to ammonia gas which is evolved (Xing & Zhu, 2000). Calcareous nature of Pakistani soils also increases the relative rate of NH_3 volatilization when N fertilizers are applied (Hamid & Ahmad, 1988; Wang *et al*., 2004).

Relationship between physico-chemical properties of soil and plant available NO_3-N content: Correlation analyses are summarized in (Table 7). A significant ($p \leq 0.05$) positive relationship was observed between the plant available NO_3-N content and soil organic matter content. While the sand fraction of soil texture and pH of soil were negatively correlated with plant available NO_3-N content. However, this relationship was significant in case of pH while non-significant in case of sand fraction. Positive relationship between plant available NO_3-N and soil organic matter might be due to enhanced ability of soil to retain moisture in the soil which in turn leads to higher nitrification rates. Moreover, mineralization of organic matter releases substantial amount of nutrients (Ahmed *et al*., 2014). Again negative relationship between sand and plant available NO_3-N content might be due to low water holding capacity of sandy soils, as leaching of NO_3-N content is a common phenomenon in the light textured soils (Rizwan *et al*., 2016).

Table 5. Descriptive statistics of soil NO_3-N and cotton foliage-N of surveyed area.

Nutrient	Mean	SD	Minimum	Maximum	CV (%)	Skewness	Kurtosis
Soil NO_3-N ($\mu g\ g^{-1}$)	8.47	3.43	3.43	14.24	40.00	0.10	-1.57
Foliage-N (%)	3.52	0.49	2.44	4.55	13.92	0.22	-0.34

Table 6. Soil series wise deficiency of NO_3-N in the soils of Rahim Yar Khan district.

Soil series	NO_3-N deficient sites (%)	Soil series	NO_3-N deficient sites (%)
Awagat	100	Missan	100
Bagh	50	Nabipur	43
Bahalike	0	Pacca	60
Dungi	100	Rustam	100
Harunabad	50	Shahdara	0
Jhakkar	33	Sodhra	100
Malti	40	Sultanpur	54
Miani	40	Yazman	67

Table 7.Correlation between soil physico-chemical properties andbioavailablesoilNO_3-Ncontent.

	$CaCO_3$	NO_3-N	Organic matter	pH	Clay	Sand
NO_3-N	-0.07^{NS}					
OM	-0.38^{*}	0.3213^{*}				
pH	0.27^{*}	-0.29^{*}	-0.42^{*}			
Clay	0.42^{*}	-0.024^{NS}	-0.20^{NS}	0.10^{NS}		
Sand	-0.35^{*}	-0.10^{NS}	0.033^{NS}	-0.11^{NS}	-0.77*	
Silt	0.20^{NS}	0.034^{NS}	0.10^{NS}	0.089^{NS}	0.34*	-0.87*

*Significant at $p \leq 0.05$; ^{NS} = Non-significant

Spatial variability of plant available NO_3-N and foliage N content: Datasets having skewness values between -2 and +2 are considered to have normal distribution which is pre-requisite for carrying out geo-statistical analysis of any dataset (Trochim & Donnelly, 2006; Field, 2000; Gravetter & Wallnau, 2014).

Semivariogram modeling was carried out to examine the spatial structure of plant available NO_3-N and associated cotton foliage-N content (Table 8). Spherical model was found best fit to describe spatial structure of plant available NO_3-N content. Plant available NO_3-N content were found moderately spatial dependent. Semivariogram modeling suggested a range of 0.178 km for the spatial dependence of NO_3-N content in the surveyed soils (Fig. 2a). This spatial dependence of plant available NO_3-N might be due to the application of nitrogenous fertilizers at recommended uniform rates without considering the spatial variability of the nutrient in the soils (Ahmed *et al*., 2014; Liu *et al*., 2004; Spiker *et al*., 2005). Semivariogram modeling indicated moderate spatial dependence of plant available NO_3-N content. Similarly, a strong spatial dependence was observed in case of cotton foliage-N contents (Fig. 2b). Digital maps of plant available NO_3-N and cotton foliage-N content prepared using ordinary kriging technique are presented in Fig. 2c, d. Similar techniques were successfully used by different researchers to delineate various areas having low, medium and high nutrient content for site specific nutrient management (Shah *et al*., 2013; Rafique *et al*., 2006; Ahmed *et al*., 2014; Arain *et al*., 2017).

Table 8. Parameters related to semivariogram model and interpolation of plant available soil NO_3-N and associated cotton foliage-N content.

Nutrient	Model	Range (km)	Nugget/Sill (%)	RMSSE[a]	ASE[b]	RMSE[c]
Soil NO_3-N	Spherical	0.178	32.43	1.13	3.29	3.72
Cotton Foliage-N[d]	Spherical	0.299	19.86	1.30	0.38	0.50

[a] Root Mean Square Standardize Error, [b]Average Standardize Error, [c]Root mean square error, [d] Nitrogen content in the foliage

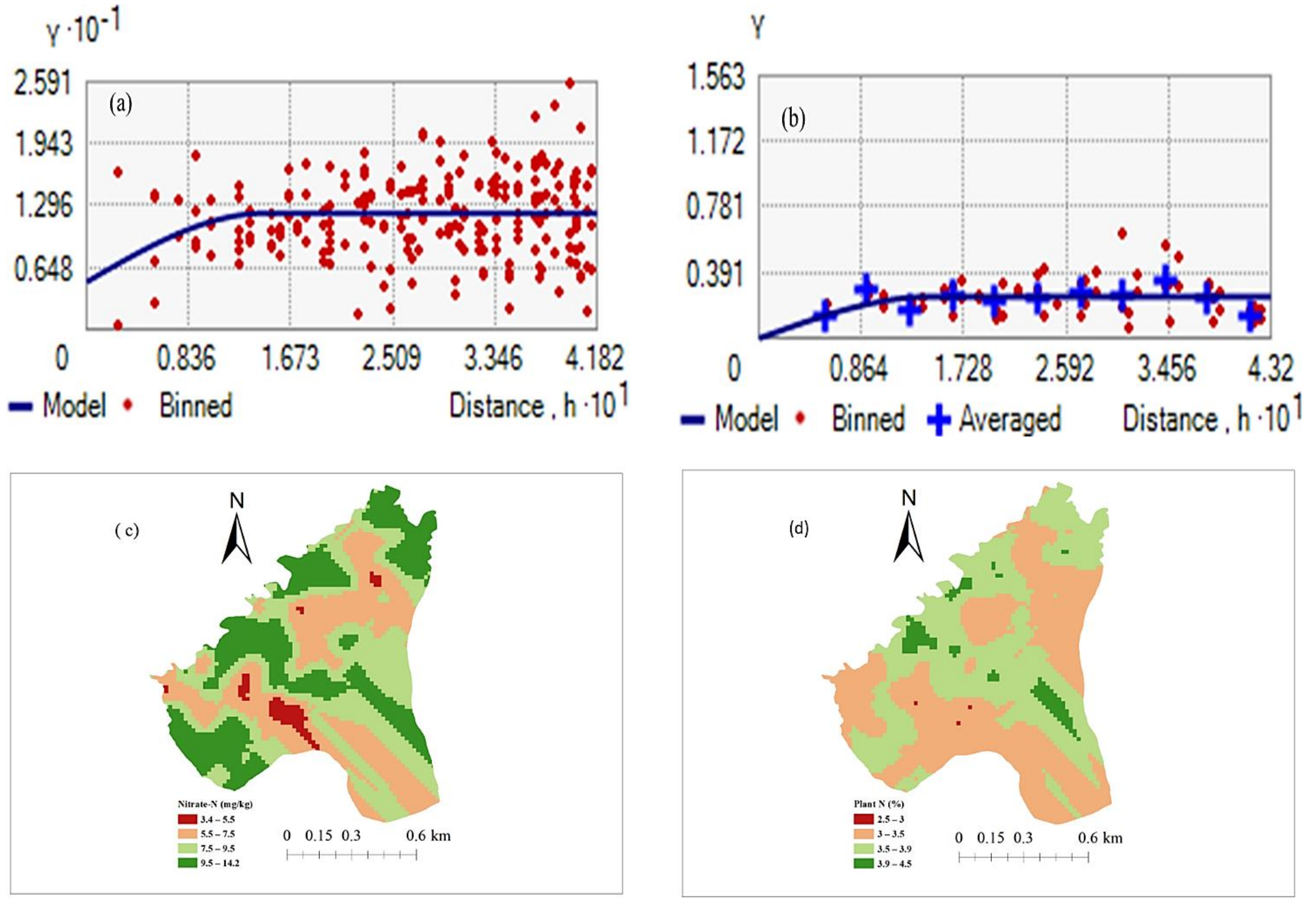

Fig. 2. Semivariogram models indicating spatial dependence of plant available NO_3-N (a) and cotton foliage-N (b), Spatial distribution of plant availableNO_3-N (c), and cotton foliage-N (d).

Conclusion

Deficiency of NO_3-N in the soils and total N in cotton producing areas of Pakistan was observed which need to be managed according to site-specific nutrient recommendations by classifying whole area into various nutrient management zone. A detailed survey and GIS based modelling of soil NO_3-N and total N for district Rahim Yar Khan indicated acute deficiency of nitrogen in the soils and foliage. A widespread deficiency of soil organic matter was also observed. Significant positive relationship was observed between plant available NO_3-N content and organic matter and clay content. Therefore it is needed to formulate recommendations for N to cotton crop on the basis site-specific nutrient management techniques for different zones of whole province. Information generated in this study will be helpful to the researchers and policy maker for planning future studies and devising policies.

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