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SOIL AND PLANT NUTRIENT STATUS AND SPATIAL VARIABILITY FOR SUGARCANE IN LOWER SINDH (PAKISTAN)

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Abstract

Soil and plant nutrient status (N, P, K, B, Cu, Fe, Mn, and Zn) of sugarcane fields with the spatial variation and associated was investigated plant nutrient concentrations of sugarcane grown in district Thatta of lower Sindh, through a field survey approach. Soils were low in nitrogen (NO_3-N 0.55-9.20 mg kg^{-1}), low to medium in phosphorus (1.20 to 9.48 mg kg^{-1}), and adequate in extractable potassium (above 108 mg kg^{-1}). Among the micronutrients, zinc was low (0.80 mg kg^{-1}), boron was medium (0.56) while copper and iron were adequate (3.02 and 19.48 mg kg^{-1}, respectively). The soil test values had spatial structure especially in case of soil phosphorus, nitrate, copper and manganese, which better fit in the linear model implying that variance in these soil nutrients was yet increasing with the distance of sampling scale. The spatial structure of soil potassium and zinc fit the spherical model indicating that they varied in a “patchy” way; and the range of spatial correlation provides an average extent of these patches.

The nugget/sill value between 25 and 75 % indicated medium spatial dependence with the range of 89 km for plant available zinc. Among plant nutrients, the mean nitrogen (1.76%) was slightly below the critical value in 49% samples and phosphorus with mean content of 0.18% blow critical level in 43% plant samples suggesting deficiencies of these nutrients, while the potassium content (1.87%) was indicative of a luxurious uptake. Among micronutrients plant zinc level with mean value of 19.52 mg kg^{-1} was below critical level in 24% and boron with mean value of 6.81 mg kg^{-1} was below in 21% plant samples. While copper, iron and manganese were in optimum range.

Key words: Soil and plant macro and micronutrients, Critical nutrient level, Spatial variation, Sugarcane, Lower Sindh.

Introduction

Sugarcane (*Saccharum officinarum* L.) has an economic importance as cash crop for the farmers and for its contribution in national gross domestic products. However, the average sugarcane yield of Pakistan is much lower (57.55 t ha^{-1}) (Anon., 2014) than the potential yield of 150-200 t ha^{-1} obtained at research stations (Malik, 1990 & 2009). As a long duration exhaustive crop, enhanced uptake of major nutrients relating to increased growth and mining of nutrients causes the wide spread deficiencies (Nasir *et al*., 2000; Bokhtiar *et al*., 2001; Akhtar *et al*., 2003; Abbas *et al*., 2011). High calcareousness, elevated levels of soluble salts, low organic matter contents, intensive cultivation, more importantly the imbalanced use of fertilizers are some other factors responsible for poor growth and eventually the decrease in the cane yield. More than 90% soils of Sindh are deficient in nitrogen (N) and phosphorus (P), 40% in potassium (K) (Ahmad & Rashid, 2004), 50% in Zinc (Zn) (50%) (Memon, 1986; Arain *et al*., 2000; Akhtar *et al*., 2003) in addition to boron (B) (Memon *et al*., 2012a). The low (<1%) levels of organic matter have further aggravated the situation by lowering the fertility of soil (Sarwar *et al*., 2010; Memon *et al*., 2012b). The sugarcane fields have been reported under severe deficiency of macro and micro nutrients in Nawabshah, Patidan and Sakrand (Arain *et al*., 2000). The soils of district Thatta were low in N and Zn, medium in P and adequate in K (Panhwar *et al*., 2003). Adequate levels of AB-DTPA extractable K in sugarcane fields of Tandojam and Tando Allahyar, Sindh are also on record (Khuhro *et al*., 2014). The crop response, to added nutrients under field trials have been reported by several researchers (Sharif & Chaudhry, 1988; Malik, 1990; Khan *et al*., 2002). These studies showed that balanced application of NPK improved the yields to as high as 165.2 t ha^{-1}.

The soil nutrients vary spatially due to edaphic characteristics and soil management practices. The developments in geo-statistics increase the ability to summarize and interpret soil data (Yost *et al*., 1982; Bond-Lamberty *et al*., 2006; Robinson & Metternicht, 2006; Loescher *et al*., 2014). Thus, geo-statistical methods applied to soil studies over distances ranging from a few meters to several kilometers improve understanding on causes of spatial variance (Trangmar *et al*., 1986, 1987; Ovalles & Collins, 1986; Jian-Bing *et al*., 2006; Marchetti *et al*., 2012). Furthermore, this spatial variability of soil properties helps in variable-rate application of fertilizers (Shahandeh *et al*., 2005). Major nutrients and trace elements in northern Tunisia (Berndtsson *et al*., 1993) and Indonesia (Trangmar *et al*., 1984) had a clear spatial structure. The temporal and spatial variability has been determined for sugarcane (Johnson & Richard Jr., 2005). Majority of the soil properties of South Louisiana sugarcane fields had non-normal distribution with coefficient of variation ranging from 1 to 56% over all years and locations. All the soil properties were spatially correlated with the range varying from 26 to 241 m. Cane and sugar yields and quality parameters were spatially correlated with a range varying from 26 to 187 m. Further, the kriging reduces sampling compared to classical technique as the means of observed and kriged values are similar (Grewal *et al*., 2001).

Soil analysis estimates the plant available nutrients, while, plant analysis measures the uptake of nutrients until sampling (Smith & Loneragan, 1997). Soil test along with specific plant tissue analysis is more suitable in determining the nutrient requirements (Memon *et al*., 2005). To interpret the data, critical values for soil and various field crops are established (Smith & Loneragan, 1997). The nutrient requirements of sugarcane developed, are based on analysis of third leaf (Clements & Ghotb, 1968; Suggu *et al*., 2010). District Thatta of Sindh province, on coast of Arabian Sea is major sugarcane growing area of Pakistan. This study targeted to determine the extent and spatial variability of nutrient deficiencies for sugarcane and interpret the results in the light of critical nutrient level (CNL) approach for nutrient deficiency diagnosis and recommendation for sugarcane growers.

Site description: The agro-ecological zone lies between latitude 24°0' to 25°27' N and longitude 67°35' to 68°45' E as presented in a site map (Fig. 1) from lower Indus plain up to Indus Delta. It is characterized by the arid and marine tropical climate with rainfall between 150 to 280 mm and mean maximum temperature of 35.8°C during May and mean minimum temperature of 10.4°C during January. The maximum summer temperature does not exceed 46.0°C, while the minimum in cold weather does not fall below 0°C (Khan *et al.,* 1979). The Indus Delta is formed by the gradual filling up of low lying areas with alluvium derived from Himalayas on the basement of Tertiary limestone which outcrops at places (Khan *et al.*, 1979; Rasul, 2012). Most soils are developed in the river plain without any effect of sea and the estuary plain with fresh water deposits made under the influence of sea tides (Din *et al.*, 1969; Khan *et al.*, 1979; Memon *et al*., 2011). Sugarcane is a major crop of the area and grown on 33.2 thousand hectares (Anon., 2009) in sugarcane-sugarcane, rice-alfaalfa and rice-sugarcane cropping patterns.

Materials and Methods

Surface soils (0-15 cm) and plant tissue (3rd leaf from spindle) samples were collected (geo-referenced with Magellan GPS 315) from one hundred twenty three farmers' fields at grand growth stage (140-240 days after planting) (Clements, 1980), and the yield was recorded at maturity. In addition, information on sugarcane variety, cropping pattern, agronomic practices, plant crop or ratoon crop were recorded through a developed proforma. Composite leaf samples were collected between 7-10:30 am in a "V" shaped transect. Fifteen cm long leaf blade (for N) was cut from the center of leaf after removing the mid rib, and leaf sheath (for all other nutrients) after removing the extreme ends (Samuels, 1969; Mackowiak *et al*., 2013; Keeping *et al*., 2014). The plant samples were washed with distilled and de-ionized water, air-dried, packed in the paper bags to dry in convection oven at 70±1°C for 48 h and ground in a Wiley Mill (Thomas USA) to pass through a 60-mesh stainless steel sieve. Soil samples were air-dried, crushed, passed through 2 mm nylon screen and processed for analysis. Yield of each sampled field was recorded at maturity by harvesting a representative area (5m x 3m), canes were de-trashed removing senesced and green leaves, weighed as one bundle and converted to Mg ha^{-1}.

Soil and plant analysis: The soil was analyzed for ammonium bicarbonate diethylene triaminepenta- acetic acid (AB-DTPA) extractable NO_3-N, P, K, Cu, Fe, Mn and Zn (Soltanpour & Workman, 1979; Estefan *et al*., 2013), hot water extractable B (Berger & Truog, 1944), pH (1:2) (McLean, 1982) and calcium carbonate ($CaCO_3$) (Ryan *et al.*, 2001; Estefan *et al*., 2013). Soil $CaCO_3$ was measured by adding excess acid and back titrating the unconsumed acid with NaOH. Soil particle size analysis was done by dispersion in 4% sodium hexametaphosphate [$(NaPO_3)_6$] solution and recording density by a hydrometer after 40 s and 120 min (Day, 1965). Simultaneous extraction of soil nutrients was done by shaking the air-dried soil suspension (1:2 ratio) in 125-mL polyethylene Erlenmeyer flasks on a reciprocating shaker (Eberbach, USA) 180 cycles per min for 15 min. The suspension was filtered and analyzed for the soil nutrients. The mass ratio of all the nutrients was expressed on oven-dried (105ºC) soil weight basis.

The P concentration in the extracts was determined spectrophotometericaly (Murphy & Riley, 1962). Micronutrients (Cu, Fe, Mn and Zn) were analyzed by atomic absorption spectroscopy (Baker & Amacher, 1982) using Perkin Elmer Spectrophotometer Analyst 800. Potassium was determined by emission spectroscopy using flame photometer (PFP7 Jenway) (Wright & Stuczynski, 1996) after known dilution in 100 mg L^{-1} LiCl. Soil NO_3–N was determined by hydrazine reduction method with the absorbance read at 540 nm using spectrophotometer (Shimadzu UV-180) (Kamphake *et al.*, 1967). Boron was separately extracted in hot water and measured colorimetrically using azomethine-H (Keren, 1996) at 420 nm.

Plant tissue N was measured by Kjeldahl's method (Helrich, 1990). The sample was digested in H_2SO_4 in the presence of a catalyst and distilling N into boric acid (H_3BO_4). Plant B was determined by dry ashing in a muffle furnace (Bench Top Preiser, FB1410M) and measured colorimetrically using azomethine-H (Gaines & Mitchell, 1979; Keren, 1996). For P, Cu, Fe, Mn and Zn, the plant material was wet digested in a 5:1 acid mixture (HNO_3:$HClO_4$), and the digest was diluted to 100 mL with distilled water. The P concentration in the digests was determined by developing vanadomolybdo-phosphoric acid yellow color and read at 410 nm (Estefan *et al*., 2013) and micronutrients Cu, Fe, Mn and Zn were measured using atomic absorption spectrophotometer (AA-7000, Shimadzu, Japan) (Wright & Stuczynski, 1996). Plant K was measured on a flame photometer (PFP7 Jenway) after addition of 1 N LiCl as ionization suppressant (Wright & Stuczynski, 1996).

Statistical analysis and spatial variability: Descriptive statistics (mean, standard deviation, and coefficient of variation) of selected soil properties and soil and plants nutrients was obtained using statistical techniques (Steel & Torrie, 1980). The soil and plant contents were compared with the critical limits or optimal ranges as given by Soltanpour & Schwab (1977); Anderson & Bowen (1990) and McCray & Mylavarapu (2010). In order to determine the nature of relationship between soil and plant nutrients, the data was used to determine Pearson's correlation (r^2). The spatial dependence between the measurements pair of locations as a function of distance of separation (lag, *h*) was examined through semi-variograms (Bhatti *et al.*, 1991). Interpolation of value at un-sampled locations was derived from kriging and by developing semi-variogram model for the data (Bhatti *et al.*, 1991). GS+ and Arc GIS (version10.1) software packages were used for the geo-statistical and spatial analysis. The Kriged maps were prepared for the medium spatial dependent nutrients only.

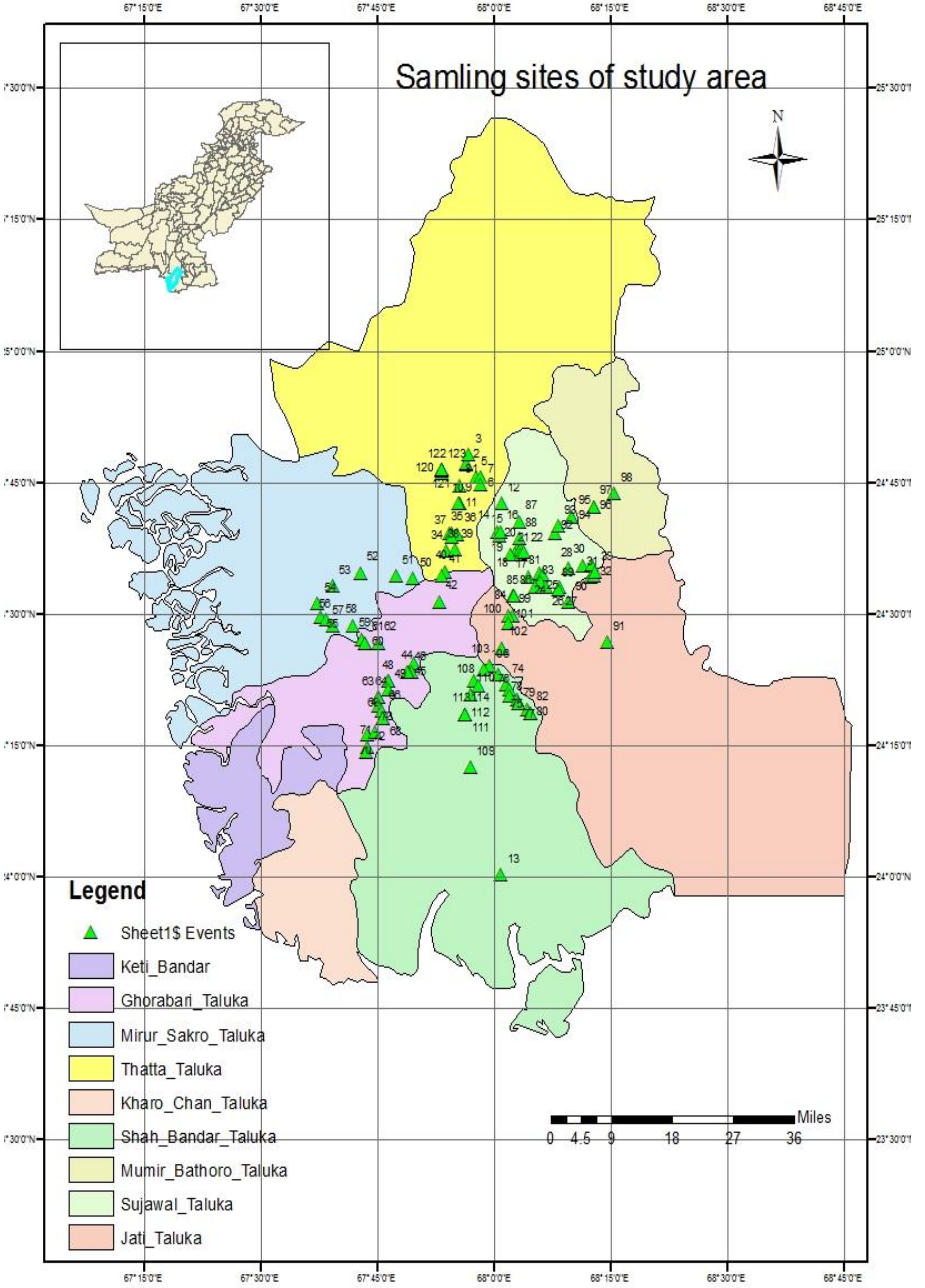

Fig. 1. Site map of study area with geo-referenced soil and plant sampling points.

Results

Soil characteristics: The soils of sugarcane crop were mostly silty loam (48%) and silty clay loam (23%) in texture. Further, the soils of same fields were calcareous ($CaCO_3$ content of 2.50-18.00%), non-saline to moderately saline (0.44-7.80 dS m^{-1}) and alkaline (pH 7.67-8.69) in reaction. The data regarding fertility parameters of the study area presented in Table 1. depicted that the soils were low in N (0.55-9.20%) and Zn (0.23 to1.92 mg kg^{-1}), low to medium in AB-DTPA P (1.25 to 9.20 mg kg^{-1}) and hot water extractable B, (0.15 to 1.23 mg kg^{-1}) and adequate in AB-DTPA K (150 to 325 mg kg^{-1}), Cu (2.0 to 4.0 mg kg^{-1}), Fe (5.0-61.0 mg kg^{-1}) and Mn (3.0-12.4 mg kg^{-1}).

Spatial variation of available nutrients: Spatial variation of macro and micro nutrients in soil is presented in Table 2. A linear model has explained the spatial structure of soil P, NO_3-N, Cu and Mn. The variance in these nutrients was still increasing as the distance of sampling increased. In other words, it had still not reached the upper bounds. The nugget: sill ratio of >75% specify a weak spatial dependence of these nutrients. In case of K and Zn, the values varied in a "patchy" way from smaller to larger as best explained by the spherical model. The variability of spatial correlation for every variogram gives an average extent of these patches. The semi-variogram of AB-DTPA extractable Zn fitting the spherical model had a nugget: sill ratio of 49.9, implying to a moderate spatial dependence. The nugget:sill values between 25-75% point out medium spatial dependence with 89 km range for AB-DTPA extractable Zn.

The maps of surface soil (0-15 cm) nutrients (Zn, Fe, K and B) prepared through ordinary kriging show spatial dependence as depicted in Fig. 2. The concentration of Zn (0.50-0.90 mg kg^{-1}) in soil represented most of the area in Thatta district under sugarcane (Fig. 2a). Lower AB-DTPA extractable Zn (<0.50 mg kg^{-1} soil) was observed in Mirpur Sakro and Thatta sub-districts (Talukas), and high (0.90 mg kg^{-1} soil) towards Sujawal-Jati sub-districts. The plant available Fe content was largely between 12.50-24.40 mg kg^{-1} soil (Fig. 2b) and K predominantly in the range of 170 and 220 mg kg^{-1} soil (Fig. 2c) in the district. Higher concentration of K was observed in the areas of Sujawal, Jati and part of Shah Bander sub-districts with pockets of K as high as 300-360 mg kg^{-1} soil. Hot water extractable B (0.50-1.20 mg kg^{-1} soil) were broadly spread in Sujawal, Shah Bander and Jati sub districts. Whereas, the areas having B concentration of 0.40-0.50 mg kg^{-1} soil were spread all the way to other sub-districts (Fig. 2d).

Plant tissue nutrient status: Leaf tissue contents of sugarcane plants were variable for each nutrient, ranging from 1.20-2.90% N, 0.09-0.29% P, 1.05-2.90% K, 1.80-22.00 mg kg^{-1} B, 4.90-15.00 mg kg^{-1} Cu, 55.00-99.00 mg kg^{-1} Fe, 15.00-58.00 mg kg^{-1} Mn and 8.00-46.00 mg kg^{-1} Zn. The mean nutrient contents in leaf tissue of sugarcane plants (Table 3) were compared with the critical values and optimum ranges. The mean N (1.76%) and P (0.18%) contents in leaf tissue were below the respective critical values of 1.80 and 0.19 % and obviously below the optimum range for N (2.00-2.60%) and K (0.22-0.30%). The other nutrients K (1.87%), B (6.82 mg kg^{-1}), Cu (9.94 mg kg^{-1}), Fe (84.80 mg kg^{-1}), Mn (26.06 mg kg^{-1}) and Zn (19.52 mg kg^{-1}) were above their respective critical values (0.90%, 4.00, 3.00, 50.00, 16.00 and 15.00 mg kg^{-1}) as well as the respective optimum ranges (1.00-1.60%, 4.0-8.0, 55-105, 20-100 and 17-32 mg kg^{-1}) except B. Boron in leaf tissue (6.82 mg kg^{-1}) was although above the critical limit of 4.00 mg kg^{-1} but still below the optimum range of 15.00-20.00 mg kg^{-1}.

Table 1. Summary statistics of soil (n 123), their critical levels and frequency distribution.

Nutrient	Range	Mean	CV%	Critical nutrient Levels (mg kg^{-1})			Frequency of samples	
				Low	Medium	High	Low	Adequate
NO_3-N	0.55-9.20	4.23	36.58	<11	11-20	>20	123 (100%)	0
Phosphorus	1.25-9.48	4.55	32.06	<4	4-7	>7	51 (41%)	68
Potassium	108-360	236	25.81	<60	60-120	>120	0	0
Boron	0.15-1.23	0.56	39.54	<0.5	0.5-1.0	>1.0	56 (45%)	64(53%)
Copper	1.04-5.03	3.02	27.11	<0.2	-	>0.5	0	0
Iron	5.00-61.00	19.48	49.83	<2.0	2.1-4.0	>4.0	0	0
Manganese	3.00-12.40	6.35	28.60	<1.8	-	>1.8	0	0
Zinc	0.23-1.92	0.82	44.02	<1.0	1.0-1.5	>1.5	94 (76%)	26 (22)

AB-DTPA extractable critical nutrients levels (Berger & Truog, 1944; Soltanpour & Schwab, 1977)

Table 2. Spatial dependence parameters for plant available nutrients in sugarcane soils of district Thatta.

Nutrient	Model	RangeA_0	Nugget: Sill	r^2	RMSSE[a]	ASE[b]	RMSE[c]
		km	%				
Phosphorus	Linear	-	100	0.57	-	-	-
Nitrate	Linear	-	100	0.22	-	-	-
Copper	Linear	-	100	0.21	-	-	-
Manganese	Linear	-	100	0.17	-	-	-
Potassium	Spherical		28.49	0.25	61.54	56.95	1.069
Zinc	Spherical	89	35.25	0.35	0.3517	0.3587	0.98
Iron	Exponential	76	40.11	0.021	9.80	10.7	0.98
Boron	Exponential	-	40.11	0.056	0.2196	0.2192	1.001

[a]Root mean square standardized error; [b]Average standardized error; [c]Root mean square error

Table 3. Summary statistics of nutrient content in sugarcane plant tissue, their critical values and frequency distribution.

Variable	Range	Mean	CV (%)	Critical value[$]	Optimum range	% Samples below critical level
			Macronutrients (%)			
Nitrogen	1.21-2.90	1.76	14.26	1.80	2.00–2.60	49
Phosphorus	0.09-0.29	0.18	24.96	0.19	0.22–0.30	43
Potassium	1.05-2.90	1.87	19.52	0.90	1.00–1.60	0
			Micronutrients (mg kg^{-1})			
Boron	1.80-22.00	6.82	57.24	4.0	15–20	21
Copper	4.90-15.00	9.94	22.26	3.0	4–8	0
Iron	55.00-99.00	84.80	10.57	50.0	55–105	0
Manganese	15.00-58.00	26.06	32.78	16.0	20–100	8
Zinc	8.00-46.00	19.52	40.23	15.0	17–32	24

[$]Sugarcane leaf nutrient critical values and optimum ranges (Anderson & Bowen, 1990; McCray & Mylavarapu, 2010)

Relationship between soil and plant nutrient contents: Relationship between available nutrients in soil and associated total contents in leaf tissue of sugarcane indicated a significant, positive and linear relationship for N, P, K, B, Cu and Zn, and a non-significant one for Mn and Fe (Fig. 3). The Pearson correlation coefficient "r^2" was 0.81 for N-NO_3 and 0.83 for P, 0.83 for each B and Zn and 0.72 for Mn, compared to the one for K (r^2=0.58) implying its availability to crop from pools other than exchangeable and soluble.

Discussion

Most of the soils in the study area are developed in the fluvial deposits without an influence of sea, and partly, the fluvial deposits carry signature of over spilling of the back heading under high sea tides (Khan *et al.*, 1979; Rasul, 2012). Soils in the district are also developed in piedmont alluvia derived mainly from different rock formations of Tertiary age consisting of calcareous sandstone, shale, marls and conglomerates to a lesser extent (Khan *et al.*, 1979). Most soils are calcareous without a distinct zone of lime accumulation. Presence of free $CaCO_3$ (10.2%) maintains pH 8.2 (Buehrer & Williams, 1936). Soil pH of >8.4 in the study may be related to sodium in soil solution and on exchange complex. The average values are similar as reported by several authors working in the area (Arain *et al.*, 2000; Panhwar *et al.*, 2003; Abbas *et al.*, 2011; Memon *et al*., 2012a).

The results of this study revealed that all the soils of sugarcane growing fields in district Thatta had adequate levels of available K, Cu, Fe and Mn. However, 100, 41, 45 and 76 % soils were respectively low in NO_3-N (<11 mg kg^{-1}), P (<4.0 mg kg^{-1}), B (<0.50 mg kg^{-1}) and Zn (<1.0 mg kg^{-1}) based on the critical values for AB-DTPA extractable nutrients and hot water extractable in case of B (Soltanpour & Schwab, 1977; Havlin & Soltanpour, 1981; Johnson & Fixen, 1990). These nutrient levels generally correspond to several studies (Bajwa, 1990; Memon, 2005, Khalid *et al.*, 2012) and influence the yield potential of field crops (Meynard, 1984; Rosen & Allan, 2007). The soils of Pakistan being inherently low in organic matter (<1.0%, mostly in the range of 0.36-0.61%) relate to low soil N. High oxidation rate of soil organic matter in the dry subtropical climate impoverishes the soils, and low carbon return limits possible recycle of the plant nutrients present in the residues (Khalid *et al*., 2012). Low P fertilizer input, in addition to formation of calcium phosphates as a result of calcareousness, limit extractable P in the soils (Memon *et al.*, 1992). Another sink of phosphates identified in calcareous soils of arid region soils is crystalline Fe-oxides. Particularly, the goethite crystallite with star-shape twinning retain phosphates against extraction by HCO_3 (Memon *et al.*, 2011). Extractable K remained between 150 to 325 mg kg^{-1} for all the soil samples, which is far above the critical value of <60 mg kg^{-1} soil and suggest that there may be a minimum crop response to additional K application (Soltanpour & Schwab, 1977). This is in line with the adequate levels of K reported for sugarcane fields in district Nawabshah (Arain *et al.*, 2000). The young soils of the area have weatherable minerals consisting K as biotite (Akhtar & Dixon, 2009). Besides, the canal water diverted from the rivers (Shaikh *et al.*, 2007) and burning of sugarcane trash in routine (Malik, 2009) may also be the source of K. Considering Zn deficiency of sugarcane fields in the study area, a large number of studies have supported these results. About 40-60% soils in the province of Sindh have been reported to be deficient (Memon *et al.*, 1988-89; Dahar *et al.*, 2014). The solubility of Zn is highly pH dependent and decreases as pH increases (Rashid, 1996). Boron, another micronutrient found deficient in local soil, particularly, a narrow range of soil test B was reported for rice soils (Rashid *et al.*, 1991). Soil Cu, Mn and Fe levels were high as per critical (Havlin & Soltanpour, 1981; Johnson & Fixen, 1990). The findings are in agreement with previous investigations in Hyderabad and other districts of Sindh reporting an adequate supply of these elements (Memon *et al.*, 1988-89; Dahar *et al.*, 2014).

Plant data was in line with the soil data showing no issue with the total leaf contents for K, Cu, Fe and Mn in sugarcane growing areas of Thatta. Nonetheless, 49, 43, 21 and 24% leaf samples were below the optimum range of N (2.00-2.60%), P (0.22-0.30%), B (15.0-20 mg kg^{-1}) and Zn (17.0-32.0 mg kg^{-1}) which is in line with the soil data. The nutrient status of plant influences dry biomass production, thus the deficiencies for some essential nutrients may prevent obtaining the maximum potential yield. A mean plant N value (1.76%) suggests slightly low N uptake, and low P values (0.18%) emphasizing towards more P application. The mean plant K content of 1.87% is indicative of luxurious use of K from soil resources (Anderson & Bowen, 1990; McCray & Mylavarapu, 2010). The plant N, P and K contents in third leaf at grand growth stage are comparable to sugarcane genotypes as given by Kumar & Verma (1997). Boron and Zn deficiencies reported by Panhwar *et al.* (2003) are in line with the results of this study.

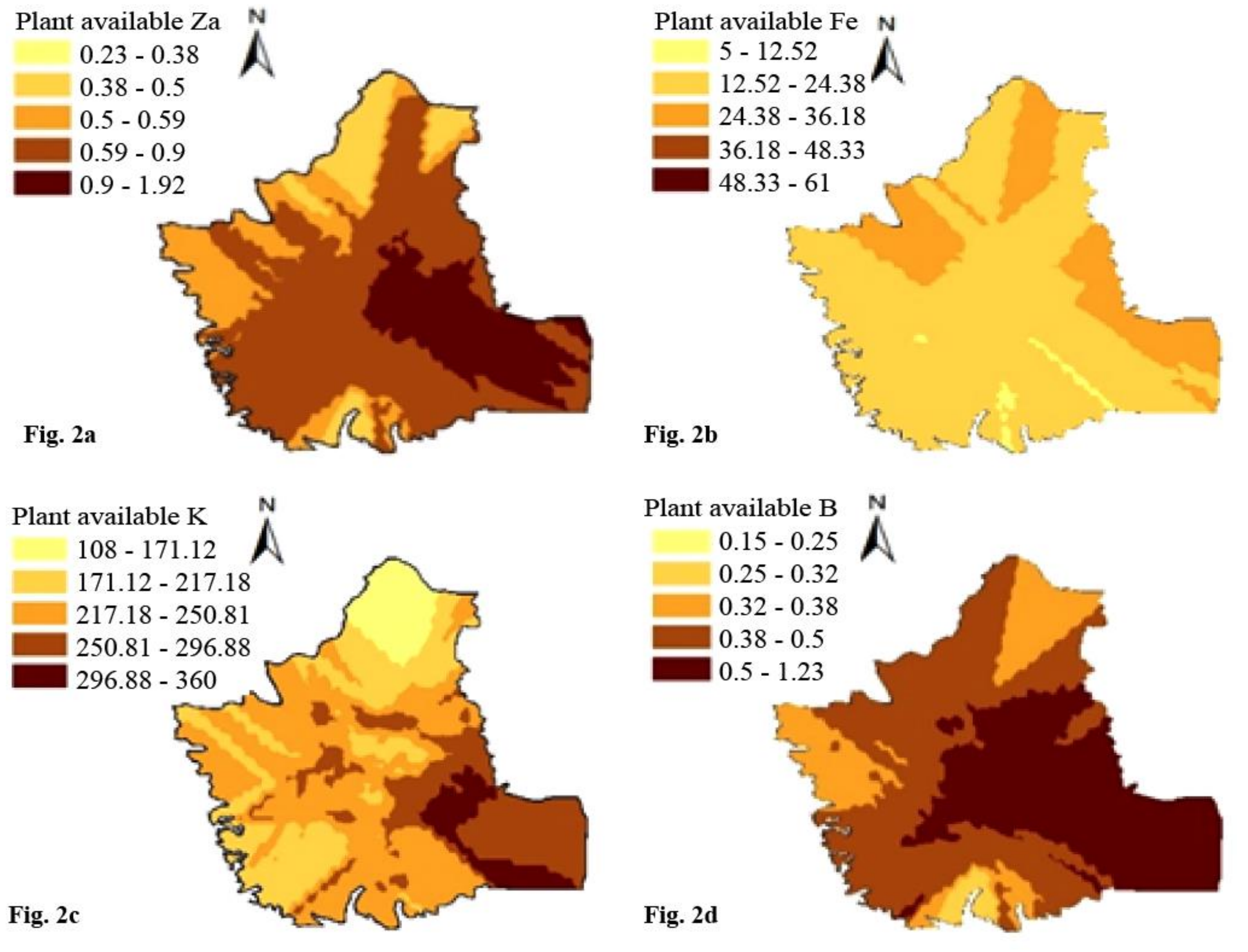

Fig. 2. The spatial variation (kriged map) of soil nutrients (zinc, iron potassium and boron).

The spatial variability of nutrients is created by soil forming factors (the intrinsic factors) and the soil management practices i.e. fertilization, tillage and crop cover (the extrinsic factors). Strong spatial dependence can be attributed to intrinsic factors (parent material) while a weak spatial dependency can be attributed to extrinsic factors (Cambardella *et al*., 1994). Spatial dependence of Zn and K with the range of 31.5 and 0.74 km, respectively in Heris region of Iran were reported (Haghdar *et al*., 2012). The intrinsic or inherited properties of soils to supply the nutrients had a dominant role than the management practices. Spatial structure of plant available B and Fe best fit the exponential model. Exponential isotropic model is similar to the spherical model in that it approaches the sill gradually, but different in the rate at which the sill is approached and the fact that the model and the sill never actually converge. Medium spatial dependence of Fe and B, the range for the spatial dependency of plant available Fe was 76 km comparable to Liu *et al.* (2012) range of 63.91 km. Average standardized error close to Root Mean Squared Error (RMSE) is considered as prerequisite for correct prediction (Hani *et al*., 2010). The spatial variance appeared to have been influenced by the soil type as seen by overlaying the soil boundaries on the kriged map; and land capability map further helped to understand the spatial variation of the nutrient level. The higher concentration of the nutrients toward Shah Bander, Bathro and Jati areas where dominantly Shahdara, Daro, Bulri soils occur. The Shahdra and Daro associations contain soils which are dominantly very fine sandy loams. These soils are well drained and easy to till, and hence intensively farmed for various crops including sugarcane, vegetables, rice and sunflower. Land capability Class-I covers more than 10% area and Class II more than 20% of the land of this area as reported in the Land Capability map by the Soil Survey of Pakistan (Din *et al.,* 1969; Khan *et al.,* 1979).

Plant nutrients i.e. N, P, K, B, Cu and Zn are correlated well with the soil test values for respective nutrients except for Mn and Fe. Relatively low correlation between soil and plant K suggest availability of K to plant from sources other than exchangeable and soluble K pools. Crop response to soil K is generally erratic as the availability of K depends on soil test value and the transformations from non-exchangeable to exchangeable K (Wang *et al*., 2004). Soil and plant correlations of Zn and B were stronger (r^2=0.83) below the adequate level of the nutrients in soil (<0.7 mg B and 1.0 mg Zn kg^{-1} soil). The micronutrients, Mn and Fe in plant and soil had poor or no relationship both of these elements in soil were far above the adequate level. The correlation develops only when soil test values are lower than the adequate value. Generally, the correlations developed for sugarcane crop are between soil properties and yield (Cerri & Magalhaes 2012) with minor studies relating to soil and leaf (Khuhro *et al*., 2014).

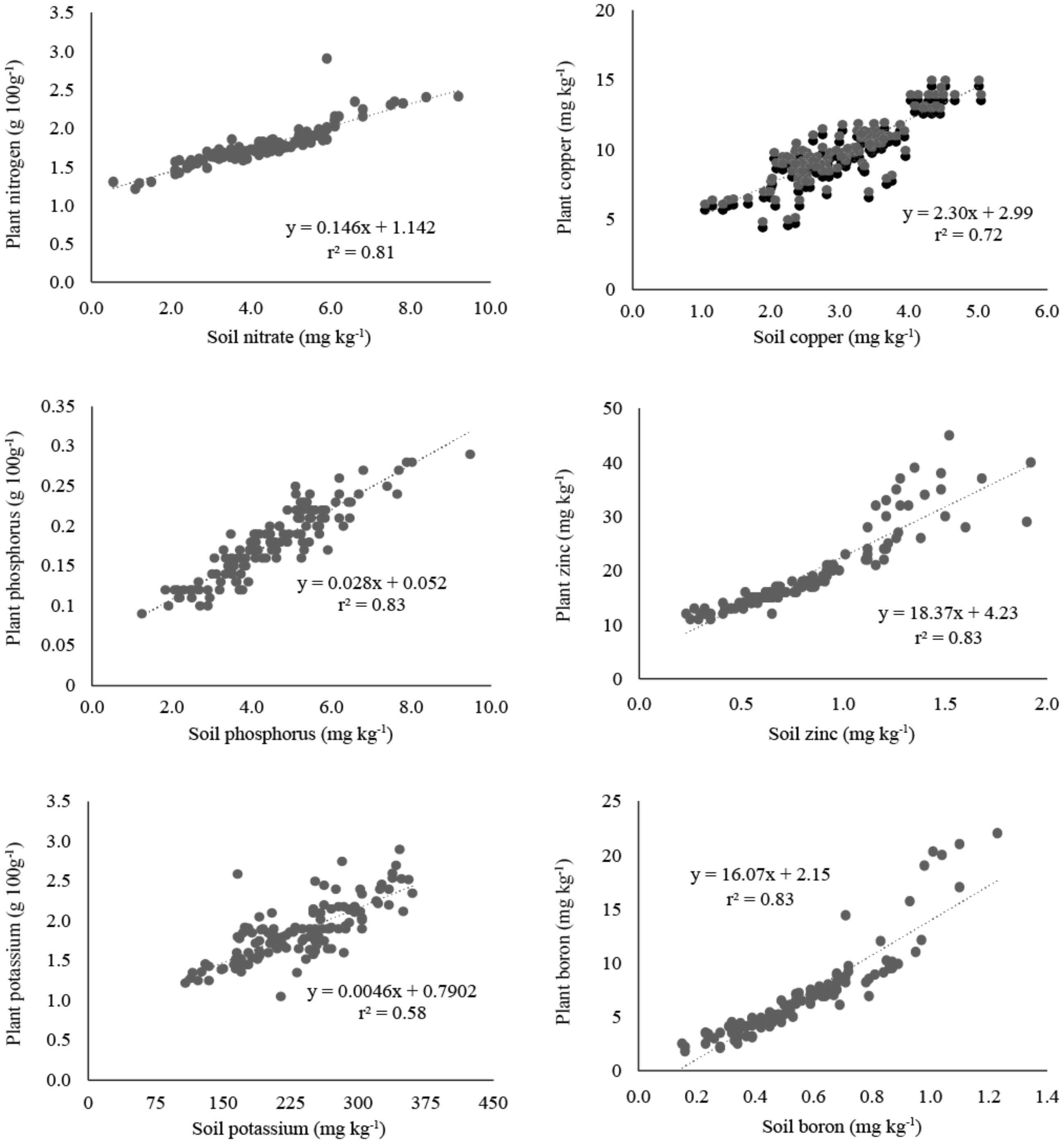

Fig. 3. Soil and plant nutrients correlation of nitrogen, phosphorus, potassium, boron, copper, and zinc.

Conclusion

Plant and soil nutrient status as sugarcane yield limiting factor, was evaluated through a survey study in lower Sindh (district Thatta). The soils were found low in N, low to medium in AB-DTPA extractable P and adequate in K. Among the soil micronutrients, Zn was low, B was medium, and Cu and Fe were high. The soil nutrients were found spatially variable; and soil Zn was lower in Mirpur Sakro and Thatta sub districts (Talukas) and high towards Sujawal-Jati sub districts. A spatial pattern existed for soil Fe, K and B. The nutrient contents of N and P in the plant index tissue were slightly below the critical values, and K was above the critical value and higher than the optimum range. The micronutrients B, Cu, Fe, Mn and Zn concentrations were in sufficiency range. Soil and plant interaction existed for N, P, K, B, Cu and Zn nutrients. The study therefore, recommends the increase in present levels of N and P along with B and Zn application.

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