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Variability of major soil properties of a fallow-acidic-level upland with high and multiple spatial resolutions

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Abstract

Variation of the soil attributes of a land in an area is dependent on topography, time, climate, parent material, land use land cover, land management, distance and scale. This variation affects the representation of soil of a land in an area. The study aimed to assess the variations in the representation of major soil properties of a unique fallow-acidic-undisturbed-level upland in different spatial resolutions of soil sampling. A fallow and level upland of 1500 m^2 as separately gridded with the spacing of 5mx5m, 10mx10m and 15mx15m and geo-referenced surface (0-20 cm) soil samples were collected from the corner of each grid. The collected soil samples were analyzed for texture (Tx), organic carbon (OC), pH, total N (TN), available P (AP), exchangeable K (exch K), available S (AS), available Fe (AFe), available Zn (AZn) and available Mn (AMn) in soil. Statistical and geospatial analyses of the dataset were done with the relevant softwares. For the nutrients TN, AP, AZn and AFe, coefficients of variation (CV) showed a trend of increment across high-medium-low spatial resolutions, and their variability ranked as AZn (mean CV=104.03%, great variation)>AFe (mean CV=41.67%, moderate variation)>AP (mean CV=20.32%, moderate variation)>TN (mean CV=4.92%, low variation) based on average CV of three spatial resolutions of sampling. In case of other soil attributes, no particular trend of increment or decrement was observed across the resolutions and their variability was moderate except for pH which had low variability. Their variability ordered as exch K (mean CV=35.17%)>AS (mean CV=34.98%)>SOC (mean CV=31.71%)>Tx (mean CV=31.17%)>AMn (mean CV=30.10%)>Soil pH (mean CV=6.96%). Rationale correlations were observed between some soil attributes (pH *vs* AZ, AFe, OC; Tx *vs* TN, AP; Exch K *vs* AZn *vs* AFe; OC *vs* Exch K, AZn, AFe) with different degrees of associations (r), and increased trend in r value was found across the resolutions of high-medium-low except for pH and Tx. Different spatially gradient structures of the ordinary krigged interpolated maps were observed for different soil properties and for different spatial resolutions. Quantitatively, calculated (from semivariograms) nugget effects of 0-100% indicated that spatial dependency of studied soil properties could be very strong to very weak. The heterogeneity of soil in the upland as revealed by our results would assist scientists or farm managers to use or compare scale-dependent soil data wisely and precisely.

Keywords: Geospatial, soil attributes, correlation, heterogeneity, map.

Introduction

Soils of a land of an area vary across distance and over time. This variation (spatial and/temporal) of soil constructs soil heterogeneity affected generally by the soil forming factors (Jenny, 1941), and also by some specific aspects as land use land cover (Zhang et al., 2015; Panday et al., 2019; Sharma and Sood, 2020), soil series (Behera and Shukla, 2014), soil category (Usowicz and Lipiec, 2017; Delbari et al.,, 2019), soil depth (Behera et al., 2016; Negassa et al., 2019), parent material (Dengiz et al., 2013; Şenol et al., 2018) locations

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(Reza et al., 2016; 2017), tillage (Özgöz et al., 2010), soil erosion (Salviano, 1996), scale or size of the area (Wang et al., 2017), and land management (Shukla et al., 2016; Metwally et al., 2019). Conversely, this variability affects application of irrigation water (Zhang et al., 2013), nutrient management (Fang et al., 2020), crop growth and yield (Usowicz and Lipiec, 2017; Su et al., 2018; Castellini et al., 2019). Soil variability assessment is also needed for food safety and environmental modeling (Hangsheng, 2005; Bhunia et al., 2018). For carrying out a study on soil in an area, sampling of soil (an invasive method) is usually done to represent the land of an area. This sampling of soil of an area is done by random sampling with more or less well distribution between sampling points (Wang et al., 2017; Reza et al., 2017; Bhunia et al., 2018; Niederberger et al., 2019) or by grid-basis maintaining a specific distance between sampling points (e.g., Negassa et al., 2019). The variable distance between sampling points can be designated as spatial resolution of soil sampling (soil sampling densities). In regards to grid-basis sampling, different spatial resolutions of soil samplings such as 3 m × 3 m (Negassa et al., 2019), 50 m × 50 m (Bogunovic et al., 2014), 60 m × 60 m (Su et al., 2018), 70 m × 70 m (Delbari et al., 2019) were used in the previous studies to represent various study areas and to study spatial variability of soil properties in the respective spatial resolution. This spatial resolution of soil sampling is supposed to affect the representation of soil of a particular land in an area thereby affecting the variability of soil properties of study area. Study regarding soil properties variability in a unique land with multiple spatial resolutions is rare. Keeping other factors unchanged, a well aerated, fallow, anthropologically undisturbed, acidic and topographically leveled land with humid subtropics needs to be studied for variability of major soil properties as a function of spatial resolutions of soil sampling. The hypothesis of this study was if the soil properties of the same unit of land vary as a function of the sampling densities or spatial resolution of sampling. The research question of the study was how the major soil properties of unique unit upland are represented differently with different soil sampling densities (referred as spatial resolution of soil sampling). The information would assist the soil scientists or soil surveyors or farm managers to compare or use soil data logically and precisely. Therefore, the present study was systematically designed to assess the variability of major soil properties of a unique unit of upland depending on spatial resolution of soil sampling.

Material and Methods

Study area and soil sample collection: Geo-referenced (averaging three GPS readings) surface soil (0-20 cm) samples were collected from upland (1500 m^2) with the assistance of GPS device in the three spatial resolutions making grids across the land located in Sylhet district of Bangladesh (Figure 1).

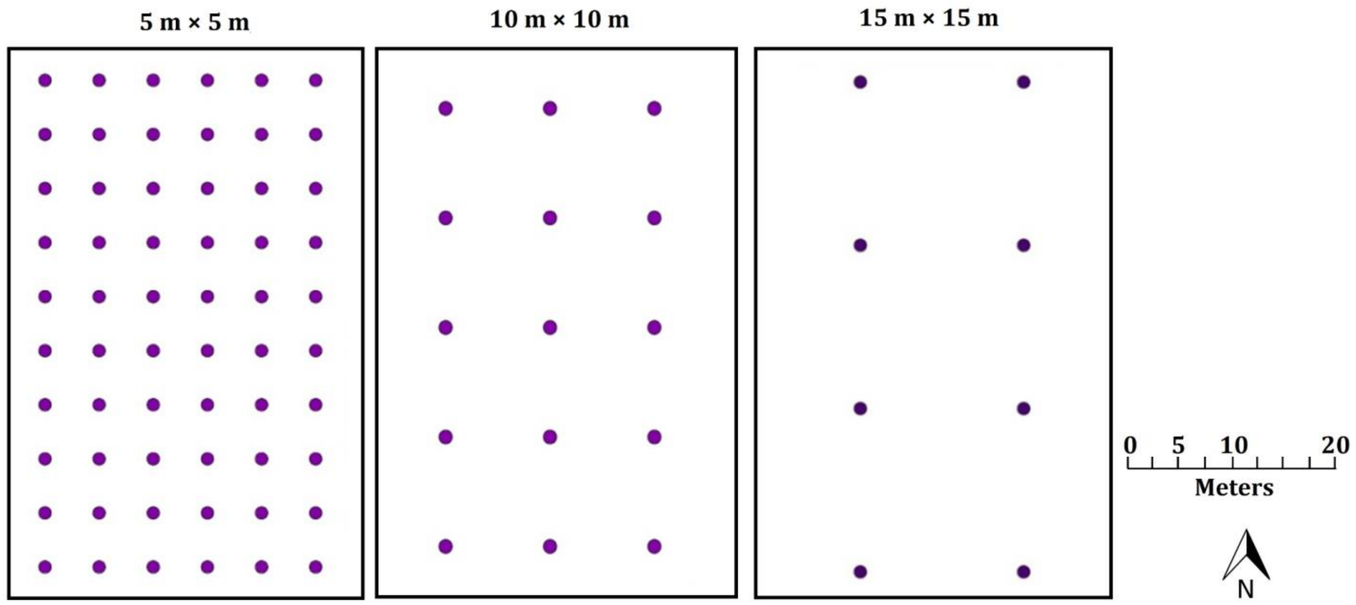

Figure 1. Sampling points in various spatial resolutions (5 m × 5 m, 10 m × 10 m, 15 m × 15 m; from left to right) in the study upland located in Bangladesh

The grids were at the spacing of 5 m × 5 m, 10 m × 10 m, and 15 m × 15 m. Soil samples were collected from the corner of grids (Figure 1). Errors on certain points of GPS readings were adjusted with the known values (distance) between points. The land was a fallow land which was anthropologically undisturbed for about 1.5 years. The area received an average annual air temperature of 24.8 °C, an average annual rainfall of 3876 mm. The land of the area is situated at 35 m above sea level (masl), which is topographically leveled. The samples were collected during dry season (November) of the year 2018 from fallow land with very thin grass layer.

Soil sample processing and analysis

The collected soil samples were brought to the laboratory and dried in the air by spreading them over the sheet of brown paper. Then they were ground and passed through 10 mesh sieve (2 mm), and kept in small plastic pot (upon labeling) for further analyses. The analytical methods followed for the determination of soil attributes are presented in Table 1.

Table 1.The analytical methods followed for the determination of soil attributes

Soil Parameter Analyzed	Unit	Methods of Analysis Followed
Particle Size Analysis	% of individual fractions	Hydrometer method (Bouyoucos, 1962)
Soil pH	____	Glass electrode pH meter method (soil: water ratio being 1: 2.5) (Jackson, 1973)
Organic carbon	%	Wet oxidation method (Walkley and Black, 1934)
Total Nitrogen (TN)	%	Micro-Kjeldahl method (Bremner and Mulvaney, 1982)
Available Phosphorus (AP)	mg/kg	Bray and Kurtz method (Bray and Kurtz, 1945)
Exchangeable Potassium (ExchK)	$cmol_c/kg$	Ammonium acetate method (Jackson, 1973)
Available Sulphur (AS)	mg/kg	Calcium Bi-phosphate Extraction Method (Fox et al., 1964)
Available Zink (AZn)	mg/kg	DTPA Extraction method (Lindsay and Norvell, 1978)
Available Iron (AFe)	mg/kg	DTPA Extraction method (Lindsay and Norvell, 1978)
Available Manganese (AMn)	mg/kg	DTPA Extraction method (Lindsay and Norvell, 1978)

Statistical analyses of the dataset

Summary statistics of mean, standard deviation (derived coefficient of variation, CV), minimum and maximum (i.e., range) were found out for soil parameters of total N (TN), available P (AP), exchangeable K (Exch K), available S (AS), available Zn (AZn), available Mn (AMn), available Fe (AFe), soil texture (individual soil fractions), pH and organic carbon (OC). This statistical analysis was done with the spreadsheet. Pearson correlation matrix (with the level of significance) of the said soil parameters was found out using the statistical package of SPSS (version 16). Zhang et al. (2007) mentioned that variability of a soil property can be described by coefficient of variation (CV). A class of CV (CV<10%: Low variability; CV=10-90%: Moderate variability; CV>90%: Great variability) as provided by Jiang et al. (2003) and cited by Zhang et al. (2007) was used to denote the degree of variation of soil attributes studied.

Geostatistical analyses of the dataset with various spatial resolutions

Interpolations from the sampling points of respective sampling densities (here referred as spatial resolutions) for creating continuous surface maps of the soil attributes onto the land of interest by ordinary kriging (Journel and Huijbregts, 1978; Clark, 1979) method were performed and the classifications of the soil parameters were done with the same class intervals for making comparisons. ArcGIS 10.3 was used for this analysis. During the geostatistical analyses, fitted semivariograms (Goovaerts, 1997) with any of suited models (Stable, J-bessel, K-bessel, Hole effect, Pentaspherical) for the studied soil parameters were inspected to derive nugget effects (nugget/sill ratio). Nugget/Sill ratio class (<25%: strong autocorrelation, 25-75%: moderate autocorrelation, >75%: low autocorrelation) given by Cambardella et al. (1994) was used to indicate the spatial correlations of the studied soil parameters in the land for each spatial resolution of soil samplings. The data normality was checked visually (normal or near-normal distribution) by histograms. The root mean squired errors (RMSE) were checked (for lower values) and recorded from the summary report of the analysis. The report of Ettema and Wardle (2002) was also used for the quantification as well as explanation of spatial variability and heterogeneity of the soil attributes.

Results

Statistical variability of major soil propertiesat various spatial resolutions

Classical statistics of the soil attributes for the spatial resolutions of 5 m × 5 m, 10 m × 10 m and 15 m × 15 m are presented in the Table 2. Soil texture (as indicated by Sand: Clay) ranged 3.22:1 to 21.09:1, 5.08:1 to 11.66:1 and 4.11:1 to 9.23:1, respectively across the resolutions. In the three spatial resolutions (high, medium, low), its corresponding coefficients of variation (CV) were 41.69, 25.04 and 26.77%, respectively. Particular trend of CV (high-medium-low or vice versa) was not observed across the spatial resolutions, although its higher CV (41.69%) was observed in high resolution. Soil organic carbon ranged 0.60-2.20, 0.67-2.19 and 0.81-2.19%, respectively across the spatial resolutions. In the three resolutions, the corresponding CVs were 34.35, 30.10, and 30.67%, respectively. Particular trend of its CV was not observed across the spatial resolutions, although higher CV (34.35%) was in case of high resolution. Regarding soil pH, it ranged from 4.1

to 5.8, 4.1 to 5 and 4.1 to 5.1 for high, medium, and low resolutions, respectively. In the three resolutions, its corresponding CVs were 7.33, 5.40, and 8.16%, respectively. In contrast to soil texture and SOC, its higher CV (8.16%) was found for low resolution, although no particular trend of CV was observed across the spatial resolutions. Total nitrogen spanned from 0.079 to 0.091, 0.079 to 0.09, and 0.08 to 0.09%, respectively with CV values of 4.42, 4.77, and 5.56%, respectively. Its CV increased gradually with the decrease in spatial resolutions. In case of available phosphorus, its range varied from 6.8 to 17.3, 6.8 to 16.1, and 7.5 to 15.9 mg/kg, respectively across the resolutions. Its corresponding CVs were 16.59, 19.99, and 24.39%, respectively. Similar to TN, its CV increased gradually with the decrease in spatial resolutions. Exchangeable potassium ranged 0.06-0.24, 0.07-0.19, and 0.06-0.19 $cmol_c$/kg, respectively across the three resolutions. Its corresponding CVs were 32.93, 30.92, and 41.66%, respectively. Contrary to TN and AP, no particular trend of CV for Exch K was observed across the resolutions. Available sulphur in the three spatial resolutions of soil sampling spanned from 4.7 to 51.4, 4.7 to 42.2, and 14.3 to 42.2 mg/kg, respectively. Its corresponding CVs were 29.48, 38.63, and 36.84%, respectively. Although higher CV of available S (38.63%) was found in moderate spatial resolution, no particular trend of CV was observed across the resolutions.

Table 2.Descriptive statistics of soil texture, organic carbon, pH, total N, available P, exchangeable K, available S, available Zn, available Fe, and available Mn

Resolutions	5 m×5 m		10 m×10 m		15 m ×15 m		Mean
Soil variables	CV (%	Range	CV (%)	Range	CV (%)	Range	CV
Tx	41.69	3.22:1 - 21.09:1	25.04	5.08:1 - 11.66:1	26.77	4.11:1 - 9.23:1	31.17
OC (%)	34.35	0.60 - 2.20	30.10	0.67 - 2.19	30.67	0.81 - 2.19	31.71
Soil pH	7.33	4.10 - 5.80	5.40	4.10 - 5.00	8.16	4.10 - 5.10	6.96
TN (%)	4.42	0.08 - 0.09	4.77	0.08 - 0.09	5.56	0.08 - 0.09	4.92
AP (mg/kg)	16.59	6.80 - 17.30	19.99	6.80 - 16.10	24.39	7.50 - 15.90	20.32
Exch K ($cmol_c$/kg)	32.93	0.06 - 0.24	30.92	0.07 - 0.19	41.66	0.06 - 0.19	35.17
AS (mg/Kg)	29.48	4.70 - 51.40	38.63	4.70 - 42.20	36.84	14.30 - 42.20	34.98
AZn(mg/kg)	75.41	0.21 - 4.53	107.93	0.28 - 4.53	128.74	0.31 - 4.53	104.03
AFe (mg/kg)	35.10	32.00 - 167.00	43.06	37.00 - 167.00	46.84	42.00 - 165.00	41.67
AMn (mg/kg)	31.33	12.10 - 52.20	21.97	12.90 - 34.50	36.99	17.70 - 52.20	30.09

Tx= Soil texture (Sand/Clay); OC=Organic Carbon; TN= Total nitrogen; AP= Available phosphorus; Exch K= Exchangeable Potassium; AS= Available Sulphur; AZn= Available Zinc; AFe= Available Iron; AMn= Available Manganese; CV= Coefficient of variation

Available Zn ranged from 0.21 to 4.53, 0.28 to 4.53, 0.31 to 4.53 mg/kg, respectively. The corresponding CVs were 75.41, 107.93, and 128.74%, which showed a particular trend of increment of CV across high-medium-low spatial resolutions. Available Fe ranges from 32-167, 37-167, and 42-165 mg/kg for three spatial resolutions, respectively. Similar to available Zn, CVs of available Fe in the said resolutions were 35.10, 43.06, and 46.84%, respectively which also demonstrated a trend of increment of CV across high-medium-low spatial resolutions. For available Mn, it ranged from 12.1 to 52.2, 12.9 to 34.5, and 17.7 to 52.2 mg/kg, respectively (Table 2). In the three resolutions, the corresponding CVs of available Mn were 31.33, 21.97 and 36.99%, respectively of which higher one was in case of low resolution with no particular trend (increment or decrement) of CVs across the resolutions.

Considering the overall (average CVs of all spatial resolutions) variations of each soil attributes, all attributes showed moderate variability (CV within the range of 10-90%) except TN (CV = 4.92%, low variability), pH (CV = 6.96%, low variability) and AZn (CV = 104.03%, great variability).

Variations in correlations matrix of soil attributes as a function of sampling density

Data presented in Table 3 shows that soil pH is significantly and negatively correlated (r=-0.32** to -0.41**) with available Zn, available Fe and OC. Available P has significant strong correlation (r=0.94**) with total N. Mineral nutrient elements exchangeable K, available Zn and available Fe have positive and significant correlations (r=0.27-0.66) with each other.

Data presented in Table 4 shows that SOC positively correlated with exchangeable K (r=0.60*), available Zn (r=0.61**) and available Fe (r=0.66**) in soil. Soil available P has strong positive correlation with total N (r=0.92**). Strong correlation (r=0.68**) exist between exchangeable K and available Zn in soil. Again, exchangeable K is positively correlated (r=0.56*) with Fe in soil. Similarly, micronutrient available Zn is positively correlated (r=0.72**) with available Fe in soil. And, SOC has moderately positive correlation (r=0.60* to 0.66**) with exchangeable K, available Zn and available Fe.

Table 3. Pearson correlation matrix between the soil properties with 5m x 5m sampling density

	AP	TN	Exch K	AZn	AFe	AMn	AS	SOC	pH	Tx
AP	1.00									
TN	0.94**	1.00								
ExchK	-0.14	-0.11	1.00							
AZn	-0.16	-0.17	0.39**	1.00						
AFe	0.00	0.00	0.27*	0.66**	1.00					
AMn	-0.17	-0.04	0.08	0.12	0.20	1.00				
AS	0.12	0.07	0.02	0.14	0.07	0.06	1.00			
SOC	-0.03	-0.06	0.26*	0.37**	0.48**	-0.15	0.05	1.00		
pH	0.21	0.23	-0.21	-0.41**	-0.39 **	0.09	0.11	-0.32**	1.00	
Tx	0.08	0.07	0.01	-0.01	0.02	0.10	0.05	-0.16	-0.01	1.00

** Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).
AP= Available phosphorus; TN= Total nitrogen; Exch K= Exchangeable Potasium; AZn= Available Zinc; AFe= Available Iron; AMn= Available Manganese; AS= Available Sulphur; OC=Organic Carbon; Tx= Soil texture (Sand/Clay).

Table 4. Pearson correlation matrix between the soil properties with 10m x 10m sampling density

	AP	TN	Exch K	AZn	AFe	AMn	AS	SOC	pH	Tx
AP	1.00									
TN	0.92**	1.00								
Exch K	-0.36	-0.27	1.00							
AZn	-0.21	-0.20	0.68**	1.00						
AFe	0.12	0.11	0.56*	0.72**	1.00					
AMn	-0.37	-0.16	0.36	0.30	-0.02	1.00				
AS	0.19	0.31	-0.06	0.38	0.15	0.35	1.00			
SOC	0.17	0.10	0.60*	0.61*	0.66**	0.00	0.25	1.00		
pH	-0.05	-0.06	-0.47	-0.44	-0.42	-0.06	0.06	-0.42	1.00	
Tx	-0.63*	-0.60*	0.48	0.21	0.12	-0.17	-0.27	0.20	-0.21	1.00

** Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).
AP= Available phosphorus; TN= Total nitrogen; Exch K= Exchangeable Potasium; AZn= Available Zinc; AFe= Available Iron; AMn= Available Manganese; AS= Available Sulphur; OC=Organic Carbon; Tx= Soil texture (Sand/Clay).

On the other hand, soil texture (Tx) has strong and negative correlation with available P (r=-0.63*) and total N (r=-0.60*). This means contents of available P and total N in soil increase with increasing fineness of soil. Data presented in Table 5 shows that available P has negative correlation with available Mn (r=-0.73*) and strong positive correlation with total N (r=0.95**) in soil. Macronutrient exchangeable K is strongly and positively correlated (r=0.91** to 0.95**) with micronutrients available Zn and Fe. Similarly, available Zn is positively correlated with available Fe (r=0.80*).

Table 5.Pearson correlation matrix between the soil properties with 15mx15m sampling density

	AP	TN	Exch K	AZn	AFe	AMn	AS	SOC	pH	Tx
AP	1.00									
TN	0.95**	1.00								
Exch K	-0.43	-0.38	1.00							
AZn	-0.47	-0.48	0.95**	1.00						
AFe	-0.54	-0.48	0.91**	0.80*	1.00					
AMn	-0.73*	-0.53	0.38	0.21	0.56	1.00				
AS	-0.08	-0.28	0.36	0.38	0.34	-0.11	1.00			
SOC	-0.58	-0.60	0.86**	0.81*	0.92**	0.39	0.37	1.00		
pH	0.49	0.50	-0.48	-0.50	-0.36	-0.21	-0.03	-0.56	1.00	
Tx	0.07	-0.05	0.33	0.49	0.25	-0.51	0.17	0.36	-0.37	1.00

** Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).
AP= Available phosphorus; TN= Total nitrogen; Exch K= Exchangeable Potasium; AZn= Available Zinc; AFe= Available Iron; AMn= Available Manganese; AS= Available Sulphur; OC=Organic Carbon; Tx= Soil texture (Sand/Clay).

Again, soil organic carbon (SOC) has significant positive correlation (r=0.81* to 0.92**) with exchangeable K, available Zn and available Fe in soil.

Geospatial variability of studied soil properties at various spatial resolutions

Spatial variations in the interpolated maps of soil properties

The interpolated maps of the studied soil attributes gave the visual representation of the study area on the differences of the physico-chemical status of the soil across the spatial resolutions of 5 m × 5 m, 10 m × 10 m and 15 m × 15 m (Figure 2). Visual observation shows more patchiness in the interpolated surface map of soil texture in the higher resolutions (5 m × 5 m) compared to others (Figure 2). As indicated by the Tx value (Sand/Clay=7.2 to 10.0) of this map, greater portion of the land was medium textured soil. Other areas were either very coarse (Tx=10.0-21.0) or fine (Tx=3.2-7.2). In the least resolution or large scale (15 m × 15 m), the map showed that variance was not in spatially structured (one type of texture; the other type was not visible in the map due to the least number of data point in the classified data range) and the textural type was finer. Large and spatially gradient variability of the soil texture was found in the surface map of the unit land of which soil sampling was done in the medium scale (10 m × 10 m). In case of soil organic carbon, it was observed that the numbers of patches in the interpolated surface map of soil organic carbon (SOC) onto the land were much in the higher resolutions (5 m x 5m) compared to others. The heterogeneity of SOC of this resolution was much, where moderate status of OC (1.0-1.5%) was dominated. In the medium scale (10 m × 10 m), very prominent spatially gradient variability of the SOC exists with centering low status (<1.0%) and diverging higher status (1.0-1.5 and >1.5%) gradually towards the periphery along with nearly an equal share of areas. In the large scale (15 m × 15m) map, spatially gradient variability was also observed although it was not well-structured, where most of the areas were in the OC value of 1.0-1.5%. Patchiness in the interpolated surface map of soil pH onto the land was the higher in number in the higher resolutions (5m x 5m) compared to others.

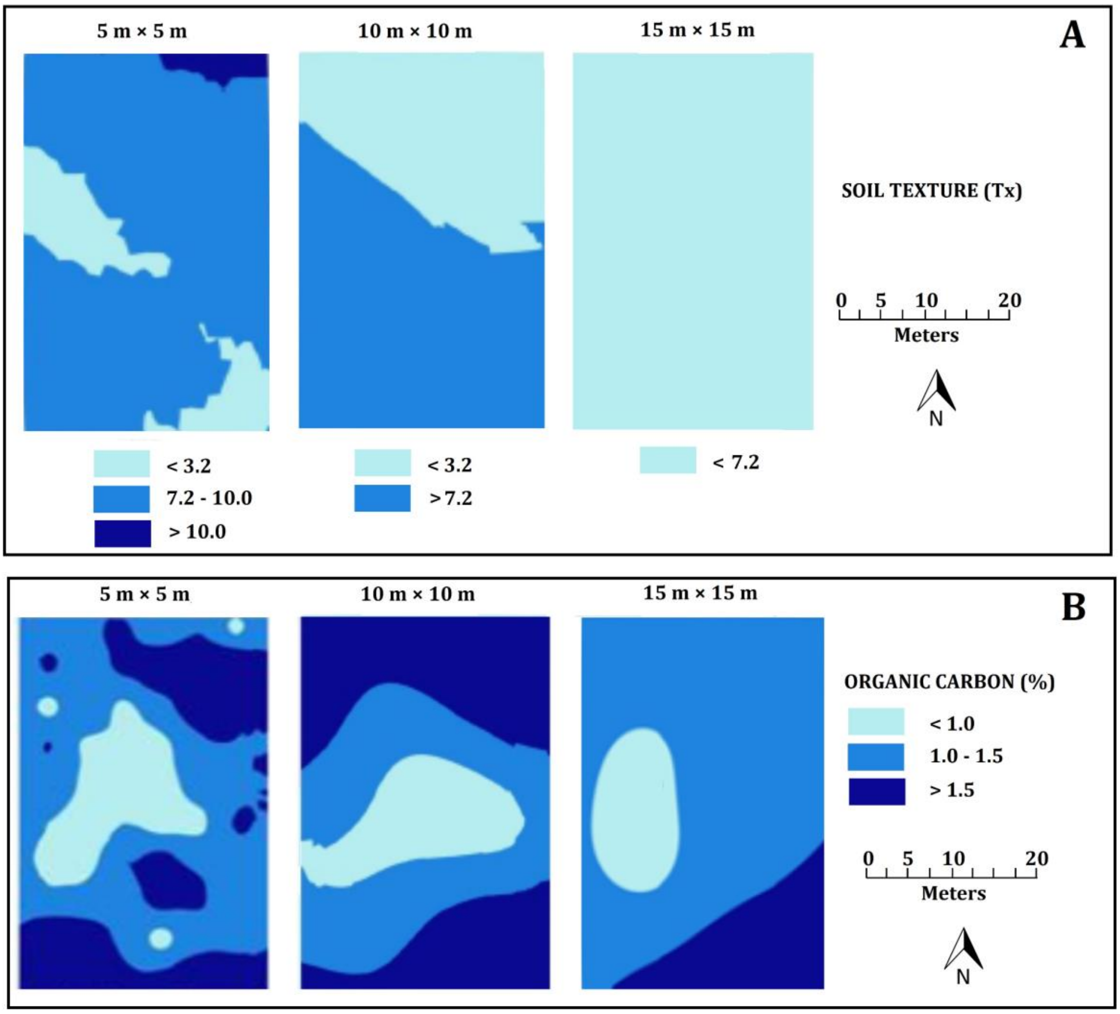

Fig.ure 2. Interpolated maps of soil texture (A), organic carbon (B), pH (C), available N (D), available P (E), available K (F), available S (G), available Fe (H), available Zn (I) and available Mn (J) obtained by ordinary kriging in the spatial resolutions of 5 m × 5 m, 10 m × 10 m and 15 m × 15 m (from left to right for each soil variable, respectively)

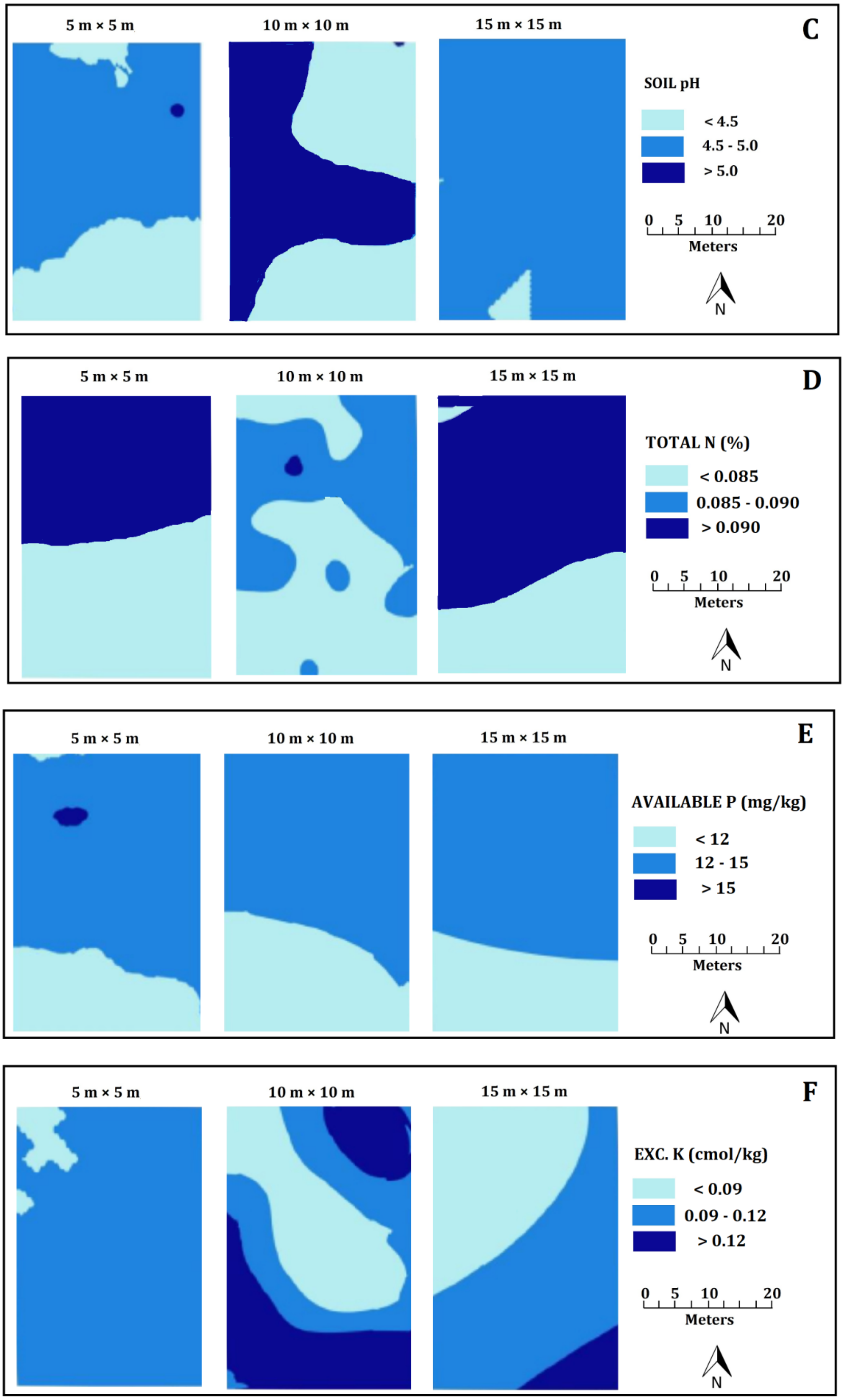

Fig.ure 2. (continued)

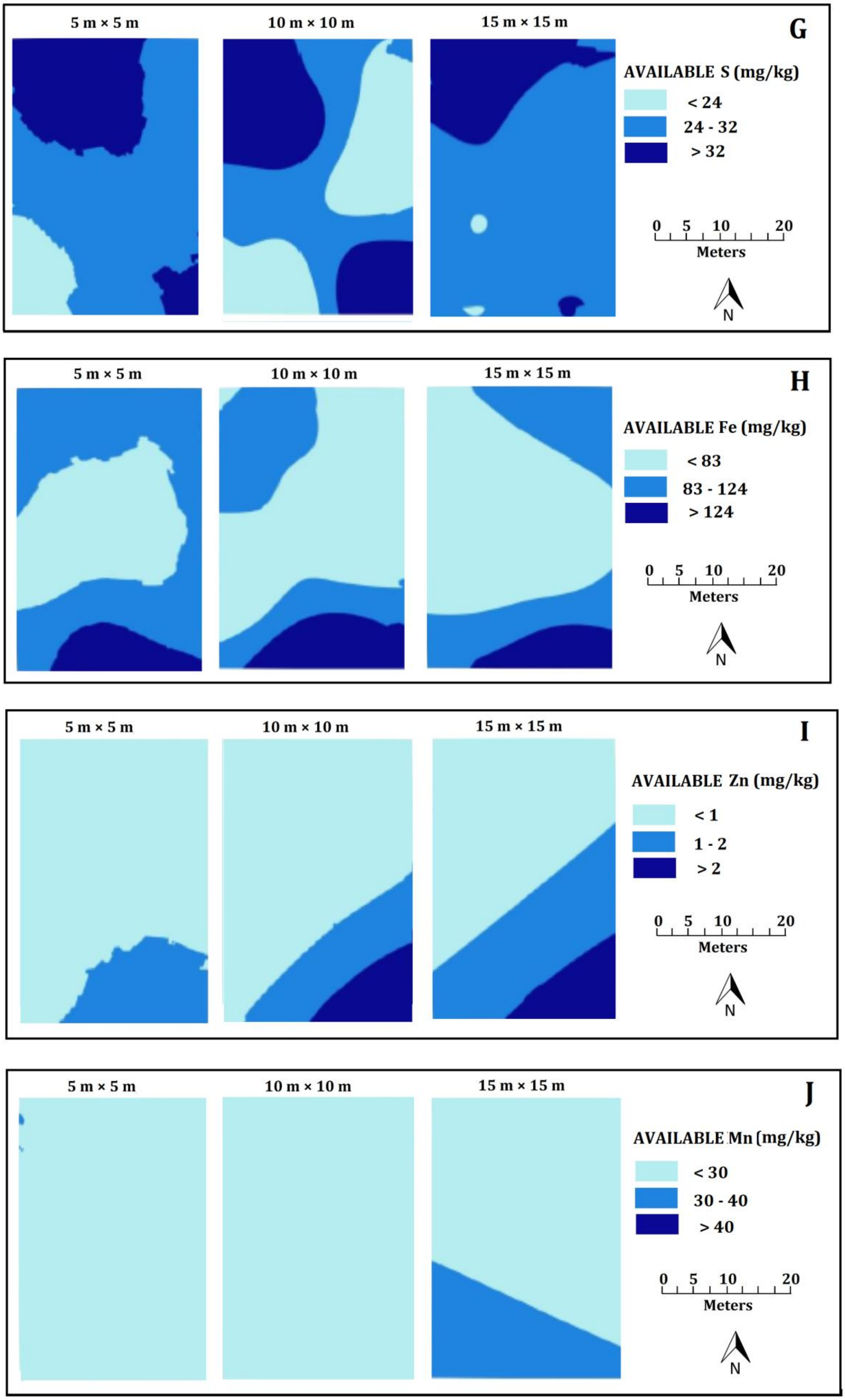

Fig.ure 2. (continued)

The greatest portion of the land was strongly acidic (pH=4.5-5.0) in reaction, considerable portion was very strongly acidic (pH=<4.5) and little portion is slightly acidic (pH>5.0) in this spatial resolution. In the medium scale (10mx10m), distinct spatially gradient variability of the soil pH exists (both strong and very strong reactions sharing almost equal areas) in the surface map of the land. In the large scale (15 m × 15 m), the map showed that variance was not distinct spatially structured where almost all areas were in the pH value of 4.5-5.0, and a small abrupt patch of very strong reaction was present at one side. It can also be noted here that in the latter scale, created surface map (by kriging) is not showing the legend color of one class (pH> 5.0) might be due to insufficient data point. Regarding total nitrogen, the patchiness in the interpolated surface map was higher in the moderate resolution (10 m × 10 m) while it was the least in high resolution (5 m × 5 m) and low resolution (15 m × 15 m). Spatially gradient structures were observed in the maps of all resolutions. In case of soil available phosphorus, the numbers of patches in the map were higher in the higher resolutions (5 m × 5 m) as compared to others. The spatial heterogeneity of AP of this resolution is more than others. Among the classified groups of AP, moderate status (12.0-15.0 mg/kg) prevailed in the major areas in the interpolated surface maps of all resolutions. The heterogeneity for AP gradually decreased with the decreasing the spatial resolution. In regards to exchangeable potassium, the patchiness (in terms of the number and areas of patches) onto the interpolated surface map was higher in the moderate resolution (10 m × 10 m) while it was the least in high resolution (5 m × 5 m).

Smooth spatially gradient structures were observed in both moderate and low resolution maps. The patchiness (in terms of the number and areas of patches) in the interpolated surface map of soil available S were higher in the moderate resolution (10 m × 10 m) while it was the least in low resolution (15 m × 15 m). Among the classes of AS in the maps, moderate one (24.0-32.0 mg/kg) appeared in the more areas in both low and high resolutions. In the moderate resolution, all three classes of AS (<24.0, 24.0-32.00 and >32.0 mg/kg) shared almost the same areas with smooth spatial gradient structure.

In regards to soil available Fe, spatially gradient structures were observed in the maps of all spatial resolutions (5 m × 5 m, 10 m × 10 m, 15 m × 15 m) of soil sampling. Among the classes of available Fe in the maps, moderate one (83.0-124.0 mg/kg) appeared in the more areas in both moderate and low resolutions. In the high resolution, two classes of available Fe (<83.0, and 83.0-124.0 mg/kg) shared almost the same areas centering the class with the lower value. Class of available Fe of >124 mg/kg covered the least areas in the maps of all resolutions. Regarding soil available Zn, the smooth and gradient spatial structures were pronounced in the maps of moderate (10 m × 10 m) and large (15 m × 15 m)-scale resolutions. The patchiness as well as the spatial heterogeneity was also higher in the surface maps of these two resolutions where low value class of Zn (<1.0 mg/kg) occupied major areas of the land in north-western side. In case of high resolution map, two classes of available Zn (<1.0, 1.0-2.0 mg/kg) covered the whole land of which low value class was dominated. In case of available Mn, the surface map showed that the variance of Mn in the high resolution (5 m × 5 m) was nearly non-spatially structured.

Similarly, the variance of Mn in the map of moderate resolution (10 m × 10 m) was perfectly non-spatially structured. Both maps showed only the lower value class of available Mn (<30.0 mg/kg) without displaying other legend colors due to insufficient data point of the concerned classes. In the large-scale resolution (15 m × 15 m), the spatially structured map was observed with two distinct classes of available Mn (<30 and 30-40 mg/kg).

Variations in the spatial autocorrelations of soil properties

The quantitative variations on the nature of spatial correlations (autocorrelation) for different soil attributes are shown in Table 6. The nugget effects as derived from the semivariograms of soil texture for the high (86%) and low resolutions (99%) indicate that soil texture has very weak autocorrelations (Table 6). Moderate spatial autocorrelation or spatial dependence of soil texture is found in case of moderate (10 m x 10 m) resolution (nugget effect: 45%). In case of all of the spatial resolutions, semivariogram of soil organic carbon gave very low to zero nugget effects (nugget/sill ratio: 0 to 7%) denoting very strong spatial autocorrelation or spatial dependence. Regarding soil pH, in the small–scale resolution (5 m × 5 m) a nugget effect of 9% denotes strong spatial autocorrelation, which is less than that of moderate spatial resolution (10 m × 10 m) (Table 6). A moderate spatial autocorrelation is found (nugget effect: 32%) in the medium-scale resolution (10 m × 10 m). On the other hand, in the large-scale resolution of soil sampling (15 m × 15 m), pure nugget effect (100%) is found meaning that there is no spatial autocorrelation or spatial dependence. For total nitrogen, in all resolutions, corresponding nugget effects of 39%, 37% and 60% indicate moderate spatial autocorrelation.

Table 6. Nugget effects as obtained from semivariogram during kriging in various spatial resolutions

Resolution	5 m x 5 m			10 m x 10 m			15 m x 15 m		
Soil Parameter	Model used	Nugget/Sill (%)	RMSE	Model used	Nugget/Sill (%)	RMSE	Model used	Nugget/Sill (%)	RMSE
Tx	Stable	0.99/1.12=86	3.659	Stable	0.25/0.55=45	1.883	Stable	2.82/2.85=99	2.093
Soil OC	Stable	0.0/2.40=0	0.409	J-bessel	0.18/2.31=7	0.343	J-bessel	0.1/2.59=3	0.273
Soil pH	J-bessel	0.1/1.078=9	0.324	J-bessel	0.21/0.65=32	0.243	Stable	1.4/1.4=100	0.407
Total N	Stable	0.55/1.4=39	0.003	Stable	0.85/2.27=37	0.004	Hole effect	1.5/2.5=60	0.005
AP	J-bessel	1.9/3.99=47	1.991	Stable	0.34/0.89=38	2.397	Pentasp-herical	0.19/1.76=10	3.001
Exch K	Stable	1.24/1.24=100	0.035	Stable	0.04/1.2=3	0.025	Stable	1.0/3.36=30	0.043
AS	Stable	0.55/1.0=55	8.174	Stable	0.05/1.65=3	7.933	J-bessel	0.83/1.42=58	10.982
AFe	Stable	0.45/1.16=38	24.35	K-bessel	0/2.15=0	25.86	Hole effect	0.15/2.3=6	29.339
AZn	Stable	0.25/.509=49	0.552	Stable	0.3/2.21=13	0.978	Stable	1.03/5.13=20	1.460
AMn	Stable	0.45/0.75=60	8.153	Stable	2.49/2.50=99	5.641	Stable	0.75/1.95=38	11.491

Tx= Soil texture (Sand/Clay); OC=Organic Carbon; TN= Total nitrogen; AP= Available phosphorus; Exch K= Exchangeable Potassium; AS= Available Sulphur; AZn= Available Zinc; AFe= Available Iron; AMn= Available Manganese; RMSE= Root Mean Squired Errors.

In case of available phosphorus, the spatial dependence increased with the decrement of sampling density as observed by the nugget effects of 47%, 38% and 10%. In regards to exchangeable potassium, for the medium–scale resolution (10 m × 10 m), a nugget effect (nugget/sill ratio) of 3% indicates the strong spatial autocorrelation. Moderate spatial autocorrelation (nugget effect: 30%) is found in the large-scale resolutions (15 m × 15 m). On the contrary, in case of small-scale (5 m × 5 m) resolution, a little (or no) autocorrelation (nugget effect of 100%) is observed. For available sulphur, in the medium–scale resolution (10 m × 10 m) a nugget effect of 3% denotes the greater spatial autocorrelation. Moderate spatial autocorrelations are found in the both small-scale (5 m × 5 m) and large-scale resolutions (15 m × 15 m) as denoted by the nugget effects of 55% and 58%, respectively.

Regarding available iron, in the medium–scale (10 m x 10 m) and large-scale (15 m x 15 m) resolutions, corresponding nugget effects of 0% and 6% denote the greatest spatial autocorrelation (Table 6), which is also qualitatively observed in the interpolated maps (Figure 2). By observing the nugget effect of 38%, it can be said that moderate spatial autocorrelation or spatial dependence of available Fe occurred in the small-scale (5 m × 5 m) resolution. The nugget effects of available Zn for the medium (13%) and low resolutions (20%) indicate that Zn has strong spatial autocorrelations. Moderate spatial autocorrelation of available Zn is found in case of high (5 m × 5 m) resolution, where the nugget effect is 49%. Small–scale resolution (5 m × 5 m) and medium-scale resolution (10 m × 10 m) gave semivariograms from which calculated corresponding nugget effects of 60% and 99% reveal that available Mn has very weak spatial autocorrelation. On the contrary, large-scale resolution (15 m x 15 m) gave nugget effect of 38% denoting that it has moderate spatial dependence.

Discussion

Statistical variability of the studied soil attributes

Coefficients of variations (CVs) of TN, AP, AZn and AFe demonstrated a trend of increment across high-medium-low spatial resolutions. This variation was due to scalar variability of soil sampling to represent a unit land. Considering average CVs of all resolutions, variability of these nutrient elements ranked as AZn (mean CV=104.03%)>AFe (mean CV=41.67%)> AP (mean CV=20.32%)> TN (mean CV=4.92%) (Table 2). The CV of these soil elements might be associated with the mobility of the elements in soil. Mia (2015) reported that Zn, Fe and P are immobile in soil. Mobile nutrient element can homogenize across the land while immobile one cannot and gets possibility of having more CV. Contrary to the above soil attributes, no particular trend of increment or decrement of CV for soil texture, OC, pH, exch K, AS, and AMn was observed across the spatial resolutions. Again, considering mean CV of all resolutions, variability of these soil attributes ordered as exch K (mean CV = 35.17%)>AS (mean CV = 34.98%)>SOC (mean CV = 31.71%)>Tx (mean CV = 31.17%)>AMn (mean CV=30.10%)>Soil pH (mean CV = 6.96%). A study with a specific scale by Sharma and Sood (2020) reported that CV of soil fertility parameters was greater than 20%, and the CV of soil pH was 6.3%, which partially supports our results. The stated variability of soil attributes among them and across the spatial resolutions revealed the heterogeneity of soil within the plain land of 1500 m^2.

In case of all three resolutions, available P has strong and positive correlations with total N (r=0.94**, r=0.92** and r=0.95**) with varying strengths of correlation coefficients across the resolutions (Tables 3, 4, 5). Fageria and Oliveira (2014) reported a synergism of N and P contents in upland rice plant that could be a reflection of synergistic interaction of these two elements in soil. It is notable that soil pH has significant negative correlations with some other soil attributes like available Zn, available Fe and OC (r = -0.41**, r = - 0.39**and r = -0.32** respectively.) in case of only 5mx5m resolution, but not in case of other resolutions (Tables 3, 4, 5). This is due to scalar variability of soil sampling from the same unit of land. Lindsay (1979) reported that solubility of Zn and Fe increased tremendously due to decrement of soil pH value that supported the correlation of pH with Zn and Fe in our study. It is observed that the significant positive correlations exist between exchangeable K, available Zn in case of all three sampling densities (spatial resolutions) of the land, with varying and increased magnitude of the correlation coefficients across the resolutions (Tables 3, 4, 5) from high to low. Approximately zero-interaction between Zn and Fe in soybean as reported by Kobraee et al. (2011) differed our findings in regards to their availability in soil, might be due to their high solubility regulated by soil acidity in our strongly acidic study soil. Similarly, Exch K (r= 0.26*, r = 0.60* and r = 0.86**), available Zn (r = 0.37**, r = 0.61* and r = 0.81*) and Fe (r = 0.48**, r = 0.66** and r = 0.92**) have significant and positive correlations with SOC with varying and increased strength of coefficient of correlations across the spatial resolutions of sampling of high-medium-low. The density of sampling might be a cause of these variations of linear associations (r). The correlation with the mentioned mineral nutrients might be owing to the mineralization of soil organic matter. It is also noteworthy that soil texture (Tx) has strong and negative correlation with available P (r = -0.63*) and total N (r= -0.60*) in case of only moderate resolution (10 m × 10 m) but not in case of other resolutions due to differences of sampling densities and sample sizes devised for representing the same unit of land. The ability of fine textured (low value of Tx) soil to hold more nutrient elements and organic matter might be a cause of such negative correlation with available P and total N. The study reports of Zhou et al. (2019) for total N and of Niederberger et al. (2019) for P supported this correlation with soil texture.

Geospatial variability of the studied soil attributes

Spatially gradient well-structured to spatially gradient poor-structured interpolated maps were observed among the studied soil properties in the various spatial resolutions. These types of spatial variability were inconsistent in nature that is they did not follow a particular trend of variation across the soil attributes or across the resolutions. This proved the heterogeneity of soil even within a land of 1500 m^2. Similarly, spatial correlation spanned from very strong (nugget effect: 0%) to a little (nugget effect: 100%) across the soil attributes or across the spatial resolutions. With a particular scale and study area, Sharma and Sood (2020) found that spatial distribution maps of soil attributes relevant to fertility were not consistent and demonstrated strong to weak spatial autocorrelations for the soil parameters studied, which was in agreement with our findings.

Conclusion

The major soil properties in an acidic-level-fallow upland of around 1500 m^2 showed different variation in respect to statistical and geospatial variability across various resolution of soil sampling (5 m × 5 m, 10 m × 10 m, 15 m × 15 m). Depending on farmer's capacity and available facility, crops especially high valued ones (e.g. strawberry, dragon fruits, garden peas etc.) can be grown with site-specific nutrients or amendments applications based on the krigged maps generated from high resolution(s) soil sampling even in the small farmland as our study area. The revealed variability of soil properties would also help soil scientist or farm manager to make comparison of soil data/maps with proper consideration of spatial resolution of soil sampling. Such type of research should be confirmed by other similar studies preferably with high resolution with greater area. We could not study with higher resolution (high sampling density) due to error factor of GPS. Similarly we could not study with low sampling density (would result in insufficient data points) because of smaller size of the land (area of interest).

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