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SPATIO-TEMPORAL VARIATION IN SOIL QUALITY AND ITS EFFECT ON PLANT GROWTH

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Abstract

Increasing urbanization and industrialization cause soil contamination, affecting agricultural production and the quality of ground and surface water. The present study was performed in residential, industrial, and commercial zones to analyze the effects of spatio-temporal changes in soil properties during the plant's root, shoot, and height growth. Sixteen soil samples were collected from each zone. An ornamental plant (Salvia scutellarioides) was used in all soil samples. Soil properties were measured at five different periods in 60 days. The results were analyzed using descriptive statistics, ANOVA, and multiple linear regression. On day 0, soils were suitable for plant growth. On day 60, moisture content, porosity, organic matter, Cl, K, and C/N ratio were decreased. The declination of these parameters was greater in industrial soil compared to other soil types. Overall, in industrial soil, plant height decreased by up to 61% compared to residential and 76% compared to commercial. Furthermore, the study revealed that significant anthropogenic load influenced soil quality, which affects plant growth in different soil types.

Keywords: Plant growth; soil physical-chemical properties; soil quality; urban land use soil

Introduction

Urbanization is a primary concern in most parts of the world. It is continuously affecting soil and water quality. The use of either biodegradable or non-biodegradable materials in daily life leads to surface soil pollution. Soil pollution affects the physical, chemical, and biological properties of soil, which results in declination in the quality and fertility of the soil. The changes in soil quality and fertility depend on the type of anthropogenic activity, land use, and management practices (Curran-Cournane et al. 2015; Joimel et al. 2016).

The construction of houses, buildings, roads, and highways alters soil texture and structure, which leads to a loss of organic matter and nutrient supply and hence, a reduction in soil fertility (Zhao et al. 2007). Mining activities have a greater effect on the physical properties of soil, resulting in soil erosion and leading to soil degradation either at the mining site or at the waste disposal site (Pandey et al. 2016). Untreated discharge from industries and residential waste contaminates soil and hence, reduces soil fertility. The effects of these anthropogenic activities, along with agricultural land use and deforestation, have been studied previously. For instance, pollution due to construction, waste disposal, and motor vehicles (Chandrasekaran & Ravisankar 2015); pollutant sources close to public places, residential areas, and industrial areas (Curran-Cournane et al. 2015), and coal mining areas (Pandey et al. 2016); quarrying activities (Rodríguez-Seijo & Andrade 2017); and forest, agricultural, urban and industrial areas (Pushpanjali et al. 2017) have all been studied. In India, several similar studies have been performed around industrial areas (Singh et al. 2015; Krishna & Mohan 2016), mining areas (Pattnaik & Equeenuddin 2016), and irrigation areas (Mhaske et al. 2018). However, none of these studies have reported how the pollutant sources vary within urban areas and what effects these pollutants have on the growth of plants. Therefore, this study was conducted within urban areas, such as residential, industrial, and commercial areas, which are generally built together in the major cities of India.

For this purpose, the present study focused on the spatio-temporal variation of soil pollutant sources within different urban land use areas and their effect on plant growth. Previous studies have reported that industrial soil is more toxic than other soil types (Arif et al. 2018). Based on this, the current study tested three hypotheses. Firstly (H1), we hypothesized that soil quality in terms of its physical, chemical, and biological properties, would be variable between industrial, residential, and commercial soils. Secondly (H2), we hypothesized that the role played by the macro elements during plant growth would not be the same in different urban land use areas. Thirdly (H3), we hypothesized that plant growth would be affected more in industrial soil than in soil from the other two urban land use areas.

The goal of this study is to analyze the effect of anthropogenic activities on soil quality in different land use and its effect on plant growth. Hence, the objectives of this study were (i) to measure, spatially and temporally, the physico-chemical and biological properties of residential, industrial, and commercial soils, (ii) to understand the relationship between different soil properties during plant growth within different urban land use areas, and (iii) to analyze the effect of soil properties on plant root growth, shoot growth and height.

Materials and Methods

Study area and data collection

The location of the study area is in the south-eastern part of India between latitudes 17°30’ to 18°11’ North and longitudes 83° to 83° 30’ East near Vishakhapatnam city, Andhra Pradesh, India. The elevation of the study area ranged from 0 m to 586 m, and the slope varies from 0 degrees to 72.8 degrees. The climate is tropical on the coast but dry and cold towards the interior places. The mean annual rainfall is 1202 mm, and the mean annual temperature ranges from 24.7°C to 30.6°C. Three major soil types are red loamy soil (69.9%), sandy-loamy soil (19.2%), and black cotton soil (VDOF, 2021). The land use in 2015-16 was urban settlement (152.34 km^2), rural areas (133.77 km^2), industrial areas (100.62 km^2), and quarries (18.35 km^2) (DMG 2018). The Biggest industry is steel plants, while others include petroleum, fertilizers, plant equipment, tiles, and zinc product manufacturers and mills.

Soil samples (up to 20-25 cm in depth) were collected from residential, commercial, and industrial zones (fourteen samples from each zone). Additionally, sandy and garden soil samples were collected. Each soil sample was a mixture of three sub-soil samples. In the laboratory, soil samples were air-dried. The clods were then crushed and ground lightly using a mortar and pestle. Then samples were passed through a 2 mm sieve and stored at room temperature (27±1 ºC) until use.

Pre-experimental study

At this stage, the physico-chemical and biological properties were measured. Physical properties such as water holding capacity (WHC), moisture content (MC), bulk density (BD), and porosity (Po) were measured (Gregorich et al. 1994). Additionally, soil organic matter content (SOM), including soil organic carbon (SOC) and soil humus (SH) was measured (Schulte et al. 1991; Yeomans & Bremner 1988; Simon & Speicher Mann 1928).

Chemical properties, including pH and electrical conductivity (EC); macro elements, such as sodium (Na), chlorine (Cl), calcium (Ca), magnesium (Mg), nitrate (NO), total nitrogen (N), potassium (K), phosphorous (P), and sulfur (S); and microbial activity (MA) were measured using standard methods described by APHA (2005), Rodríguez-Seijo & Andrade (2017), and Yesilonis et al. (2016).

Experimental setup and plantation

The sterile soil, non-sterile soil, and polluted soil were prepared for the experimental setup. For sterile soil, sandy and garden soil were mixed in a 3:1 ratio and kept in a hot air oven at 100°C for approximately 3 hours to kill soil biota. Non-sterile soil was just a mixture of sandy and garden soil. For polluted soil, all samples were mixed with sterile soil in a 1:1 ratio because sterilized soil is used as a control to differentiate between microbial processes and abiotic reactions (Liebich et al. 2006), and sterilization prevents any external contamination by microbes. Polluted soil was put in pots with their respective controls and placed in a built-up greenhouse. In the greenhouse, temperature ranged from 28°C to 32°C, and humidity ranged from 60% to 80%. The ornamental plant, Salvia Scutellarioides, was grown through the vegetative propagation process in each pot with a 2 cm stem length. A total of 42 pots for polluted soil and two control pots for sterile and non-sterile soil were set up in the greenhouse. An equal amount of water was given to each pot at the same time (every day). Plants were allowed to grow for 60 days under controlled conditions.

Post-experimental study

The 60 days study period was divided into five equal periods to analyze changes in soil properties. Test soil samples (approximately 100 g) were collected from the experimental pots on day 0th, 15th, 30th, 45th, and 60th day (Chaurasia & Khare 2006) and measured their physico-chemical and biological properties. It should be noted here that additional nutrients in the form of Hoagland’s solution were provided for each pot except sterile and non-sterile soil for a period of 15 days (Hoagland & Aron 1950). On the 60th day, root growth, shoot growth, and plant height for all pots was measured.

Statistical analysis

Soil parameters, their variations, and relationships during plant growth were analyzed by descriptive statistics and analysis of variance (ANOVA) with repetitive measures, using SPSS statistical software (IBM, Armonk, NY, USA). Wilk’s lambda (λ) values and p values were used to identify the role of a specific parameter during plant growth. Skewness and kurtosis were used to analyze the distribution of soil parameters in pre- and post-experimental studies (Bulmer 1979). Whereas, multiple linear regression was used to understand the relationships between soil parameters and root growth, shoot growth, and plant height. The dependent variable was plant height, and the independent variable was soil parameters. Adjusted R^2 values were calculated for each regression analysis. In addition, coefficients values with positive adjusted R^2 values were analyzed to determine their effect on the dependent variables. Furthermore, negative adjusted R^2 values were not considered due to the absence of an effect of that particular parameter on the dependent variable.

Results

Assessment of physical properties of soils samples in pre-experimental study

Physical properties, macro-elements, pH, and EC values in three zones are given in Table 1.

Table 1. Data summary of different parameters of soil samples in three zones during pre-experimental study

Parameters	Residential				Industrial				Commercial			
	Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
pH	7.3	5.9	8.2	0.6	7.3	5.9	8.2	0.6	7.3	6.7	7.8	0.3
EC(dS/m)	1.4	0.3	4.8	1.2	1.4	0.3	4.8	1.2	0.8	0.2	3.7	0.9
WHC(%)	38.5	28.5	50.6	7.3	35.5	19.2	52.6	9.5	39.1	26.8	50.0	6.2
MC(%)	3.6	1.3	8.3	2.1	3.2	1.3	6.1	1.4	2.9	1.1	4.2	1.2
BD(g/cm^3)	1.3	1.0	1.8	0.2	1.3	1.0	1.6	0.2	1.2	1.0	1.5	0.2
Po(%)	51.0	32.3	63.9	9.3	0.5	0.4	0.6	0.1	0.5	0.5	0.6	0.1
OC(%)	4.6	3.1	5.8	0.7	4.3	2.8	5.2	0.8	4.3	2.4	5.7	1.1
OM(%)	8.0	5.3	10.2	1.2	7.4	4.8	8.9	1.3	7.4	4.1	9.8	1.8
SH(%)	1.3	0.9	3.1	0.5	1.7	0.8	3.5	0.7	2.0	1.2	3.9	0.8
Na(mg/L)	785.8	187.6	968.0	202.9	630.1	167.0	1029.6	245.9	508.2	101.1	909.2	247.9
Cl(mg/L)	291.7	30.0	843.0	270.8	260.2	40.0	906.0	310.4	122.2	25.0	495.0	152.7
Ca(mg/g)	4.2	3.9	4.6	0.2	4.6	3.9	5.2	0.4	4.9	4.2	5.3	0.3
Mg(mg/g)	4.0	3.5	4.7	0.3	4.7	3.8	5.6	0.5	4.9	4.2	5.5	0.4
NO(mg/g)	1.8	0.5	2.8	0.7	2.0	1.2	2.9	0.5	2.3	1.6	3.4	0.6
N(mg/g)	5.6	2.1	9.1	1.7	6.1	2.0	9.8	2.3	5.2	2.6	10.1	2.0
P(mg/g)	1.9	1.1	3.2	0.6	1.4	0.8	2.9	0.6	1.6	0.8	3.0	0.8
K(mg/g)	864.0	294.6	1064.0	201.1	813.6	329.0	1085.0	204.0	676.0	100.6	1091.0	307.6
S(mg/g)	4.8	3.0	6.4	1.0	5.2	2.5	9.2	1.6	5.4	3.6	7.2	1.1
C/N Ratio	3.9	1.2	14.1	3.4	3.0	1.4	4.5	0.9	6.3	1.9	21.3	4.9
MA(mg/g)	6.3	3.1	10.9	2.5	4.6	1.2	10.2	3.1	5.5	1.7	10.3	3.3

BD in most of the soil was below 1.6 g/cm^3, which restricts the plant growth (Daddow & Warrington 1983). The Po of most soil was above 0.4%. It indicates that all tested soil samples contained macropores and had free movement of air and water, which supports deep root growth (Chandrasekaran & Ravisankar 2015). MC at the wilting point for sandy loam soil ranges from 3% to 10% (Hendrickson & Veihmeyer 1945). If 3% is considered the wilting point, half of the soil samples in each zone were low in soil water content which is known to reduce plant growth and soil microbial activity due to low water availability and nutrient difference. WHC values were almost 9% higher than those reported in previous studies of sandy loam soil (Thangasamy et al., 2015). Few soil samples in any of the zones showed higher values of WHC than the American Society for Testing and Materials (ASTM) standards, which indicated the influence of the nutrient cycle, the allotment of carbon, and the rate of photosynthesis (Minasny & McBratney 2018; ASTM 2019). The SOM, SOC, and SH content range indicated sufficient soil fertility to support plant growth (Gregorich et al. 1994; Minasny & McBratney 2018).

The sterilized soil was used as a control to compare the microbial process in the soil sample. Generally, in the sterilized soil, all microbial communities die as compared to microbial community shifting in the non-sterilized soil samples. It is the basic thumb rule to monitor microbial activities in any condition.

Assessment of pH, EC, and macro-elements in soils samples during pre- and post-experimental study

The pH of most of the soil samples ranged from very slightly alkaline to slightly alkaline, which may be due to soil parent material, vegetation, anthropogenic activities, and low-to-medium rainfall in the study area.

EC measurements are used to monitor soil salinity (Corwin & Lesch 2003). High salinity causes stress to plants, nutrient loss, and hence, a hormonal imbalance (Iqbal et al. 2012). Most of the soil samples were non-saline in nature, and the soil conditions were suitable for the growth of moderately sensitive ornamental plants (Hanson et al. 1999).

Na concentration was highest in industrial areas (1,029.6 mg/L) and the lowest in commercial areas (101.1 mg/L). A high variation in Cl concentration was between soil samples from each zone. However, most soil samples did not have high salinity. Mg was sufficient to support plant growth (Helper & Calcium 2005; Behera & Shukla 2015). Summarized data of all soil properties are in Table 1. In post-experimental analysis, variation in different soil parameters during the plant growth and their effect on root growth, shoot growth, and plant height are in Figure 1.

Descriptive statistics and variation in different parameters during plant growth

Changes in the mean and standard deviation for the tested parameters during the study period (60th day) were classified as small (up to 15%), moderate (16% to 30%), large (31% to 100%), or very large (> 100%) (Table 2).

Soil structural properties were affected due to the decrease in OM and increase in BD content in all zones. However, the decline in MC was more evident in residential areas (19.5%) than in other zones. The slight increase in WHC may be due to an increment in the soil compactness (Mossadeghi-Björklund et al. 2016).

High declination in EC in all zones was due to changes in salt content. Generally, the salt ions present in the soil are Na^+, Cl^-, Ca^{2+}, Mg^{2+}, and K^+. Cl and K contents were decline during 60th day, while other ions content increased. Most of the parameter's values were within the symmetry range, and their distributions were platykurtic in nature in all zones.

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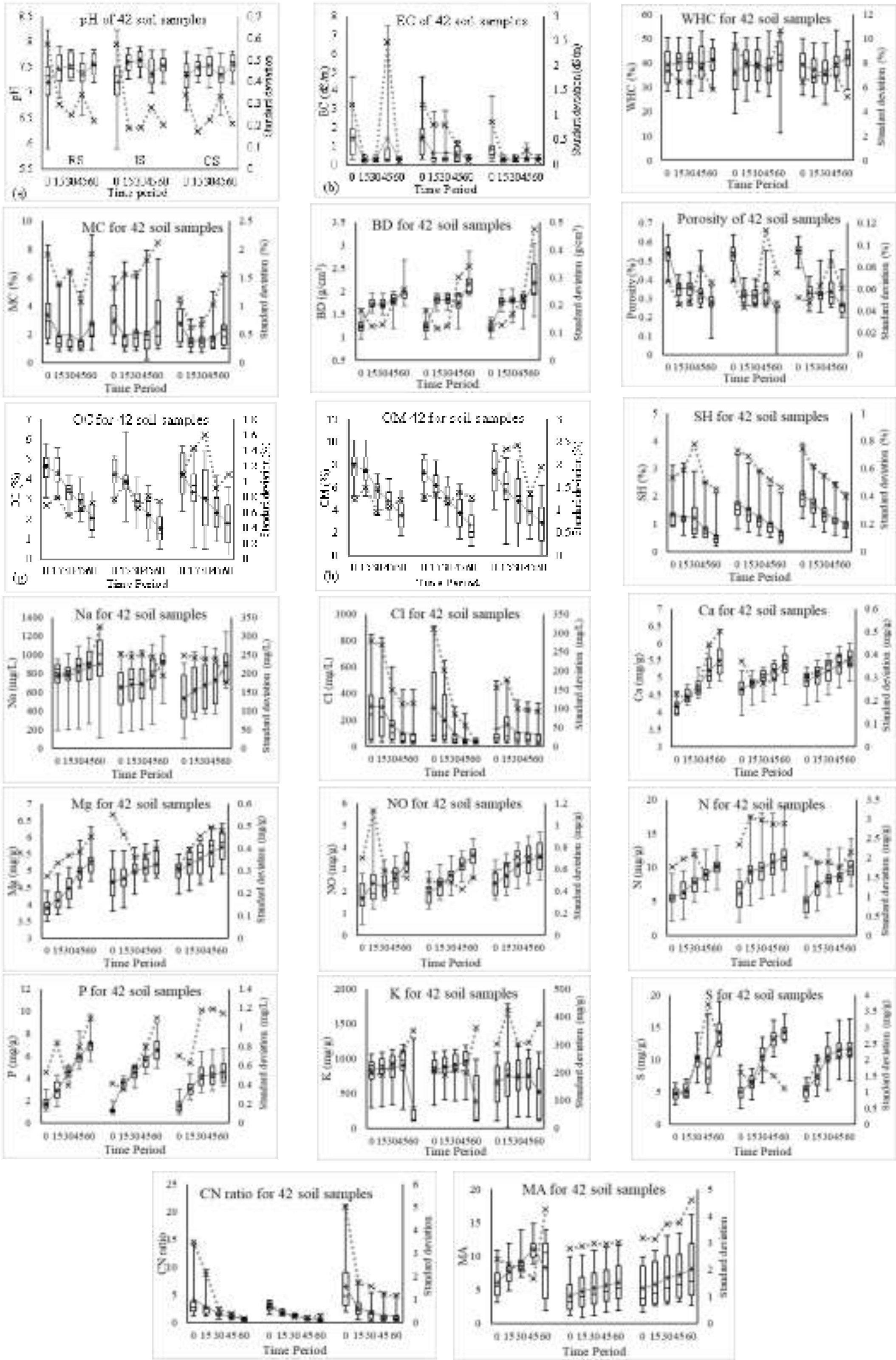

Figure 1: Whisker box plot showing the variation in parameters values in different time period (such as 0 day, 15 day, 30 day, 45 day and 60 day) during the plant growth in residential soil (RS),

industrial soil (IS) and commercial soil (CS). The secondary axis is showing the standard deviation. Symbols of mean values and standard deviation values are showing in Figure 1(b).

Table 2. Difference between 0th day and 60th day of parameter's mean and standard deviation values in percentage. Negative sign showing declination of the parameters values from the beginning of plant growth to the end of experimental period.

	Residential		Industrial		Commercial	
Parameters	Mean (%)	St. Dev (%)	Mean (%)	St. Dev (%)	Mean (%)	St. Dev (%)
pH	2.5	-39.8	2.7	-48.3	1.2	20.1
EC	-75.4	-95.2	-76.4	-93.7	-30.8	-90.2
WHC	5.5	-18.3	9.6	15.4	8.5	-17.2
MC	-19.5	-2.1	-7.6	53.7	-9.7	36.2
BD	46.3	38.4	47.8	126.6	70.8	245.9
Porosity	-44.7	36.0	-88.9	125.6	-63.9	242.0
OC	-51.9	17.7	-79.3	60.8	-51.2	23.6
OM	-55.1	0.3	-87.5	51.2	-53.6	27.2
SH	-53.5	-10.9	-110.4	-37.5	-62.0	-48.0
Na	13.4	55.4	26.6	-1.0	48.5	4.2
Cl	-70.1	-58.7	-250.5	-95.9	-14.3	-39.4
Ca	26.2	210.4	11.0	87.6	9.3	107.2
Mg	29.4	64.6	6.7	21.2	11.8	110.9
NO	74.5	-15.1	53.7	70.0	50.2	67.5
N	68.3	34.9	53.9	56.8	71.1	31.3
P	244.9	233.4	82.9	231.4	183.0	85.5
K	-55.7	101.3	-44.7	73.9	-19.9	18.4
S	13.4	55.4	26.6	-1.0	48.5	4.2
CN	-81.4	-86.2	-171.8	47.5	-160.9	-69.0
MA	31.8	75.7	17.6	14.9	59.2	45.1

Variations in mean values were observed for EC, WHC, Na, Cl, K, S, C/N ratio, and MA. Except for WHC, C/N ratio, and MA, these parameters have the lowest values in commercial areas, while residential areas showed higher mean values for these parameters. Industrial area samples were only found to have higher EC compared to samples from the other zones. This was due to anthropogenic activities, such as the use of raw materials by the industries operating in those particular areas.

ANOVA and the relationship between different parameters during plant growth

The null hypothesis was mean-variance of a parameter was equal within the group. The pH ($p = 0.173$) and WHC ($p = 0.134$) showed no statistically significant differences in residential soil during the experimental period. Similarly, WHC ($p = 0.138$), Cl ($p = 0.185$), and Mg ($p = 0.277$)

values in industrial soil and pH (p = 0.169), WHC (p = 0.053), and K (p = 0.232) values in commercial soil showed no statistically significant changes during the experimental period. All other parameters showed statistically significant changes during plant growth. Based on λ values, OM has the greatest role in affecting plant growth in all zones, which is important in regulating plant growth and morphogenesis (Ortíz-Castro et al. 2009). MA has the second greatest role in industrial and commercial soils, while it is third in residential soil. C/N ratio played a moderate role in residential and industrial soil. MC and Ca played the smallest role in industrial and commercial soils, while MC and Na played the smallest role in residential soil (Table 3).

Table 3. Variation of Wilk's λ values of all parameters in different zones.

Residential Soil		Industrial soil		Commercial soil	
Parameters	Wilk's λ	Parameters	Wilk's λ	Parameters	Wilk's λ
OC	0.027	OM	0.092	OM	0.091
OM	0.028	SH	0.095	SH	0.096
SH	0.057	OC	0.114	OC	0.109
Cl	0.124	MA	0.121	MA	0.146
MA	0.147	Porosity	0.182	S	0.161
Mg	0.163	BD	0.184	Cl	0.192
NO	0.166	P	0.184	BD	0.204
P	0.180	S	0.193	Porosity	0.207
C/N Ratio	0.184	C/N Ratio	0.228	P	0.224
S	0.190	N	0.242	NO	0.230
Ca	0.229	Na	0.265	N	0.250
Porosity	0.247	NO	0.271	C/N Ratio	0.267
BD	0.255	EC	0.293	Na	0.278
N	0.301	K	0.296	EC	0.358
K	0.326	pH	0.373	Mg	0.415
EC	0.415	MC	0.442	Ca	0.431
Na	0.448	Ca	0.453	MC	0.466

Mauchly's test of sphericity was used to identify differences in variance within groups. The null hypothesis was variances within the group was different, i.e., the variation in parameter values between different time measurements (such as 0th, 15th, etc) during plant growth was different.

Results showed that all measured parameters in each zone were significantly different ($p < 0.05$). Thus, the null hypothesis was accepted, as there were variations in parameters at different time points during plant growth. The extent of the violation of sphericity was analyzed using Greenhouse-Geisser values with a lower Greenhouse-Geisser value representing a greater violation of sphericity (Table 4).

Table 4. The value of Greenhouse-Geisser (GG) in Mauchly's test of sphericity

Residential Soil		Industrial soil		Commercial soil	
Parameters	GG	Parameters	GG	Parameters	GG
Cl	0.279	Na	0.258	Ca	0.279
Ca	0.296	NO	0.270	C/N Ratio	0.289
MA	0.310	Cl	0.283	EC	0.295
K	0.323	N	0.291	Mg	0.302
Na	0.323	K	0.292	NO	0.306
C/N Ratio	0.325	C/N Ratio	0.322	P	0.310
Mg	0.331	Mg	0.324	SH	0.324
EC	0.364	SH	0.327	S	0.346
SH	0.378	Ca	0.333	MA	0.403
P	0.412	P	0.359	Cl	0.429
N	0.439	S	0.396	Porosity	0.436
NO	0.483	pH	0.408	BD	0.438
WHC	0.495	OM	0.436	N	0.487
Porosity	0.519	MA	0.468	pH	0.538
pH	0.520	OC	0.489	K	0.538
BD	0.523	EC	0.526	Na	0.607
OC	0.560	MC	0.538	OM	0.626
S	0.582	WHC	0.650	WHC	0.641
MC	0.621	Porosity	0.710	MC	0.671
OM	0.626	BD	0.712	OC	0.675

Regression analysis and relationship between different parameters and root growth, shoot growth and height

The role of effective parameters in root growth, shoot growth, and height in all zones are shown in Table 5.

Table 5. Adjusted R^2 values (in percentages) from multiple linear regression. RS is residential soil, IS is industrial soil, and CS is commercial soil.

Parameters	Root			Shoot			Height		
	RS	IS	CS	RS	IS	CS	RS	IS	CS
pH	1.41	-2.04	17.70	-4.83	**44.23**	-39.48	-1.80	16.72	-37.74
EC	35.86	-5.51	-4.92	0.42	6.18	**65.21**	6.95	-7.59	**55.40**
WHC	-13.87	19.88	-36.44	**54.35**	**31.43**	-6.21	**41.51**	16.89	-28.25
MC	34.41	0.28	9.79	21.79	-4.31	**32.68**	**31.95**	6.31	**41.14**
BD	12.33	-27.55	-8.92	-18.33	**38.56**	-18.84	-12.28	3.25	-29.22
Porosity	12.33	-27.55	-8.92	-18.33	**38.56**	-18.84	-12.28	3.25	-29.22
OC	-21.18	10.90	-11.79	**33.02**	-15.44	**55.72**	20.78	8.40	**49.13**
OM	2.36	9.12	1.74	**45.20**	-19.03	**49.09**	**40.46**	4.69	**51.89**
SH	26.82	22.02	-25.33	**41.41**	**44.75**	**45.74**	**50.10**	**41.50**	**32.22**
Na	12.63	**53.10**	22.02	11.69	**48.25**	17.25	5.94	**70.99**	19.79
Cl	12.96	10.58	19.34	**61.03**	-4.22	-8.46	**59.46**	9.99	-8.94
Ca	37.37	28.98	14.23	**48.80**	4.89	-9.39	**52.20**	20.76	-3.58
Mg	45.93	15.13	-5.92	26.22	14.37	**37.27**	**37.54**	29.15	**35.28**
NO	-1.56	9.83	**41.29**	28.87	6.47	**34.11**	23.31	18.51	**38.02**
N	15.77	7.85	**48.28**	26.58	-2.49	**40.19**	28.27	0.68	**51.23**
P	21.35	**47.50**	**38.07**	**50.35**	**33.04**	**38.01**	**54.49**	**43.09**	**40.25**
K	-23.76	**56.66**	13.44	-8.06	**39.95**	**56.51**	-16.76	**62.02**	**64.27**
S	20.13	23.59	**36.49**	**79.15**	**38.48**	**49.66**	**79.72**	27.13	**55.53**
CN	-19.19	-2.13	-3.41	-5.62	3.16	**32.62**	-9.12	4.66	24.25
MA	35.85	18.17	-12.28	**34.78**	**36.07**	**56.23**	**45.84**	**40.74**	**59.90**

The coefficient values of the independent variables for all parameters varied either positively or negatively within the study period in all zones. Fig. 1 shows the variation in coefficient values based on standard deviations during the study period for root growth, shoot growth, and plant height.

Discussion

Soil quality is variable in industrial, residential, and commercial areas (Hypothesis 1)

In support of the first hypothesis, the overall results of soil's physical properties, such as BD, porosity, WHC, and OM content varied within different urban land use areas. Few soil samples showed an increase in WHC (> 41%), due to an increase in either silt or clay content (Thangasamy et al. 2015), or an increase in SOC (Rawls et al., 2003). However, due to the deposition of dust from various industrial activities, pH did not support the hypothesis (Rachwal & Magiera 2015). Additionally, EC results did support the hypothesis.

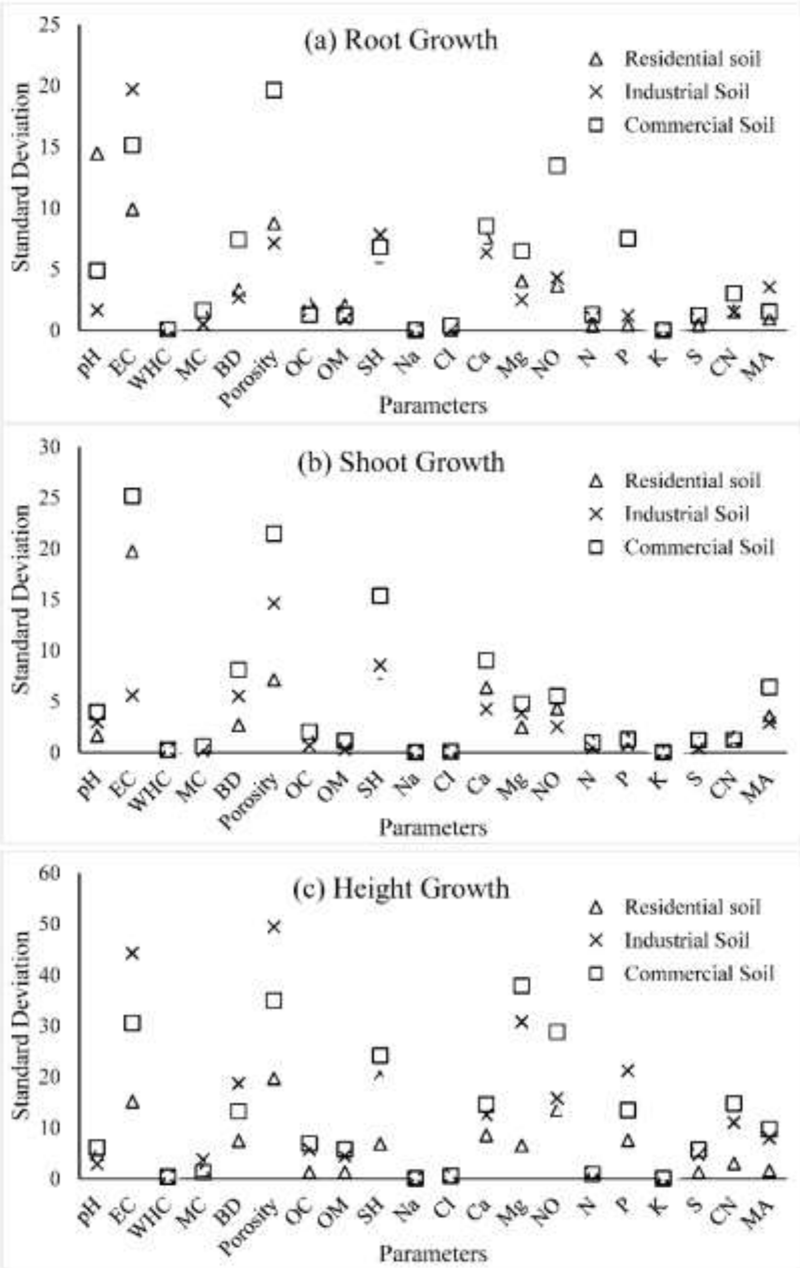

Figure 1. Variability of parameters during (a) root growth, (b) shoot growth and (c) height growth in all the zones

The distribution of N and S content indicates a deficiency for plant growth in all soil samples (ICAR-NBSS & LUP 2015). However, P and K contents were medium to very high range. Low C/N ratio values were observed in all zones. It indicates the rapid decomposition of plant residues (Ostrowska & Porębska 2015). Therefore, carbon and energy in soil samples were lacking, which limits soil MA, reduces soil quality, and results restrict plant growth (Chen et al. 2003). Soil microbes utilize OM and release N, P, and other nutrients that were used subsequently for plant growth (Chan et al. 2010). However, no relationship was found between OM and MA in any zone. It indicates that OM was consumed more by plants than by microbes. Except few samples, no relationship was found between MA and N or P in any zone.

The variation in macro elements content from day 0 to day 60 was not consistent within specific urban land use (Table 3). The Hoagland's solution was applied during plant growth to maintain nutrient availability. Heterogeneous variation in macro-elements content from different urban land use was consistent with the pattern of plant growth in the different soil samples. Reducing the Cl and K content (Table 3) could be either leaching out from pots or being consumed by plants within the 60-day experimental period. The reason is unclear because a complete mass balance study was not in the scope of this research. Similar results have also been reported in previous studies (Ravindran et al. 2007). Moreover, Cl ion concentrations were up to 250% lower in industrial soil than in other soil.

The role played by macro-elements during plant growth differs depending on the urban land use type (Hypothesis 2)

In support of Hypothesis 2, the mean changes in macro-elements content during plant growth had significant differences ($p < 0.05$). It indicates that the effects of macro elements on plant growth varied at different times. Cl (in residential), P (in industrial), and S (in commercial) had a leading role during plant growth (Table 4). These results suggested that the small increment in N content and large declination in C/N ratio and OC content in industrial soil (Table 2) was due to the N role during plant growth. Similarly, the roles of other macro-elements also varied during plant growth. These results were supported by the violation of sphericity observed in the analysis of Greenhouse-Geisser values.

Plant growth is affected more in industrial soil than other soils (Hypothesis 3)

Plant height declination in industrial soil varied from 8% to 61% compared with residential soil and from 8% to 50% compared with commercial soil. The shoots of industrial soil were 12% to 76% shorter than the plants in residential or commercial soil. However, variations up to 1 cm were observed for root length in different soil samples. OM affected shoot growth and plant height, but not root growth. Po only affected shoot growth in industrial soil. It indicates that none of the parameters were continuously involved in plant growth during the study period. Several combinations of parameters were involved in plant growth at different periods.

Overall, these results indicated a high effect of nutrients on plant height than on root growth. It is because of the larger size of the entire plant compared with the shoot or the roots. Therefore, an increase in plant height required more nutrients and MA. In addition, plants were shorter, and shoots were smaller in industrial soil compared to the residential and commercial soil.

Conclusions

Soil quality data showed that most soil samples were favorable for plant growth, in terms of their physical properties. Most soil samples were slightly alkaline and had sufficient nutrient availability to support plant growth. C/N ratio is critical for microbial growth and activity. A low C/N ratio will tend to produce excessive ammonia and VFAs, which may cause inhibition in growth. However, there may be several reasons for the poor plant growth. Except for K and Cl, soil micro-element content increased during plant growth. SOM content including SOC decreased with plant growth, which affected MA. However, an increase in MA was observed in all zones, but the level of increase was lowest in industrial soil. A relationship between MA and N concentration was not observed. Therefore, the concentration of N and some other macro-elements increased due to the application of Hoagland's solution. The overall conclusion from this study is that plant growth was slowest in soil from industrial areas, followed by commercial and residential areas. This study will provide a road map for further in-depth research to improve soil quality and assist policymakers to implement industrial pollution mitigation strategies.

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