EVALUATING SOIL FERTILITY AND PLANT NUTRIENT STATUS OF LEMON (*Citrus limon* L.) ORCHARDS IN THE NORTH-EASTERN REGION OF BANGLADESH

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Abstract

Soil (0 to 15 cm and 15 to 30 cm depth), leaf and fruit samples were collected from seventeen orchards of lemon (*Citrus limon* L.) from different locations of Habiganj district to evaluate the physico-chemical properties, nutrient status of soil, and nutrient concentrations in lemon leaves and fruits. The soil was found to vary pH from extreme to medium acidic (3.9 to 6.0), organic matter content 0.63 to 1.71% at 0 to 15 cm and 0.16 to 1.42% at 15 to 30 cm depth. Electrical Conductivity was found non-saline in nature which was 37.9 to 100.1 µS/cm at 0 to 15 cm and 25.1 to 69.0 µS/cm at 15 to 30 cm depth. The dominant soil textural class was sandy clay loam. The total N, P, K and S in soils were found 0.038 to 0.085%, 0.024 to 0.071%, 0.022 to 0.144%, and 0.040 to 0.294% at 0 to 15 cm depth, respectively and 0.012 to 0.076%, 0.024 to 0.056%, 0.012 to 0.139%, and 0.016 to 0.333% at 15 to 30 cm depth, respectively. Available N was found 20.37 to 67.90 mg/kg at 0 to 15 cm and 20.37 to 74.69 mg/kg at 15 to 30 cm depth. Major soil samples were found low in available phosphorous, 0.35 to 66.95 mg/kg at 0 to 15 cm and 0.83 to 29.19 mg/kg at 15 to 30 cm depth. Available sulphur was also found low in concentration, 4.62 to 68.48 mg/kg at 0 to 15 cm and 2.10 to 15.54 mg/kg at 15 to 30 cm depth. The exchangeable K^+, Ca^{2+} and Mg^{2+} in soils at 0 to 15 cm depth were found 0.040 to 0.221 meq/100g, 0.002 to 0.046 meq/100g and 0.017 to 0.042 meq/100g, respectively and at 15 to 30 cm depth these were found from 0.025 to 0.097 meq/100g, 0.003 to 0.054 meq/100g, and 0.016 to 0.050 meq/100g, respectively. The concentrations of total N, P, K and S in leaf were 1.198 to 2.659%, 0.500 to 0.778%, 0.112 to 0.246% and 0.010 to 0.133%, respectively. The concentrations of total N, P, K and S in fruit were 0.760 to 1.549%, 0.250 to 0.611%, 0.107 to 0.190% and 0.005 to 0.031%, respectively. The present findings illustrated the low to medium soil fertility status under the lemon plantation in the north-eastern region of Bangladesh and growers could be recommended to plant lemons after applying soil amendments to improve the physico-chemical properties of soils in the north-eastern region of Bangladesh.

***Key words*:** Lemon orchard; Fertility status; Leaf; Fruit; Habiganj.

INTRODUCTION

Citrus fruits are well known as important and economically significant crops worldwide mainly cultivated throughout the tropical and sub-tropical regions. Citrus plants are small to medium-size shrubs or trees. They are native in some parts of India, China and Northern Australia. Lemon (*Citrus limon* L.) is a very important citrus among many types of citrus fruits produced in Bangladesh. They are evergreen tree, reaching 2.5 to 3.0 m in height, from the family Rutaceae (Mabberley 2004). Lemon fruits are yellow, edible, sour and juicy containing rich amount of vitamin C and flavonoids. They have numerous nutritional and therapeutic values. They are consumed fresh for juice and used in making pickles and beverages. Vitamin C is necessary for human health. It improves the immune system and helps to prevent or treat scurvy. Its deficiency leads to many health problems. Flavonoids in lemon lead to protect human from cancer and cardiovascular diseases (Nicola *et al*. 2019).

The lemon growers are interested in lemon production for its high economic benefit but they are very much reluctant about the management of soils and trees. Soil pH, colour, drainage condition, texture, nutrient storage, nutrient availability *etc.* are the vital properties of soil in relation to the

growth and yield of lemon. Ideal soil required for the growth and yield of citrus become deep, uniform, loamy, well-drained, moderately level, free of lime and slightly acidic (Chapman 1961).

The edaphic and climatic conditions of Bangladesh are favourable for the cultivation of lemon. Plants are grown in all over Bangladesh, though their production is concentrated in Sylhet, Chittagong and the Chittagong Hill Tracts; cultivated in homestead as well as in orchard, mainly from grafts and cuttings. In Bangladesh, about 58,552 metric tons of total lime and lemon inside and outside the garden, were grown in the fiscal year 2019-2020, in which 22,242 metric tons were grown under 1,56,440 acres of lemon orchard. In Sylhet region, about 3,083 metric tons of lime and lemon were grown in the fiscal year 2019-2020 under 1,203 acres of lemon orchard, whereas in the Habiganj district, 1013 metric tons of lime and lemon were grown (BBS 2020). Habiganj district is in the north-eastern region of Bangladesh. There are diverse agricultural practices and topography in this area. Five AEZs are present in Habiganj; Old Meghna Estuarine Floodplain (AEZ-19), Eastern Surma-Kushiyara Floodplain (AEZ-20), Sylhet Basin (AEZ-21), Northern and Eastern Piedmont Plain (AEZ-22) and Northern and Eastern Hills (AEZ-29). Lemon is cultivated on a large scale in the southern and hilly areas in Habiganj. According to the information of the Department of Agricultural Extension Bangladesh, a total of 4819 metric tons of lemon was produced in the Habiganj district in the fiscal year 2021-2022. Out of which 4000 metric tons were produced in Bahubal upazila, 450 metric tons in Habiganj Sadar upazila and 171 metric tons in Chunarughat upazila (DAE 2022).

To understand the nutrient reserves of a plant, it's useful to look at the concentration of nutrients in its leaves. Knowing how nutrient levels change during a tree's growth is important for setting standards for foliar nutrients (Jiang *et al.* 2005). The content of potassium and nitrogen in leaves is linked to a plant's nutrient status, as well as factors such as flowering, yield, and overall growth (Reyes 2000). Nitrogen has a strong relationship with potassium (Bussi *et al.* 2003), and a balance of the two is important for fruit yield and quality (Egea *et al.* 1972). Given the significance of lemons for both economic and human health-related reasons, the goal of this study was to evaluate the fertility of lemon orchard soils and measure the concentration of nutrients in lemon leaves and fruit.

The results of this study can be helpfull in the further development of reliable and accurate data on nutrient conditions and can be used in assessing soil fertility program for lemon growing areas in the country.

MATERIAL AND METHODS

Collection and preparation of soil, leaf and fruit samples

The study area was Habiganj where sampling spots belong to the Northern and Eastern Piedmont Plain (AEZ-22) (SRDI 2014, SRDI 2021) and Northern and Eastern Hills (AEZ-29) (SRDI 2018, SRDI 2021). During the 3rd week of September 2020, seventeen soil samples were collected randomly from two depths, *i.e.*, 0 to 15 cm and 15 to 30 cm after removing surface litter. A description of the seventeen locations is presented in Table 1. Leaf and fruit samples (3 replications for each location) were also collected from those locations. The collected leaf samples were terminal and green coloured and fruit samples were matured and green coloured.

The soil samples were air-dried; visible roots and debris were discarded; massive aggregates were broken by using a wooden hammer and sieved by using a 2 mm sieve. The samples were kept in polyethylene bags with proper labelling. Leaf and fruit samples were collected from the same locations, labeled and carried to the laboratory in the Department of Soil, Water and Environment, University of Dhaka. In the laboratory, leaf and fruit samples were wiped with soft clothes, sliced

(fruit sample), air-dried, oven-dried (at 65ºC) and powdered with a mechanical grinder and kept in brown paper envelops for analysis.

Table 1. Geographical location of the sampling spots, associated with the name of upazila and Agro-Ecological Zone (AEZ).

Locations	Latitude	Longitude	Upazila	District	AEZ No.
Spot 1	24.250149°N	91.600468°E	Chunarughat	Habiganj	AEZ-29
Spot 2	24.250129°N	91.599760°E	Chunarughat	Habiganj	AEZ-29
Spot 3	24.249125°N	91.600835°E	Chunarughat	Habiganj	AEZ-29
Spot 4	24.246385°N	91.597404°E	Chunarughat	Habiganj	AEZ-29
Spot 5	24.226727°N	91.582294°E	Chunarughat	Habiganj	AEZ-29
Spot 6	24.215095°N	91.520567°E	Chunarughat	Habiganj	AEZ-22
Spot 7	24.214397°N	91.516583°E	Chunarughat	Habiganj	AEZ-22
Spot 8	24.214272°N	91.517761°E	Chunarughat	Habiganj	AEZ-22
Spot 9	24.342672°N	91.430893°E	Habiganj Sadar	Habiganj	AEZ-22
Spot 10	24.323344°N	91.444866°E	Habiganj Sadar	Habiganj	AEZ-22
Spot 11	24.373449°N	91.428245°E	Habiganj Sadar	Habiganj	AEZ-22
Spot 12	24.293946°N	91.616757°E	Bahubal	Habiganj	AEZ-29
Spot 13	24.295368°N	91.616370°E	Bahubal	Habiganj	AEZ-29
Spot 14	24.295967°N	91.617136°E	Bahubal	Habiganj	AEZ-29
Spot 15	24.295442°N	91.618853°E	Bahubal	Habiganj	AEZ-29
Spot 16	24.294367°N	91.619395°E	Bahubal	Habiganj	AEZ-29
Spot 17	24.293029°N	91.617089°E	Bahubal	Habiganj	AEZ-29

Analysis of physico-chemical properties of soil and plant samples

The particle size analysis of soil was done by following the hydrometer method (Bouyoucos 1962) and the textural class was determined from Marshall's triangular co-ordinate following the USDA system. A glass electrode pH meter (HANNA Instruments HI 2211 pH/ORP Meter), calibrated with buffer at pH 7.0 and 4.0 was used to measure the pH of the soil suspension maintaining soil: water ratio of 1:2.5. Electrical conductivity (EC) in soil samples was measured by using a digital conductivity meter (EUTECH Instruments CON 700) maintaining soil: water ratio of 1:5 (Richards 1954). The organic carbon content of soils was measured by the Wet Oxidation method (Walkley and Black 1934).

The organic matter (OM) was calculated by multiplying the percent organic carbon with the van Bemmelen factor of 1.72. The available nitrogen in soil samples was determined by Kjeldahl method (Marr and Cresser 1983), available phosphorus was determined colorimetrically with a spectrophotometer after developing blue color using ascorbic acid and potassium antimony tartrate as a color developing reagents, exchangeable potassium in the soil was determined by the extraction with ammonium acetate (pH 7.0) using a JENWAY flame photometer (model PFP 7) (Pratt 1965); available sulphur was determined by turbidimetric method with $BaCl_2$ using Tween-80 as the suspending agent of the sulphate precipitation (Bardsley and Lancaster 1965). The total nitrogen in the soil, leaf and fruit samples was determined by the micro-Kjeldahl steam distillation method after H_2SO_4 acid digestion (Bremner and Mulvaney 1982). For the determination of total P, K and S, the samples were digested with a mixture of concentrated HNO_3 and $HClO_4$ acid at a ratio of 2:1. Total phosphorus was determined with a spectrophotometer by using the vanadomolybdophosphoric yellow colour method (Jackson 1958); total potassium was measured with a flame photometer; and total sulphur was determined with a spectrophotometer after developing turbidity with $BaCl_2$. The concentrations of exchangeable calcium and magnesium were determined by using an atomic absorption spectrometer (AAS: PerkinElmer PinAAcle 500).

Fig. 1. View of a lemon orchard (Spot 7 - Chunarughat, Habiganj).

Statistical analysis

The studied soil sample values were compared with the optimum soil properties for lemon cultivation. The optimum soil properties for lemon cultivation are shown in the Table 2. Standard deviations are shown for leaf and fruit sample analysis. These statistical analyses were calculated using Microsoft Excel 2016.

Table 2. The optimum soil properties for lemon cultivation.

Parameters	Optimum values	Sources
Soil pH	5.0 to 8.0	Jackson and Looney (1999)
Electrical Conductivity	<400 µS/cm	Jones (1980)
Organic Matter	0.69 to 1.29%	Hayes (1960)
Available N	> 22.3 mg/kg	Zhuang *et al.* (1985)
Available P	25 to 70 mg/kg	Plessis (1977)
Exchangeable K^+	0.128 to 0.513 meq/100g	Okada *et al.* (1994)
Exchangeable Mg^{2+}	0.600 meq/100g	Spencer and Wander (1960)

RESULTS AND DISCUSSION

Soil separates

A large portion of the studied soil was enriched with sand particles at 0 to 30 cm depth. Sand particles were present with mean values of 48.78 and 54.17% at 0 to 15 and 15 to 30 cm depths, respectively. Silt was present with mean values of 27.22 and 23.54% at 0 to 15 cm and 15 to 30 cm depths, respectively. However, clay ranged from 16.67 to 37.82% with an average of 24.01% at 0 to 15 cm depth and 10.02 to 36.64% with an average of 22.29% at 15 to 30 cm depth (Table 3 and 4).

Soil pH, electrical conductivity and organic matter

The values of soil samples were found with different soil pH ranging from very strongly acidic (4.1, spot 7) to slightly acidic (5.7, spot 9) with an average of pH 4.6 at 0 to 15 cm depth and from very strongly acidic (3.9, spot 3) to slightly acidic (6.0, spot 9) with an average of pH 4.8 at 15 to 30 cm depth (Table 5). All of the soil samples were found non-saline (lower than the critical level of 400 µS/cm) (Hardie and Doyle 2012). The electrical conductivity of the samples ranged from 37.9 to 100.1 µS/cm with an average of 56.1 µS/cm at 0 to 15 cm depth and from 25.1 to 69.0 µS/cm with an average of 41.0 µS/cm at 15 to 30 cm depth (Table 5).

Table 3. Particle size distribution of some soils (0 to 15cm) of lemon orchards in the Habiganj district, Bangladesh.

Locations	Soil separates			Textural classes	Sand/Silt Ratio	Silt/Clay Ratio
	Sand (%)	Silt (%)	Clay (%)			
Spot 1	63.08	15.17	21.75	Sandy clay loam	4.16	0.70
Spot 2	55.38	17.75	26.87	Sandy clay loam	3.12	0.66
Spot 3	57.96	20.26	21.78	Sandy clay loam	2.86	0.93
Spot 4	50.00	17.86	32.15	Sandy clay loam	2.80	0.56
Spot 5	53.02	22.73	24.25	Sandy clay loam	2.33	0.94
Spot 6	3.91	60.39	35.71	Silty clay loam	0.06	1.69
Spot 7	37.93	42.90	19.18	Loam	0.88	2.24
Spot 8	47.96	35.37	16.67	Loam	1.36	2.12
Spot 9	15.52	57.01	27.47	Silty clay loam	0.27	2.08
Spot 10	5.20	56.99	37.82	Silty clay loam	0.09	1.51
Spot 11	32.67	45.56	21.77	Loam	0.72	2.09
Spot 12	65.69	15.14	19.17	Sandy loam	4.34	0.79
Spot 13	73.31	7.56	19.14	Sandy loam	9.70	0.39
Spot 14	70.73	10.09	19.18	Sandy loam	7.01	0.53
Spot 15	63.04	12.66	24.30	Sandy clay loam	4.98	0.52
Spot 16	65.68	12.62	21.70	Sandy clay loam	5.21	0.58
Spot 17	68.19	12.62	19.19	Sandy loam	5.40	0.66
Range	**3.91-73.31**	**7.56-60.39**	**16.67-37.82**	**-**	**0.06-9.70**	**0.39-2.24**
Mean	**48.78**	**27.22**	**24.01**	**-**	**3.25**	**1.12**

Soil organic matter affects the nutrient availability of soil. Organic matter contents were varied from 0.63 to 1.71% with an average of 1.11% at 0 to 15 cm depth and from 0.16 to 1.42% with an average of 0.74% at 15 to 30 cm depth (Table 5). The optimum organic matter content required for lemon growing soil is 0.69 to 1.29% (Hayes 1960).

Table 4. Particle size distribution of some soils (15 to 30cm) of lemon orchards in the Habiganj district, Bangladesh.

Locations	Soil separates			Textural classes	Sand/Silt Ratio	Silt/Clay Ratio
	Sand(%)	Silt (%)	Clay (%)			
Spot 1	67.16	12.63	20.21	Sandy clay loam	5.32	0.63
Spot 2	59.40	15.23	25.38	Sandy clay loam	3.90	0.60
Spot 3	64.67	12.62	22.71	Sandy clay loam	5.13	0.56
Spot 4	51.40	12.79	35.81	Sandy clay	4.02	0.36
Spot 5	59.49	17.73	22.79	Sandy clay loam	3.36	0.78
Spot 6	5.79	57.57	36.64	Silty clay loam	0.10	1.57
Spot 7	29.00	53.25	17.75	Silt loam	0.54	3.00
Spot 8	49.32	32.94	17.74	Loam	1.50	1.86
Spot 9	28.89	53.33	17.78	Silt loam	0.54	3.00
Spot 10	15.07	48.90	36.03	Silty clay loam	0.31	1.36
Spot 11	52.03	30.30	17.67	Sandy loam	1.72	1.71
Spot 12	67.12	10.12	22.76	Sandy clay loam	6.63	0.44
Spot 13	87.48	2.50	10.02	Loamy sand	34.92	0.25
Spot 14	69.78	10.07	20.15	Sandy clay loam	6.93	0.50
Spot 15	74.84	7.55	17.61	Sandy loam	9.91	0.43
Spot 16	72.23	10.10	17.67	Sandy loam	7.15	0.57
Spot 17	67.21	12.61	20.18	Sandy clay loam	5.33	0.63
Range	**5.79-87.48**	**2.50-57.57**	**10.02-36.64**	**-**	**0.10-34.92**	**0.25-3.00**
Mean	**54.17**	**23.54**	**22.29**	**-**	**5.72**	**1.07**

Macronutrient concentrations in soil

The available N content in the soils ranged from 20.37 to 67.90 mg/kg with an average of 43.54 mg/kg at 0 to 15 cm depth and from 20.37 to 74.69 mg/kg with an average of 41.94 mg/kg at 15 to 30 cm depth. According to Zhuang *et al.* (1985), critical available N content for lemon cultivation is

22.3 mg/kg. The majority of the soil samples fulfilled the critical by available N concentration. The total N content in the upper layer (0 to 15 cm depth) was 0.038 to 0.085% with an average of 0.062% and in the lower layer (15 to 30 cm depth) was 0.012 to 0.076% with an average of 0.042% (Table 6). The average total N content in the upper layer was almost 50% higher than that of the lower layer. Nitrogen has profound influences on fruit retention, length, diameter and fruit weight.

Table 5. pH, electrical conductivity and organic matter status of some soils of lemon orchards in the Habiganj district, Bangladesh.

Locations	pH		EC (µS/cm)		OM (%)	
	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
Spot 1	4.3	4.5	49.0	46.1	1.35	1.19
Spot 2	4.2	4.2	55.4	42.6	1.38	1.12
Spot 3	4.7	3.9	64.5	54.7	1.71	0.76
Spot 4	4.5	4.3	48.5	43.6	1.25	1.42
Spot 5	4.4	4.1	47.6	51.4	0.82	0.79
Spot 6	4.6	5.1	56.4	35.5	1.19	0.92
Spot 7	4.1	4.9	40.8	36.0	0.86	0.59
Spot 8	4.5	4.5	42.5	39.3	0.96	0.73
Spot 9	5.7	6.0	100.1	53.5	1.32	0.53
Spot 10	4.6	5.3	84.1	69.0	1.15	0.69
Spot 11	5.4	5.6	37.9	25.1	0.66	0.33
Spot 12	4.4	4.4	66.7	45.3	1.32	1.12
Spot 13	5.0	5.3	66.8	27.6	0.76	0.26
Spot 14	4.6	4.7	46.6	28.7	1.05	0.63
Spot 15	4.4	4.7	43.1	34.8	1.15	0.49
Spot 16	4.4	4.7	41.3	27.2	0.63	0.16
Spot 17	4.3	4.9	63.0	37.1	1.24	0.78
Range	**4.1-5.7**	**3.9-6.0**	**37.9-100.1**	**25.1-69.0**	**0.63-1.71**	**0.16-1.42**
Mean	**4.6**	**4.8**	**56.1**	**41.0**	**1.11**	**0.74**

Data regarding available phosphorous is presented in Table 5. Most of the studied soils of lemon orchards were found to be deficient in phosphorus. The optimum available P content for lemon cultivation is 25 to 70 mg/kg (Plessis 1977). The phosphorus concentration in upper depth varied from 0.35 to 66.95 mg/kg (82% was Phosphorous deficient and 18% was medium fertile), while in the lower depth, it ranged from 0.83 to 29.19 mg/kg (94% was Phosphorous deficient and 6% was medium fertile). On an average, available P was almost deficient at 0 to 15 cm depth (12.28 mg/kg) and 15 to 30 cm depth (5.63 mg/kg). Phosphorous deficiency was associated with low pH. At lower pH, adsorption results from the reaction with iron and aluminium (Muindi 2019). Maximum P availability is attained in most of the soils at pH ranged from 6.0 to 6.5 (Tisdale *et al.* 1985). Total phosphorus content ranged from 0.024 to 0.071% with an average of 0.045% at the upper depth and 0.024 to 0.056% with an average of 0.039% at the lower depth (Table 6).

The total K content varied from 0.022 to 0.144% at 0 to 15 cm depth and 0.012 to 0.139% at 15 to 30 cm depth. The exchangeable K^+ content in soil was observed to be decreased with increasing soil depth. The exchangeable K^+ content in the experimental area ranged from 0.040 to 0.221 meq/100g at 0 to 15 cm depth and 0.025 to 0.097 meq/100 at 15 to 30 cm depth. The mean value of exchangeable K^+ content was 0.084 meq/100g (0 to 15 cm depth) and 0.053 meq/100g (15 to 30 cm depth) (Table 6). For lemon grown soil exchangeable K^+ content is needed 0.128 to 0.513 meq/100g (Okada *et al.* 1994). Eighty two per cent of the samples from the upper depth and all from the lower depth were found deficient in K.

Table 6. Macronutrients (Nitrogen, Phosphorous and Potassium) status of some soils of lemon orchards in the Habiganj district, Bangladesh.

Locations	Nitrogen				Phosphorous				Potassium			
	Available (mg/kg)		Total (%)		Available (mg/kg)		Total (%)		Exchangeable (meq/100g)		Total (%)	
	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
Spot 1	40.74	20.37	0.073	0.061	2.00	1.73	0.024	0.024	0.062	0.060	0.046	0.056
Spot 2	40.74	40.74	0.070	0.053	4.80	2.22	0.040	0.032	0.070	0.062	0.076	0.061
Spot 3	47.53	33.95	0.085	0.056	33.27	2.63	0.048	0.032	0.057	0.045	0.056	0.086
Spot 4	54.32	74.69	0.079	0.076	3.31	3.47	0.024	0.048	0.070	0.055	0.095	0.110
Spot 5	67.90	67.90	0.072	0.070	0.97	0.96	0.032	0.024	0.045	0.045	0.037	0.042
Spot 6	33.95	27.16	0.061	0.058	2.65	1.29	0.056	0.056	0.124	0.062	0.144	0.139
Spot 7	20.37	40.74	0.050	0.026	2.83	1.25	0.048	0.040	0.040	0.035	0.071	0.086
Spot 8	20.37	40.74	0.053	0.035	2.65	2.33	0.048	0.056	0.052	0.097	0.051	0.076
Spot 9	47.53	54.32	0.067	0.029	11.30	6.80	0.071	0.048	0.221	0.060	0.115	0.120
Spot 10	20.37	33.95	0.073	0.047	4.43	1.08	0.071	0.056	0.144	0.037	0.105	0.139
Spot 11	33.95	47.53	0.038	0.020	0.35	0.83	0.048	0.040	0.042	0.040	0.081	0.081
Spot 12	47.53	47.53	0.070	0.051	12.44	4.70	0.040	0.040	0.072	0.047	0.042	0.046
Spot 13	61.11	27.16	0.041	0.012	12.33	8.45	0.032	0.032	0.177	0.057	0.032	0.012
Spot 14	67.90	47.53	0.050	0.032	2.65	0.90	0.032	0.024	0.060	0.052	0.032	0.042
Spot 15	61.11	40.74	0.061	0.023	13.43	5.95	0.040	0.032	0.075	0.072	0.022	0.027
Spot 16	33.95	33.95	0.047	0.018	66.95	21.97	0.063	0.032	0.060	0.025	0.037	0.027
Spot 17	40.74	33.95	0.070	0.038	32.39	29.19	0.056	0.048	0.060	0.052	0.042	0.046
Range	**20.37-67.90**	**20.37-74.69**	**0.038-0.085**	**0.012-0.076**	**0.35-66.95**	**0.83-29.19**	**0.024-0.071**	**0.024-0.056**	**0.040-0.221**	**0.025-0.097**	**0.022-0.144**	**0.012-0.139**
Mean	**43.54**	**41.94**	**0.062**	**0.042**	**12.28**	**5.63**	**0.045**	**0.039**	**0.084**	**0.053**	**0.064**	**0.070**

Among the secondary nutrients, the total S content ranged from 0.040 to 0.294% while the average was 0.138% at 0 to 15 cm depth and from 0.016 to 0.333% while the average was 0.147% at 15 to 30 cm depth. The available S content in the studied lemon orchard soils ranged from 4.62 to 68.48 mg/kg while the average value was 14.83 mg/kg at 0 to 15 cm depth and from 2.10 to 15.54 mg/kg while the average value was 7.95 mg/kg at 15 to 30 cm depth (Table 7).

Table 7. Macronutrients (Sulphur, Calcium and Magnesium) status of some soils of lemon orchards in the Habiganj district, Bangladesh.

Locations	Sulphur				Calcium		Magnesium	
	Available (mg/kg)		Total (%)		Exchangeable (meq/100g)		Exchangeable (meq/100g)	
	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
Spot 1	13.44	9.24	0.095	0.095	0.002	0.007	0.018	0.019
Spot 2	13.44	8.82	0.111	0.095	0.003	0.004	0.018	0.017
Spot 3	15.96	12.60	0.079	0.063	0.007	0.003	0.022	0.016
Spot 4	15.12	13.86	0.167	0.246	0.005	0.008	0.019	0.019
Spot 5	27.45	9.24	0.119	0.111	0.004	0.005	0.017	0.017
Spot 6	68.48	2.10	0.278	0.333	0.032	0.054	0.041	0.049
Spot 7	13.02	5.46	0.127	0.175	0.007	0.034	0.021	0.039
Spot 8	10.92	7.14	0.119	0.143	0.011	0.013	0.019	0.024
Spot 9	4.62	2.52	0.206	0.183	0.046	0.043	0.042	0.043
Spot 10	8.82	2.10	0.294	0.294	0.031	0.051	0.034	0.050
Spot 11	5.04	3.36	0.190	0.119	0.027	0.039	0.030	0.040
Spot 12	12.18	6.72	0.056	0.119	0.010	0.008	0.020	0.019
Spot 13	6.30	7.56	0.040	0.016	0.013	0.005	0.020	0.017
Spot 14	7.14	5.88	0.103	0.119	0.008	0.004	0.019	0.017
gSpot 15	11.76	9.66	0.159	0.127	0.007	0.004	0.019	0.017
Spot 16	10.08	15.54	0.103	0.119	0.010	0.010	0.019	0.018
Spot 17	8.40	13.44	0.095	0.135	0.009	0.007	0.021	0.018
Range	**4.62-68.48**	**2.10-15.54**	**0.040-0.294**	**0.016-0.333**	**0.002-0.046**	**0.003-0.054**	**0.017-0.042**	**0.016-0.050**
Mean	**14.83**	**7.95**	**0.138**	**0.147**	**0.014**	**0.018**	**0.024**	**0.026**

The standard value of available S for crop cultivation is 31.5 µg/g and the critical value is 8 mg/kg (BARC 2018). The results revealed that all of the samples, except for the spot 6 at upper depth, contained a lower level of S than that of the standard value, and 23% of the samples from the upper depth and 53% of the samples from the lower depth were below the critical S value.

Table 8. Nutrient concentrations in the leaves of the lemon garden under Habiganj District.

Locations	N (%)	P (%)	K (%)	S (%)
Spot 1	2.250 ± 0.344	0.556 ± 0.047	0.246 ± 0.015	0.046 ± 0.016
Spot 2	2.280 ± 0.154	0.528 ± 0.027	0.166 ± 0.019	0.010 ± 0.018
Spot 3	2.133 ± 0.453	0.778 ± 0.058	0.141 ± 0.012	0.041 ± 0.013
Spot 4	2.630 ± 0.324	0.528 ± 0.043	0.193 ± 0.027	0.056 ± 0.011
Spot 5	1.198 ± 0.170	0.500 ± 0.071	0.112 ± 0.018	0.092 ± 0.015
Spot 6	1.695 ± 0.284	0.528 ± 0.103	0.180 ± 0.019	0.061 ± 0.017
Spot 7	2.250 ± 0.238	0.528 ± 0.024	0.146 ± 0.014	0.133 ± 0.024
Spot 8	1.870 ± 0.203	0.583 ± 0.042	0.180 ± 0.026	0.031 ± 0.016
Spot 9	1.464 ± 0.363	0.500 ± 0.044	0.129 ± 0.016	0.031 ± 0.016
Spot 10	2.309 ± 0.318	0.528 ± 0.053	0.173 ± 0.018	0.117 ± 0.015
Spot 11	1.754 ± 0.272	0.500 ± 0.033	0.137 ± 0.015	0.087 ± 0.022
Spot 12	2.396 ± 0.192	0.556 ± 0.038	0.168 ± 0.010	0.128 ± 0.016
Spot 13	2.659 ± 0.458	0.528 ± 0.020	0.222 ± 0.016	0.092 ± 0.011
Spot 14	2.127 ± 0.252	0.500 ± 0.063	0.200 ± 0.031	0.082 ± 0.016
Spot 15	2.623 ± 0.306	0.556 ± 0.113	0.220 ± 0.023	0.066 ± 0.014
Spot 16	2.426 ± 0.257	0.583 ± 0.040	0.185 ± 0.020	0.041 ± 0.016
Spot 17	2.426 ± 0.413	0.667 ± 0.029	0.141 ± 0.016	0.036 ± 0.015
Range	**1.198-2.659**	**0.500-0.778**	**0.112-0.246**	**0.010-0.133**
Mean	**2.147**	**0.556**	**0.173**	**0.068**

'±' Standard deviation.

The exchangeable Ca^{2+} content in the experimental area ranged from 0.002 to 0.046 meq/100g (0 to 15 cm depth) and 0.003 to 0.054 meq/100 (15 to 30 cm depth). The mean value of exchangeable Ca^{2+} content was 0.014 meq/100g (0 to 15 cm depth) and 0.018 meq/100g (15 to 30 cm depth). The exchangeable Mg^{2+} content in the experimental area ranged from 0.017 to 0.042 meq/100g (0 to 15 cm depth) and 0.016 to 0.050 meq/100 (15 to 30 cm depth). The mean value of exchangeable Mg^{2+} content was 0.024 meq/100g (0 to 15 cm depth) and 0.026 meq/100g (15 to 30 cm depth) (Table 7). For lemon grown soil exchangeable Ca^{2+} content is needed 0.600 meq/100g (Spencer and Wander 1960). All of the samples were below the optimum exchangeable Ca^{2+} level.

Table 9. Nutrient concentrations in the fruits of the lemon garden under Habiganj District.

Locations	N (%)	P (%)	K (%)	S (%)
Spot 1	1.052 ± 0.245	0.361 ± 0.078	0.132 ± 0.280	0.010 ± 0.003
Spot 2	1.286 ± 0.302	0.444 ± 0.052	0.107 ± 0.240	0.026 ± 0.005
Spot 3	1.403 ± 0.237	0.583 ± 0.087	0.149 ± 0.035	0.020 ± 0.005
Spot 4	1.461 ± 0.222	0.417 ± 0.049	0.154 ± 0.052	0.020 ± 0.003
Spot 5	1.520 ± 0.136	0.472 ± 0.072	0.156 ± 0.249	0.010 ± 0.003
Spot 6	0.906 ± 0.284	0.361 ± 0.088	0.144 ± 0.245	0.010 ± 0.002
Spot 7	1.549 ± 0.323	0.556 ± 0.030	0.124 ± 0.241	0.031 ± 0.005
Spot 8	1.169 ± 0.120	0.250 ± 0.057	0.141 ± 0.034	0.020 ± 0.004
Spot 9	1.052 ± 0.236	0.611 ± 0.070	0.146 ± 0.037	0.005 ± 0.002
Spot 10	1.023 ± 0.141	0.361 ± 0.045	0.146 ± 0.054	0.005 ± 0.002
Spot 11	0.760 ± 0.275	0.472 ± 0.084	0.178 ± 0.024	0.020 ± 0.002
Spot 12	1.490 ± 0.311	0.306 ± 0.073	0.156 ± 0.033	0.031 ± 0.003
Spot 13	1.052 ± 0.165	0.278 ± 0.041	0.132 ± 0.026	0.010 ± 0.002
Spot 14	1.490 ± 0.245	0.500 ± 0.035	0.190 ± 0.057	0.026 ± 0.008
Spot 15	1.432 ± 0.178	0.389 ± 0.082	0.129 ± 0.031	0.015 ± 0.002
Spot 16	1.374 ± 0.254	0.444 ± 0.038	0.156 ± 0.247	0.020 ± 0.003
Spot 17	1.023 ± 0.209	0.361 ± 0.058	0.110 ± 0.242	0.026 ± 0.004
Range	**0.760-1.549**	**0.250-0.611**	**0.107-0.190**	**0.005-0.031**
Mean	**1.238**	**0.422**	**0.144**	**0.018**

Nutrient status in the leaf and fruit of lemon

In the lemon leaves, the nitrogen level ranged from 1.198 to 2.659% with an average of 2.147%. Phosphorus level ranged from 0.500 to 0.778% with an average of 0.556%. Potassium and Sulphur levels in the lemon leaves ranged from 0.112 to 0.246% with an average of 0.173% and 0.010 to 0.133% with an average of 0.068%, respectively (Table 8).

In the lemon fruits, the nitrogen level ranged from 0.760 to 1.549 % with an average of 1.238%. The phosphorus level in the lemon fruits ranged from 0.250 to 0.611% with an average of 0.422%. The potassium level in the lemon fruits ranged from 0.107 to 0.190% with an average of 0.144%. The sulphur level in the lemon fruits ranged from 0.005 to 0.031% with an average of 0.018% (Table 9).

The soils under seventeen lemon orchards in the Habiganj district were found to be low to moderately fertile for lemon cultivation, with deficiencies in phosphorus, potassium, sulfur, calcium, and magnesium. Proper soil nutrient management is essential for improving soil health in this region. Inorganic fertilizers along with organic amendments needed to be applied in the soil not only for sustainable management of soil fertility, but also for the improvement of nutrient contents in lemon in the north-eastern region of Bangladesh.

ACKNOWLEDGEMENTS

The first author gratefully acknowledges the financial assistance of the Ministry of Science and Technology, Government of the People's Republic of Bangladesh for funding under The National Science and Technology Fellowship and also thankful to the chairman of the Department of Soil, Water and Environment, University of Dhaka for allowing to carry out the analysis of soil, leaf and fruit samples in the laboratory.

REFERENCES

BARC. 2018. *Fertilizer Recommendation Guide-2018*. BARC Soils Publication No. 45. Bangladesh Agricultural Research Council, Farmgate, Dhaka, Bangladesh. 200 pp.

Bardsley, C. E. and J. D. Lancaster. 1965. Sulfur. In: C. A. Black (ed.). *Methods of Soil Analysis.* American Society of Agronomy, Madison, Wisconsin, USA., pp. 1102-1114.

BBS (Bangladesh Bureau of Statistics). 2020. *Yearbook of Agricultural Statistics-2020.* Planning Division, Government of Peoples Republic of Bangladesh. 221 pp.

Bouyoucos, G.T. 1962. Hydrometer method improved for making particle size analysis of soils. *Agron. J.* **54**: 461-465.

Bremner, J. M. and C. S. Mulvaney. 1982. Total nitrogen In: A. L. Page, R. H. Millerand and D. R. Keeney. *Method of Soil analysis* (eds.). Agronomy monograph No. 9. American Society of Agronomy. Madison, Wisconsin, USA., pp. 595-622.

Bussi, C., J. Bessetand and T. Girard. 2003. Effects of fertilizer rates and dates of application on apricot (cv Bergeron) cropping and pit burn. *Scientia Horticulturae*. **98**(2): 139-147.

Chapman, H. D. 1961. The evaluation and management of citrus soil. *Indian J. Hort*. **18**: 251-276.

DAE. 2022. *Unpublished works*. Department of Agricultural Extension, Khamarbari, Shayestanagar, Habiganj, Bangladesh.

Egea, L., A. Leonand and O. Carpena. 1972. Nutrition minérale chez certains Prunus L. Influence del'espece. *Fruits.* **27**(4): 287-291.

Hardie, M. and R. B. Doyle. 2012. Measuring Soil Salinity. *Methods in Molecular Biology.* Clifton, N.J., USA., pp. 415-425.

Hayes, W. B. 1960. *Fruit Growing in India*. 3rd edition. Kitabistan, Allahabad, U. P. India. 118 pp.

Jackson, D. J. and N. E. Looney. 1999. *Citrus: Temperate and sub-Tropical Fruit Production*. 2nd edition. CAB International, UK., pp. 1-10.

Jackson, M. L. 1958. *Soil Chemical Analysis*. Prentice-Hall, Inc., Englewood Cliff, NJ, USA. 498 pp.

Jiang, W. F., Y. F. Cui, W. D. Zhang, J. Chen, W. P. Fan, X. D. Yu and J. B. Zhou. 2005. Annual changes of mineral elements in foliar of Thompsons seedless. J. Northwest Sci-Tech University of Agriculture and Forestry. *Nat. Sci. Edn*. **33**(8): 91-95.

Jones, J. B. Jr. 1980. *Handbook on Reference Methods for Soil Testing*. Council Soil Testing and Plant Analysis. Athens, Georgia, USA., pp. 260-280.

Mabberley, D. J. 2004. Citrus (Rutaceae): A review of recent advances in etymology, systematics and medical applications. *Blumea J. Plant Taxon. Plant Geogr.* **49**: 481-498.

Marr, I. L. and M. S. Cresser. 1983. The lithosphere. In: *Environmental Chemical Analysis*. Blackie and Son, UK., pp. 155- 182.

Muindi, E. 2019. Understanding Soil Phosphorus. *Int. J. Plant Soil Sci*. **31**: 1-18.

Nicola, P. B., D. Frederik, K. Cecilie and M. H. Jonathan. 2019. Flavonoid intake is associated with lower mortality in the Danish Diet Cancer and Health Cohort. *Nat. Comm*. **10**: 36-51.

Okada, N., A. Ooshiro and T. Ishida. 1994. Effect of the level of fertilizer application on the nutrient status of Satsuma mandarin trees. *Proc. Int. Soc. Citriculture.* **2**: 575-579.

Plessis, S. F. Du. 1977. Soil analysis as a necessary complement to leaf analysis for fertilizer advisory purposes. *Proc. Int. Soc. Citricul*. **1**: 18-21.

Pratt, P. S. 1965. Potassium. In: C. A. Black (ed.). *Methods of Soil Analysis.* Part 2. American Society of Agronomy, Inc., Madison, Wisconsin, USA., pp. 1022-1030.

Reyes, R. A. 2000. Effect of mineral nutrition on bud flower drop of apricot 17-10 selection. *Terra.* **18**(4): 299-304.

Richards, L. A. 1954. *Diagnosis and Improvement of Saline and Alkali Soil*. USDA Handbook No. 60. US Govt. Print Office, Washington, USA., pp. 84-156.

Spencer, W. F. and I. W. Wander. 1960. A comparison of magnesium sources in orange trees. *Proc. Fla. State Hort. Soc.* **73**: 28-35.

SRDI. 2014. *Land and soil resources utilization guide (in Bengali)*. Upazila Nirdeshika Series (Habiganj). Soil Resources Development Institute, Dhaka, Bangladesh. 54 pp.

SRDI. 2018. *Land and soil resources utilization guide (in Bengali)*. Upazila Nirdeshika Series (Bahubal). Soil Resources Development Institute, Dhaka, Bangladesh. 56 pp.

SRDI. 2021. *Land and soil resources utilization guide (in Bengali)*. Upazila Nirdeshika Series (Chunarughat). Soil Resources Development Institute, Dhaka, Bangladesh. 61 pp.

Tisdale, S. L., W. L. Nelson and J. D. Beaton. 1985. *Soil Fertility and Fertilizers*. 4th edition. Macmillan Publishing Company, New York, USA., pp. 189-248.

Walkley, A. and I. A. Black. 1934. An experiment of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci*. **37**: 29-38.

Zhuang, Y. M., L. R. Li, Y. Jing, R. J. Wang and M. H. Su. 1985. Study on rational fertilizer application in the citrus orchards in Fujian province by nutritional diagnosis. *J. Fujian Agr. College.* **14**(1): 23-29.

(Manuscript received on 16 January, 2023)