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Dry Season Chemical Properties and Nutrient Status of Agricultural Soils in Gopalganj District Bangladesh

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ABSTRACT

Background: Agricultural land is essential for food production and rural livelihoods, while soil is a diverse and nutrient-rich surface material containing both organic and inorganic matter. It supports organisms, regulates water availability and nutrient cycling and influences greenhouse gas emissions. The physicochemical characteristics of agricultural soils are important indicators of soil fertility, productivity, quality and overall ecosystem health.

Objective: This study aimed to determine the chemical properties and nutrient status of agricultural soils in Gopalganj District.

Methods: Twenty-six representative soil samples were collected during the dry season from a depth of 0–20 cm. The samples were analyzed for pH, EC, organic carbon, organic matter, alkalinity, available nitrogen (N), phosphorus (P), potassium (K), sulfur (S), zinc (Zn), iron (Fe), boron (B), calcium (Ca), magnesium (Mg), copper (Cu), and manganese (Mn).

Results: The soils were neutral to slightly alkaline. Soil pH ranged from 6.62 to 8.90, EC from 0.57 to 8.09 dS m^{-1}, and OC from 0.39% to 5.19%. Total N ranged from 0.22% to 0.24%, K from 0.09 to 0.70, P from 3.4 to 13.2, S from 14.52 to 133.3, Zn from 0.24 to 2.44, B from 0.27 to 2.10, Ca from 51 to 99.5, Mg from 0.5 to 4.0, Cu from 0.18 to 12, Fe from 2.84 to 50.44 and Mn from 2.06 to 13.62.

Conclusion: The agricultural soils were generally suitable for dry-season cultivation, although low organic matter and insufficient N, P and K indicated moderate fertility constraints. Continuous cultivation and improper fertilizer management may contribute to declining soil quality.

Keywords: Agricultural soil; Soil quality; Nutrient status; Physicochemical properties; Dry season; Gopalganj.

1. Introduction

Soil is one of the important and valuable resources of the nature. For daily needs, all living species rely on soil, both directly and indirectly, and the ground provides 95% of human nourishment. Soil acts as a thin layer of earth's crust which serves as a natural medium for the growth of plants and it is the unconsolidated mineral matter influenced by genetic and environmental factors [1].It is a natural body consisting of layers (soil horizons) of mineral constituents of variable thicknesses, which differ from the parent materials in their morphological, physical, chemical and biological properties [2]. The only method to ascertain the soil's available nutrient status and to create precise fertilizer recommendations is through soil testing. Results of physical and chemical tests provide information about the capacity of soil to supply mineral nutrients [3] the context of sustainable agricultural production, soil characterisation is crucial for assessing the fertility state of the soils in a certain area or region. Nitrogen, phosphorous, potassium and sulphur are important soil elements that control its fertility and yields of crops [4]. Soils provide all sorts of requirements such as physical support, nourishment, nutrients and so on to plants for [5]. Soil is a key element of agriculture. Bangladesh is an agrarian country with an area of 144,862 square kilometer (m3) and the area fluctuates depending on the alluvial formations within the main river channels and the Meghna estuary [6], About 60% of the entire people of this country depend on agriculture for their living. Though the country is small in area, it possesses a wide variety of soil types and most crops respond to fertilizers on almost all soils because of their low fertility status. Through reconnaissance soil survey from 1965 to 1976, Soil Resource Development Institute (SRDI) identified 465 soil series of which the physical and chemical properties were determined in the laboratory and published in thirty-three reconnaissance soil survey reports. Later, SRDI cumulated a large amount of information on soil properties of different Upazilas through semi-detailed soil survey during the period of 1985 to 2001 which were published in three hundred twenty-four Land and Soil Resource Utilization Guide popularly known as Upazila Nirdeshika [7]. The analysis of soil is necessary to determine the inherent nutrient status of soil. To achieve higher crop yield, it is essential to estimate the demand of fertilizers for a specific crop as well as to ensure efficient use 1 of fertilizer. By accurately assessing the fertility of the soil through soil testing, fertiliser

recommendations can be made [8]. Regular soil testing programs, which are growing in popularity due to the rising expense of fertilisers, can also lessen nutrient loss [9,10]. Sustainable soil management is essential for maintaining proper soil health for future production of crops. In order to observe the current fertility and physical changes of soils over time due to various land uses, comparative research was conducted at the Dumuria soil series in Khulna district. Soil physical (soil texture, water holding capacity, bulk density and total porosity) and chemical properties (Nitrogen (N), Phosphorous (P), Potassium (K), Sulphur (S), soil organic matter (SOM), soil organic carbon (SOC) along with cation exchange capacity (CEC), sodium absorption ratio (SAR), exchangeable sodium percentage (ESP), base saturation percentage (BSP) and % salt properties were determined [11]. The quality of soil depends both on its physical properties (color, texture, moisture contents, pH, organic matter content etc) and chemical properties (cation exchange capacity, organic matter contents, phosphate phosphorous, nitrate nitrogen, nitrite nitrogen etc). The fertility of a soil determines its potential uses and, to a greater extent, its yields. The physical and chemical characteristics of a soil determine its fitness for its planned use and management requirements to keep it most productive to a limited extent [12]. One of the most important ecological elements is soil, which provides plants with water, nutrients and minerals [13,14]. Comprehensive studies assessing the physicochemical properties and macro- and micronutrient status of soils in the Gopalganj district are still limited. Therefore, this study was conducted to characterize the physicochemical properties of agricultural soils collected during the dry season, quantify the concentrations of macro- and micronutrients, and assess the measured soil properties and nutrient concentrations in relation to the WHO/FAO guideline standards. The findings of this study are expected to provide valuable baseline information on soil quality and nutrient status in the Gopalganj district, contributing to the sustainable management of soil resources and supporting informed agricultural and environmental management practices.

2. Materials and methods

2.1 Sample stations of study area

Gopalganj District covers 1,468.74 sq. km (567.08 sq. miles) and lies along the Madhumati River at 23°00'47.67" N and 89°49'21.41" E. The study focused on agricultural fields in Gopalganj Sadar and Tungipara upazilas, which are two subdistricts of Gopalganj District, Bangladesh [15].

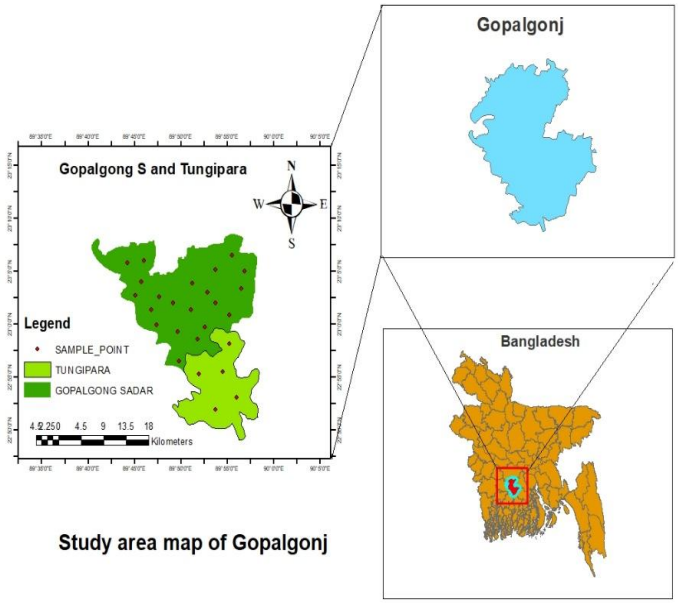


Fig 1: Sample stations of study area

2.2 Collection and Storage of samples

Using sterile sampling equipment, 26 agricultural soil samples were randomly collected during the dry season from November 2025 to March 2026 in two upazilas of Gopalganj District, Bangladesh. Twenty-one samples were obtained from Gopalganj Sadar Upazila, and the remaining five were collected from Tungipara Upazila. At each location, grasses, litter and other plant residues were removed from the soil surface before samples were collected from a depth of 0-15 cm with an auger. A triangular sampling block was marked and the collected soil was placed in properly labelled zip-lock plastic bags that were sealed immediately. The samples were transported to the laboratory, dried in a hot-air oven, homogenized and passed through a 2 mm sieve before analysis.

2.3 Soil pH and Electrical Conductivity

For pH determination, a soil-to-water suspension was prepared at a ratio of 1:5, whereas EC was measured in a 1:2.5 soil-to-water suspension. Both measurements were obtained

with a HANNA HI9813-6 pH/EC meter according to the procedure described by [16]. Soil pH was measured potentiometrically following [17] and EC was determined according to the salinity and electrical conductivity principles described by [18].

2.4 Organic Carbon and Organic Matter

Organic carbon was quantified using the Walkley and Black wet oxidation method [19]. In this procedure, soil organic matter was oxidised with potassium dichromate and the remaining dichromate was back-titrated with ferrous sulphate using diphenylamine as the indicator. Organic matter was calculated by multiplying the measured organic carbon content by the Van Bemmelen factor of 1.73, as recommended by [20]. The recognised sources of variation and limitations associated with this wet oxidation procedure were considered as discussed by [21].

2.5 Total Nitrogen

Total nitrogen was measured using the Kjeldahl method [22]. Soil samples were digested in concentrated sulphuric acid with copper sulphate and potassium sulphate as catalysts. The ammonia released during steam distillation was collected in standard acid and quantified by titration according to the general procedure described by [23].

2.6 Available Phosphorus, Potassium and Sulphur

Available phosphorus was extracted with sodium bicarbonate according to Olsen's method [24] and measured colorimetrically at 660 nm using a spectrophotometer. Available potassium was extracted with neutral normal ammonium acetate and quantified using a flame photometer calibrated against standard potassium solutions, following [25]. Available sulphur was extracted with 0.15% calcium chloride and determined turbidimetrically at 420 nm using a spectrophotometer based on the method of [26].

2.7 Micronutrients (Zn, Cu, Fe, Mn), Calcium and Magnesium

Zinc, copper, iron and manganese were extracted with a diethylenetriaminepentaacetic acid (DTPA) solution according to [27]. Exchangeable calcium was extracted using 1 mol/L ammonium acetate and measured with a LAQUAtwin B-751 calcium ion meter. The meter was calibrated with calcium standards prepared in the same extractant, and the ammonium acetate extraction procedure followed [20]. Available magnesium was extracted with 0.5 M ammonium acetate at pH 7 and quantified using atomic absorption

spectroscopy (AAS), inductively coupled plasma-optical emission spectrometry (ICP-OES) or a colorimetric method after calibration with standard magnesium solutions.

2.8 Available Boron

Available boron was released by acid digestion with hydrochloric and nitric acids, after which the digest was neutralised and filtered. Boron was quantified spectrophotometrically after complexation with azomethine-H reagent [28]. Absorbance values were compared with a boron calibration curve using the refinements to the azomethine-H procedure reported by [29].

3. Result

Table 1. Classification of soil pH and organic matter according to [30].

Soil pH		**Soil Organic Matter**	
Value	Soil Reaction Class	Value	Status
<4.5	Very strongly acidic	<1.00	Very low
4.6-5.5	Strongly acidic	1-1.70	Low
5.6-6.5	Slightly acidic	1.71-3.40	Medium
6.6-7.3	Neutral	3.41-5.50	High
7.4-8.4	Slightly alkaline	>5.50	Very high
8.5-9.0	Strongly alkaline	-	-
>9.0	Very Strongly alkaline	-	-

Table 2. Standard value of Soil [30–33].

Parameters	**WHO/FAO**
pH	6-7.5
EC (dS/m)	2
Organic Matter	3-4.5
Total Nitrogen	.4
Cupper	5-8
Zinc	.5-2
Phosphorus	25
Magnesium	35
Calcium	50-75
Potassium	.4-.8
Manganese	20
Iron	.2-55
Boron	.7
Sulphur	15

Table 3: Physicochemical properties of soil used in the experiment.

SL	pH	EC (dS/m)	Organic Matter (%)	Total Nitrogen (%)	Phosphorous (µg)	Potassium	Sulphur (µg)	Zinc (µg)	Boron (µg)	Calcium	Magnesium	Copper (µg)	Iron (µg)	Manganise (µg)
1	7.86	0.75	1.13	0.07	3.60	0.40	38.75	0.28	2.10	74.00	0.50	2.48	16.30	11.34
2	7.93	0.57	1.64	0.10	13.10	0.20	29.99	0.78	1.38	84.50	0.50	0.88	6.62	4.44
3	7.55	2.14	2.54	0.15	4.30	0.38	127.92	0.68	0.78	72.00	0.50	4.08	37.66	13.62
4	7.43	3.04	3.92	0.24	4.00	0.70	20.67	0.82	1.19	77.50	0.50	7.66	50.44	9.20
5	8.00	0.81	0.87	0.05	4.20	0.12	19.73	0.36	0.29	90.50	2.00	12.00	10.62	5.56
6	7.76	1.24	0.39	0.02	4.15	0.29	31.34	0.66	0.67	58.00	0.50	1.18	4.40	8.14
7	7.81	0.75	0.42	0.03	3.40	0.09	36.99	0.24	0.33	59.00	2.00	0.42	3.62	10.52
8	7.64	0.91	2.13	0.13	8.30	0.52	47.10	0.74	0.48	67.50	0.50	0.64	3.26	8.04
9	7.67	1.36	1.06	0.06	3.80	0.35	42.38	0.48	0.84	90.00	0.50	2.28	15.52	8.36
10	7.46	0.85	2.51	0.15	7.80	0.34	21.30	0.36	1.49	63.50	0.50	0.78	6.00	10.94
11	7.56	0.62	1.71	0.10	8.30	0.21	38.83	0.60	0.41	83.00	0.50	1.80	36.52	9.56
12	7.64	1.08	1.38	0.08	3.70	0.13	34.97	0.30	0.52	70.00	4.00	0.18	4.34	2.06
13	7.66	7.66	0.61	0.12	11.40	0.25	73.46	0.76	0.33	88.00	0.50	2.04	27.84	12.46
14	7.15	7.15	0.97	0.05	6.00	0.23	133.30	0.48	0.27	58.00	0.50	0.60	5.28	7.56
15	7.79	7.79	0.72	0.09	8.40	0.17	24.37	0.48	0.48	82.00	0.50	1.10	16.72	3.94
16	7.57	7.57	1.29	0.09	6.10	0.16	14.52	1.50	0.51	74.50	0.50	1.54	31.26	8.78
17	6.62	6.62	1.31	0.12	7.80	0.31	46.51	1.52	0.39	99.50	1.50	0.78	27.90	4.42
18	7.52	7.52	3.75	0.20	7.30	0.47	21.34	1.52	0.46	99.50	0.50	0.68	19.18	6.20
19	7.39	7.39	5.19	0.23	6.20	0.54	43.36	2.44	0.63	98.50	0.50	0.80	24.26	8.62
20	7.43	7.43	1.87	0.14	5.30	0.42	47.78	2.44	0.49	98.00	2.00	0.90	32.86	8.28
21	7.80	7.80	0.81	0.04	4.40	0.34	66.46	2.08	0.74	51.00	2.00	0.30	3.84	3.70
22	7.62	7.62	0.52	0.16	13.20	0.24	23.554	1.08	0.53	99.50	2.00	0.66	28.72	3.10
23	7.82	7.82	0.56	0.14	4.50	0.26	31.79	0.90	0.59	97.00	2.00	0.56	8.38	2.74
24	7.63	7.63	3.03	0.06	4.90	0.70	17.67	0.42	0.69	99.50	1.00	0.36	2.84	6.94
25	8.09	8.09	0.85	0.08	7.10	0.26	25.80	0.72	0.81	92.50	0.50	1.18	38.96	9.92
26	8.06	7.96	1.68	0.07	6.10	0.45	21.34	1.50	.62	90.50	0.60	1.54	19.15	8.85

The analysis included 26 agricultural soil samples. Samples S1-S20 were collected from agricultural fields in Gopalganj Sadar, whereas samples S21-S26 were collected from agricultural fields in Tungipara Upazila.

3.1 pH :

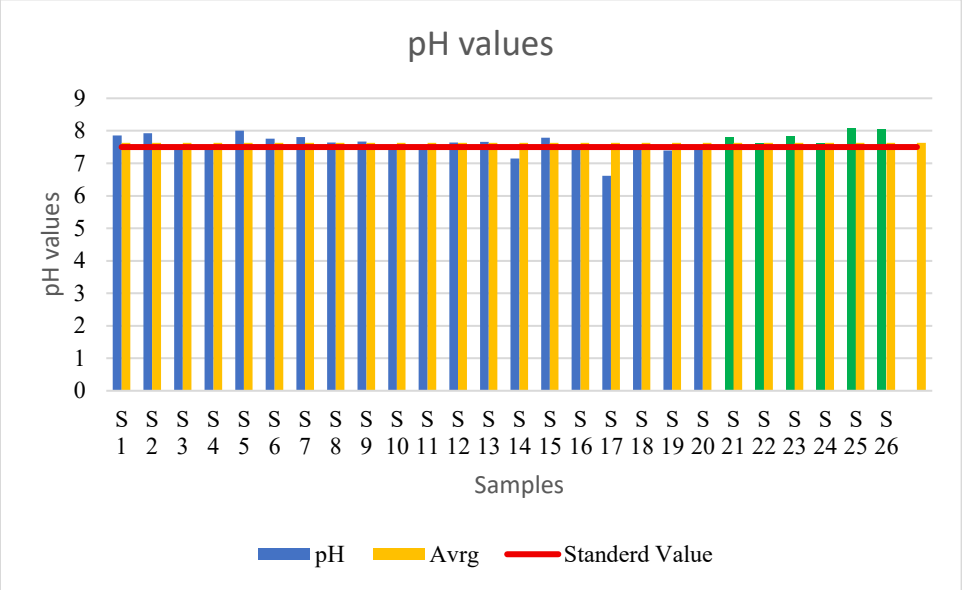


Fig 2: Soil pH across the agricultural field

Soil pH across the 26 samples ranged from 6.62 to 8.09, with an overall mean of 7.63. In Gopalganj Sadar (S1-S20), pH ranged from 6.62 at S17 to 8.00 at S5, with a mean of 7.57. Tungipara Upazila (S21-S26) had a higher mean pH of 7.84, ranging from 7.62 at S22 to 8.09 at S25 (Fig. 2).

3.2 EC

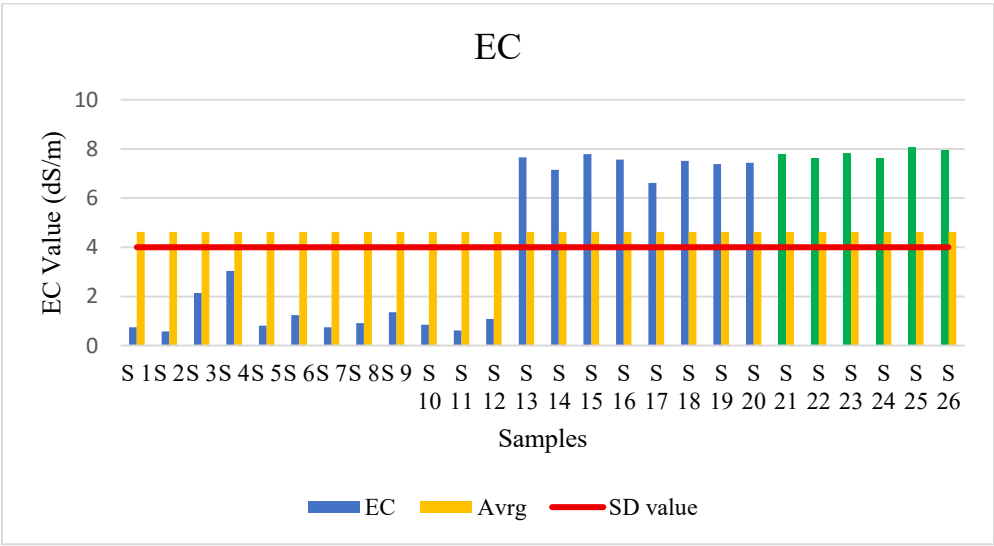


Fig 3: EC across the agricultural field

Electrical conductivity ranged from 0.57 to 8.09 dS m^{-1}, with an overall mean of 4.62 dS m^{-1}. Values in Gopalganj Sadar ranged from 0.57 dS m^{-1} at S2 to 7.79 dS m^{-1} at S15 and averaged 3.66 dS m^{-1}. Tungipara recorded consistently higher values, with a mean of 7.82 dS m^{-1} and a range of 7.62-8.09 dS m^{-1} (Fig. 3).

3.3 Organic Matter

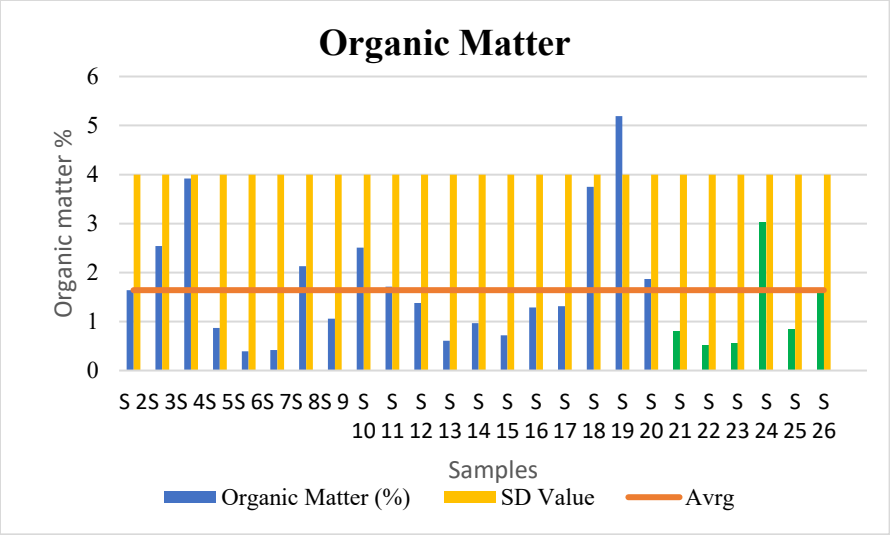


Fig 4: Organic matter across the agricultural field

Organic matter content ranged from 0.39% at S6 to 5.19% at S19, with an overall mean of 1.64%. The mean content was higher in Gopalganj Sadar (1.77%) than in Tungipara (1.24%). Within Tungipara, organic matter ranged from 0.52% at S22 to 3.03% at S24 (Fig. 4).

3.4 Total nitrogen

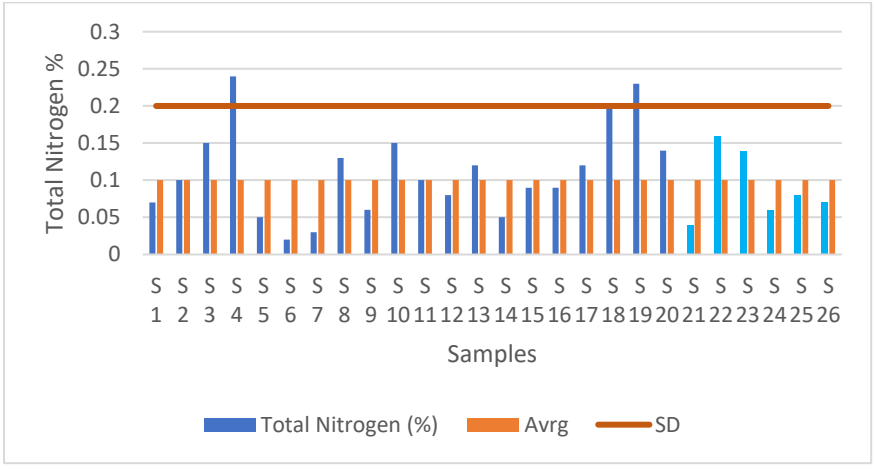


Fig 5: Total nitrogen across the agricultural field

Total nitrogen varied from 0.02% at S6 to 0.24% at S4, with an overall mean of 0.107%. Gopalganj Sadar had a mean concentration of 0.111%, compared with 0.092% in Tungipara. In Tungipara, values ranged from 0.04% at S21 to 0.16% at S22 (Fig. 5).

3.5 Phosphorous

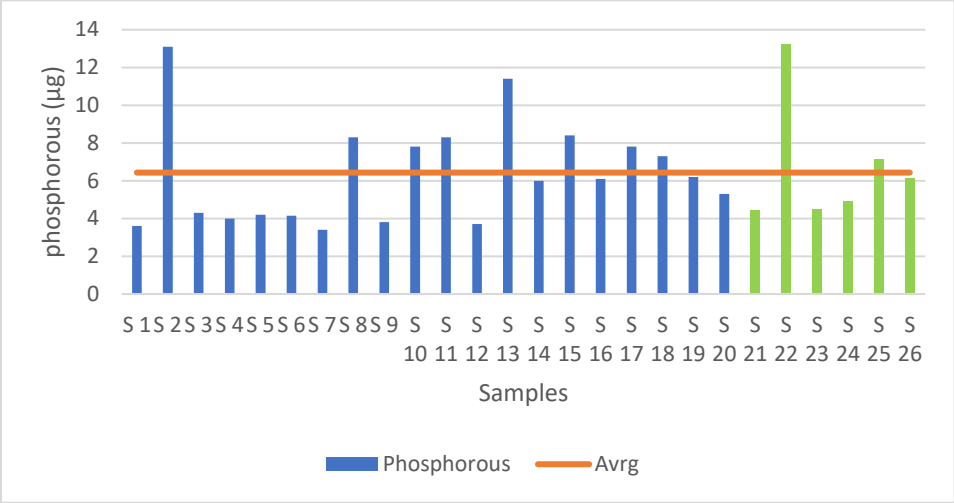


Fig 6: Phosphorus across the agricultural field

Available phosphorus ranged from 3.4 µg at S7 to 13.2 µg at S22, with an overall mean of 6.44 µg. The mean concentration was slightly lower in Gopalganj Sadar (6.36 µg) than in Tungipara (6.70 µg). The highest value in Gopalganj Sadar was 13.1 µg at S2, whereas the highest overall value occurred in Tungipara at S22 (Fig. 6).

3.6 Potassium

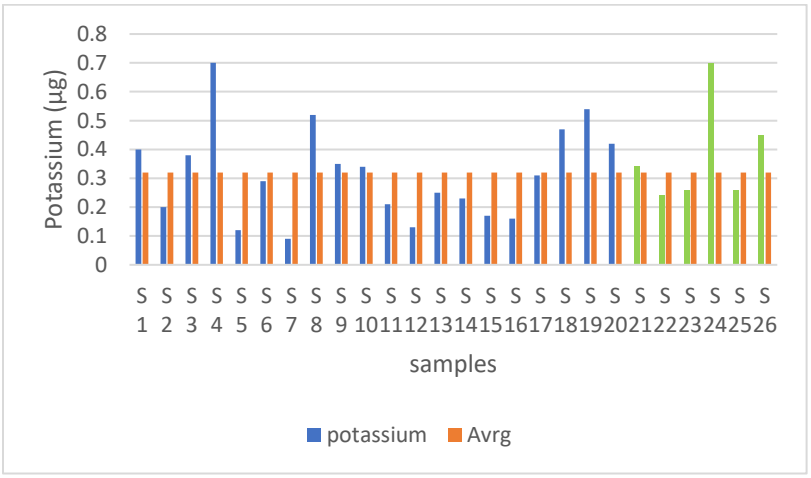


Fig 7: Potassium across the agricultural field

Available potassium ranged from 0.09 µg at S7 to 0.70 µg at both S4 and S24, with an overall mean of 0.328 µg. Gopalganj Sadar had a mean concentration of 0.314 µg, while Tungipara had a higher mean of 0.375 µg. Values in Tungipara ranged from 0.24 µg at S22 to 0.70 µg at S24 (Fig. 7).

3.7 Sulphur

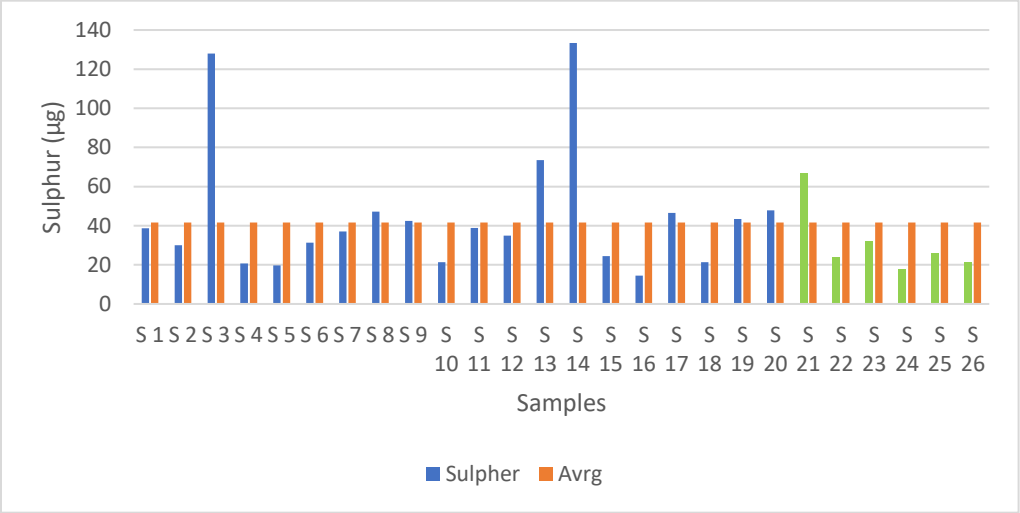


Fig 8: Sulphur across the agricultural field

Sulfur concentrations ranged from 14.52 µg at S16 to 133.30 µg at S14, with an overall mean of 41.58 µg. The mean concentration was higher in Gopalganj Sadar (44.73 µg) than in Tungipara (31.10 µg). Within Tungipara, sulfur ranged from 17.67 µg at S24 to 66.46 µg at S21 (Fig. 8).

3.8 Zinc

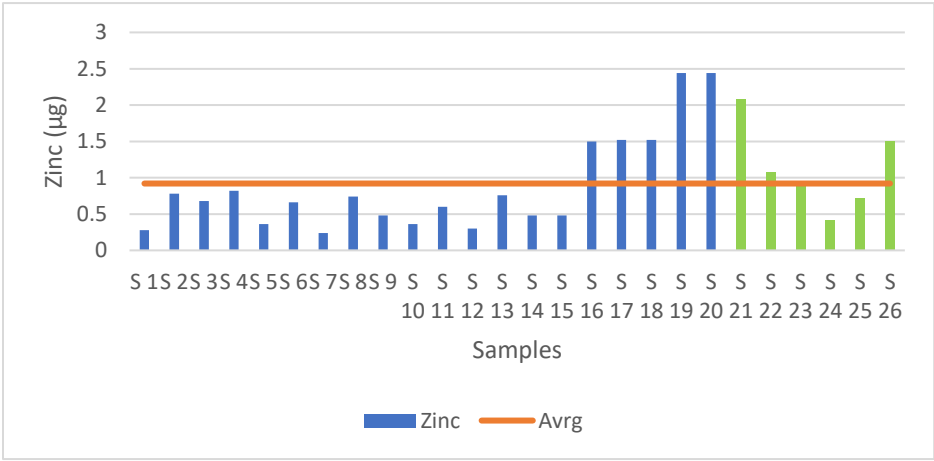


Fig 9: Zinc across the agricultural field

Zinc concentrations ranged from 0.24 µg at S7 to 2.44 µg at both S19 and S20, with an overall mean of 0.92 µg. Although the highest values occurred in Gopalganj Sadar, the mean zinc concentration was higher in Tungipara (1.12 µg) than in Gopalganj Sadar (0.87 µg). Tungipara values ranged from 0.42 µg at S24 to 2.08 µg at S21 (Fig. 9).

3.9 Boron

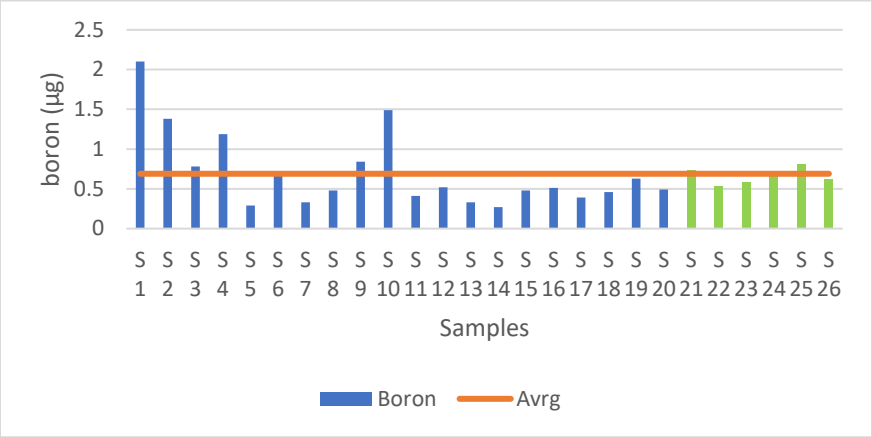


Fig 10: Zinc across the agricultural field

Boron concentrations ranged from 0.27 µg at S14 to 2.10 µg at S1, with an overall mean of 0.69 µg. The mean was slightly higher in Gopalganj Sadar (0.70 µg) than in Tungipara (0.66 µg). In Tungipara, boron varied within a narrower range of 0.53-0.81 µg, with the minimum at S22 and the maximum at S25 (Fig. 10).

3.10 Calcium

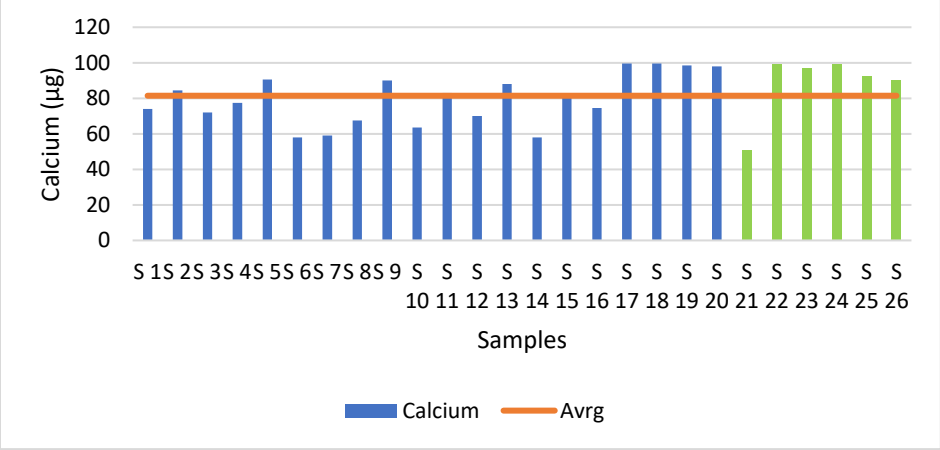


Fig 11: Calcium across the agricultural field

Calcium concentrations ranged from 51.0 µg at S21 to 99.5 µg at S17, S18, S22, and S24, with an overall mean of 81.44 µg. Tungipara had a higher mean calcium concentration (88.33 µg) than Gopalganj Sadar (79.38 µg). Despite the higher regional mean, the lowest value among all samples was recorded at S21 in Tungipara (Fig. 11).

3.11 Magnesium

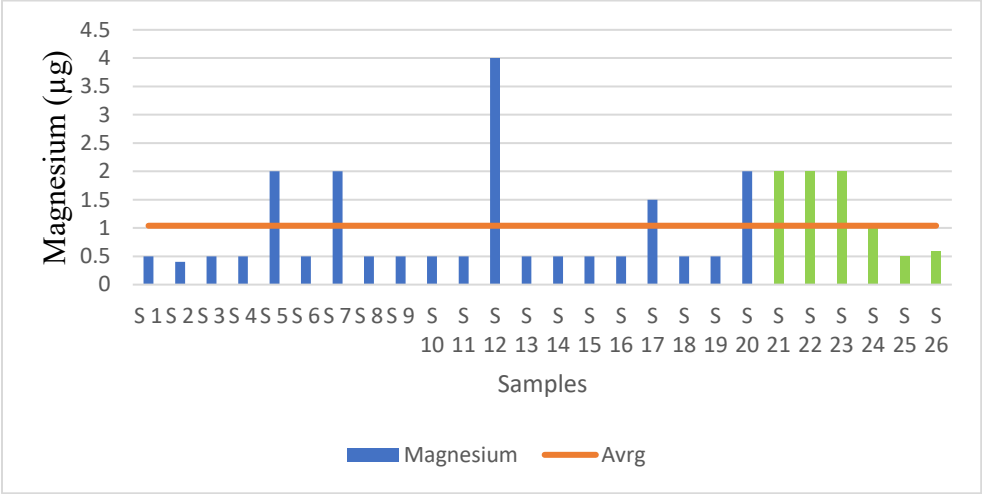


Fig 12: Magnesium across the agricultural field

Magnesium concentrations ranged from 0.40 µg at S2 to 4.00 µg at S12, with an overall mean of 1.04 µg. The mean concentration was higher in Tungipara (1.35 µg) than in Gopalganj Sadar (0.95 µg). Tungipara values ranged from 0.50 µg at S25 to 2.00 µg at S21-S23 (Fig. 12).

3.12 Copper

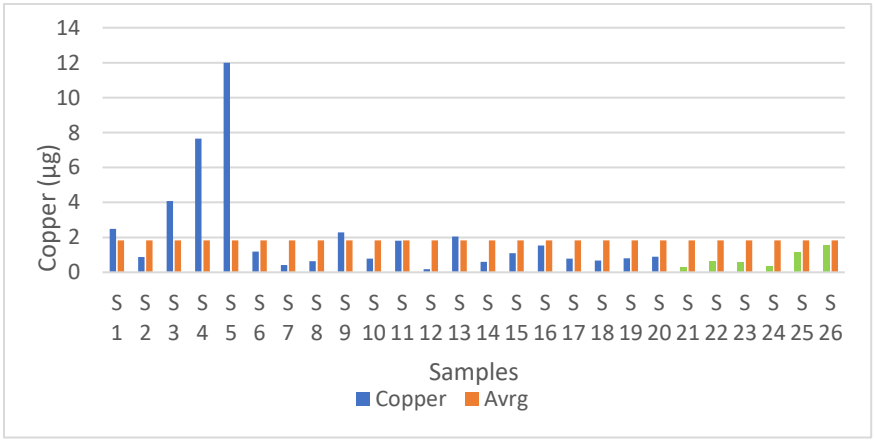


Fig 13: Copper across the agricultural field

Copper concentrations ranged from 0.18 µg at S12 to 12.00 µg at S5, with an overall mean of 1.82 µg. Gopalganj Sadar had a markedly higher mean concentration (2.14 µg) than Tungipara (0.77 µg). Within Tungipara, copper ranged from 0.30 µg at S21 to 1.54 µg at S26 (Fig. 13).

3.13 Iron

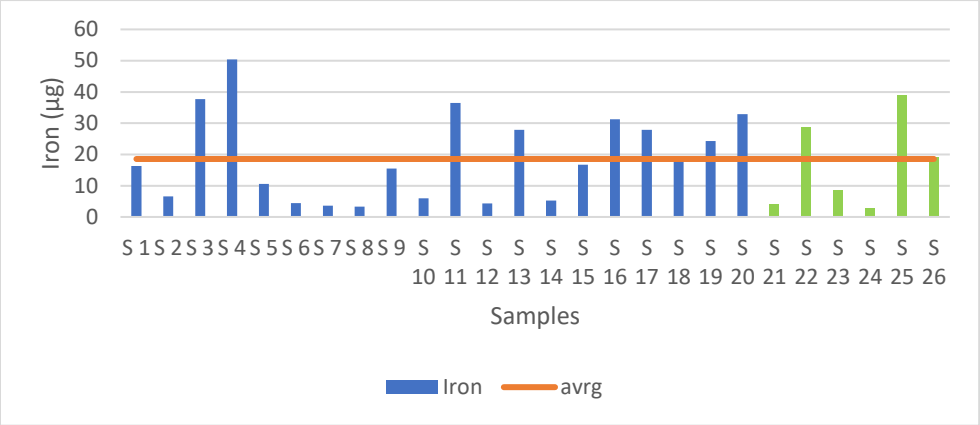


Fig 14: Iron across the agricultural field

Iron concentrations ranged from 2.84 µg at S24 to 50.44 µg at S4, with an overall mean of 18.55 µg. The mean concentration was slightly higher in Gopalganj Sadar (19.03 µg) than in Tungipara (16.98 µg). Tungipara values ranged from 2.84 µg at S24 to 38.96 µg at S25 (Fig. 14).

3.14 Manganese

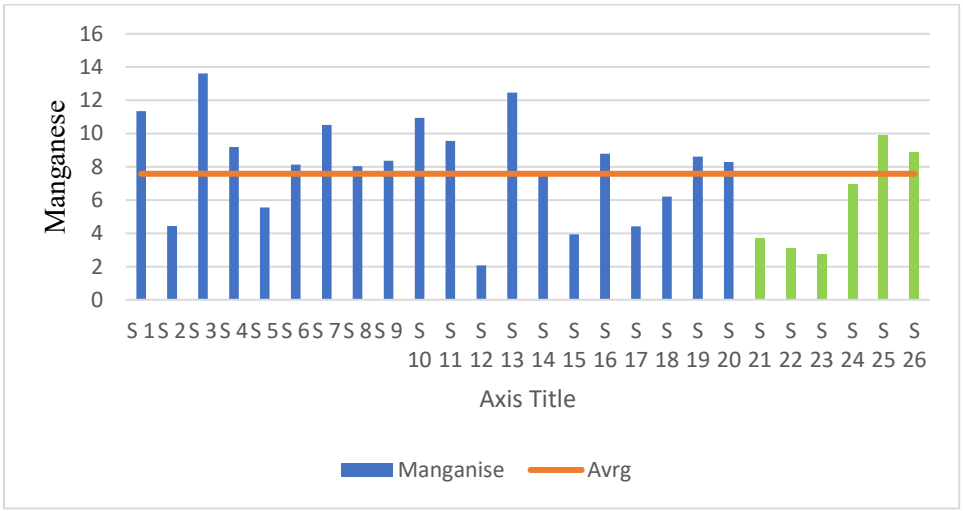


Fig 15: Manganese across the agricultural field

Manganese concentrations ranged from 2.06 µg at S12 to 13.62 µg at S3, with an overall mean of 7.58 µg. Gopalganj Sadar showed a higher mean concentration (8.10 µg) than Tungipara (5.88 µg). In Tungipara, manganese ranged from 2.74 µg at S23 to 9.92 µg at S25 (Fig. 15).

4. Discussion

The average soil pH recorded in the present study was 7.63, which is slightly higher than the recommended standard. This indicates that the agricultural soils of the study area are slightly alkaline. Such a pH condition is likely associated with the calcareous nature of the soils in Gopalganj, where calcium carbonate-rich alluvial deposits contribute to increased soil alkalinity. Comparable observations have been documented for calcareous soils of southwestern Bangladesh during the dry season [34]. The mean electrical conductivity (EC) was 4.621 dS m^{-1}, indicating that the soils were slightly saline according to the classification. The observed salinity may be related to the geographical setting of Gopalganj in the southwestern region of Bangladesh, where seasonal salt accumulation, limited rainfall during the dry season and the influence of slightly saline groundwater promote salt build-up in surface soils [35,36]. The average organic matter (OM) content of the soils was 1.648%, which is below the recommended level. Reduced organic matter is commonly associated with continuous cultivation and the limited incorporation of crop residues or organic manure into agricultural fields. Such depletion negatively affects soil fertility by lowering nutrient availability, reducing water-holding capacity and ultimately limiting crop productivity [37–39]. Similarly, the average total nitrogen (TN) content was lower than the recommended standard. This deficiency is likely the result of continuous cropping, inadequate application of nitrogen fertilizers and organic amendments and nitrogen losses through leaching and volatilization. Insufficient nitrogen availability can restrict plant growth and reduce agricultural productivity by limiting one of the essential nutrients required for crop development [38,40]. Available phosphorus (P) and potassium (K) concentrations were also below the recommended levels. The depletion of these nutrients is likely associated with continuous nutrient removal by crops, insufficient fertilizer replenishment and nutrient fixation within the soil. Deficiencies of phosphorus and potassium can impair root development, nutrient uptake, plant growth and ultimately reduce both crop yield and quality [41–43]. In contrast, the present study revealed that

calcium (Ca) and magnesium (Mg) concentrations exceeded the recommended levels. The elevated concentrations of these base cations are likely related to the calcareous parent materials of the region and the accumulation of soluble salts during the dry season, when reduced leaching and higher evapotranspiration favor their retention in the soil. Similar seasonal increases in Ca and Mg concentrations have also been observed in calcareous agricultural soils of Bangladesh during the dry season [44]. Copper (Cu) concentrations measured during the present study followed a pattern comparable to those reported for dry-season agricultural soils in previous investigations, suggesting that seasonal environmental conditions may influence the availability and accumulation of this micronutrient [45]. The average Zn concentration was 0.928 mg kg^{-1}, which falls within the recommended range, indicating adequate zinc availability for crop growth. Similar observations have been reported in previous studies [46]. The mean Boron concentration was 0.693 mg kg^{-1}, suggesting sufficient boron availability for normal plant growth. Comparable results have also been documented in earlier studies [47]. Manganese (Mn) concentrations showed moderate variation among the samples but generally remained within the acceptable range, indicating no major Mn deficiency or toxicity. Similar findings were reported previously [48,49].Iron (Fe) exhibited the highest concentration among the analyzed micronutrients. This may be attributed to the alluvial nature of the soils and dry-season conditions, which favor Fe accumulation. Similar trends have been observed in earlier studies conducted during the dry season [50–52]. Pearson correlation analysis showed significant positive relationships among OM–TN, OM–K, TN–K, EC–Zn, and Mg–Mn, indicating strong interactions among soil nutrients and physicochemical properties. These correlations suggesting that soil organic matter plays an important role in nutrient availability and overall soil fertility [53,54]. This study was based only on soil samples collected during the dry season. Soil properties can change from one season to another because of rainfall, soil moisture and farming practices. Therefore, the results may not reflect soil conditions throughout the year. Future studies should include samples from both the dry and wet seasons to provide a more complete understanding of soil quality in the study area.

5. Conclusion

Soil is a vital natural resource that supports agricultural productivity, ecosystem functioning, and food security. Assessing soil quality is essential for understanding soil fertility and developing sustainable nutrient management strategies. This study evaluated the physicochemical properties and nutrient status of agricultural soils in Gopalganj during the dry season. The results indicate that the soils are generally suitable for agricultural production, although several fertility limitations were identified. However, the comparative pattern was mixed rather than uniform: Gopalganj Sadar generally showed higher organic matter, total nitrogen, sulfur, boron, copper, iron and manganese, whereas Tungipara Upazila had higher mean pH, electrical conductivity, phosphorus, potassium, zinc, calcium and magnesium. The soils exhibited slightly alkaline pH and slight salinity, while organic matter, total nitrogen, available phosphorus and potassium were below the recommended levels, suggesting the need for improved soil fertility management. In contrast, calcium, magnesium, iron, zinc, boron, manganese and copper were present at adequate or relatively higher concentrations, reflecting the influence of the calcareous nature of the soils and dry-season conditions. Pearson correlation analysis further demonstrated significant relationships among several soil properties, indicating strong interactions that influence nutrient availability and overall soil quality. These findings highlight the importance of balanced fertilizer application, the incorporation of organic amendments, and regular soil monitoring to maintain soil fertility and sustain crop productivity. Overall, this study provides baseline information on the soil quality of agricultural lands in Gopalganj during the dry season and may serve as a useful reference for future soil management practices and sustainable agricultural planning in southwestern Bangladesh.

CRediT authorship contribution statement

Sanjida Binta Shafin Mishu: Principal investigator, research design, conceptualization, investigation, validation, formal analysis, and writing of the original draft. **Rakin Hasan:** Research design, conceptualization, statistical analysis and manuscript preparation. **Sharmin Akter:** Supervision, validation, overall monitoring of the research activities and assistance with draft preparation. **Md. Shamsur Rahman:** Validation, overall monitoring

of the research activities and assistance with draft preparation. **Md. Tanvir Anjum:** Field soil sampling, laboratory work and manuscript review. **Prottoy Nandi:** Field soil sampling, resources, statistical analysis and manuscript review. **Md Fahim Kashem Mazumder:** Field soil sampling, resources and manuscript review.

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Conflicts of Interest

The authors declare that no conflicts of interest exist.

Data availability

The data generated and analyzed during this study are available from the corresponding author upon reasonable request.

Ethics statement

Ethics approval and informed consent were not required because this study involved only environmental soil samples and included neither human participants nor animals.

Consent to Publish: Not Applicable.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

ChatGPT version 4.0 was used during manuscript preparation to support language editing, organization and compliance with journal formatting requirements. The authors subsequently reviewed and revised the content and accept full responsibility for the article.

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