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Spatial Distribution of the Fertility Parameters in Sericulture Soil: A Case Study of Dimapur District, Nagaland

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Abstract: Dimapur (Nagaland, India) is dominated by undifferentiated hillside slopes and alluvial plains. The Muga and Eri silk industries are important cultural and economic activities for the inhabitants of Dimapur. Profitable silk production requires adequate quality and quantity of healthy leaves and is highly dependent on the soil fertility of the region. Keeping this in view, the present study was carried out as a first attempt to prepare a geographic information system (GIS) map for Muga and Eri soils in Dimapur, Nagaland. A total 65 surface (0–15 cm) soil samples from Muga farms and 79 surface soil samples from Eri farms were collected and analysed for soil pH, organic carbon content and availability of macro- and micronutrients. Soils of both Muga and Eri farms were found to be extremely (<3.05) to moderately (5.09–6.84) acidic. Soils of Muga and Eri farms were found to have low to high organic carbon content (from 0.24 to 1.98%), low to high available nitrogen content (179.8–612.5 kg ha^{-1}) and medium available phosphorus content (2.68–154.6 kg ha^{-1}). The sulphur availability index was 0.26 and 11.81 for Muga and Eri host plant farms, respectively. The multi-macronutrient map revealed that 46.95% of the district's total geographical area (TGA) showed deficiencies in one or more macronutrients (high priority zone). Thus, these regions need urgent attention in terms of nutrient management decisions in order to reduce the declining trend of soil fertility and achieve sustainable sericulture production.

Keywords: acidic soil; chemical soil parameters; fertility map; GIS; multi-macronutrient map; sulphur availability index

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1. Introduction

In India, a diverse range of silk-secreting fauna is found, namely, mulberry, tropical tasar, oak tasar, Eri and Muga. India's North Eastern Region (NER), where all four varieties of silk are extensively produced, plays a key role in the manufacturing of silk [1]. The Sericulture industry is one of the most important sectors for the rural development and security of livelihood in the NER. Nagaland ranks second and third position for Eri and Muga silk production respectively after Assam and Meghalaya. It covers 7672 hectares of silkworm food plantation land growing mulberry, Eri, Muga and oak tasar and involves around 18,017 farmers from 754 villages [2]. The NER of India has flourished with a biodiversity of flora and fauna that is considered to be one of the richest in the world.

However, 77% of the NER area has a steep topography [3], which facilitates run-off and loss of high amounts of rainfall annually. This causes regular floods in the vast low-lying central plains, loss of topsoil in the hill slopes and sloping highlands, soil fertility loss, siltation of downstream water bodies and ecological imbalances in the region [4]. Due to unsustainable land use along the hills and other human activities, including deforestation, vegetation burning, urban growth, mining and quarrying, the severity of soil erosion has further worsened. The two major types of agricultural methods in the area are sedentary or plain agriculture and shifting cultivation (SC), often locally known as jhum. In the mountainous regions of South Assam, Arunachal Pradesh, Meghalaya, Mizoram, Nagaland, Manipur and Tripura, SC is mostly practised by tribal farmers [5]. Sedentary agriculture is usually practised on the plains of south-eastern Nagaland. Dimapur district of Naga land is rich in biodiversity of sericigenous flora and fauna. The climate and soil conditions prevailing in this region makes it suitable for commercial exploitation of all four varieties of silkworms, i.e., mulberry, Eri, Muga and tasar. The majority of Eri and Muga farmers produce silk using conventional methods. Sericulture, particularly of Eri and Muga silkworm in NER, involves the indigenous people, notably distinct tribal populations, despite being a traditional practice. Muga silk output has been much slower than Eri silk production, growing at a compounded rate of 6.01% from 2010–2011 to 2015–2016 [2]. The host plants available for Eri silkworms are Castor (*Ricinus communis*), Tapioca (*Manihot esculenta*), Kesseru (*Heteropanax fragrans* Seem) and Borpat (*Ailanthus grandis*). Muga silkworms are reared on Som (*Perseabombysina* Kost.) and Soalu (*Litsaeamonopetala*). It has been noted that farmers in the NER only apply fertiliser to host plants conducive to the production of Eri and Muga silk. Additionally, there is little potential for nutrient retention through leaf litter as the leaves are fed to silkworms, making it difficult to add organic matter and recycling nutrients in Eri- and Muga-producing soils [6]. As a result, it is crucial to maintain the application of an optimal fertiliser rate and proper fertility management for silk production [7]. Maintenance of soil organic carbon improves the nutritional value of the host plant while also improving the quality of the silk produced, which in turn affects the growth and economic characteristics of the silkworm. Although the addition of chemical fertilisers increases production, it has a negative influence on both cocoon quality and leaf output over time [8]. There have been several studies related to the fertility status of mulberry silk [6,8]. However, there have been relatively few studies on the fertility status of Eri and Muga silk in this fragile ecosystem. The current study focuses on the spatial distribution of the fertility parameters of Eri and Muga silk in sericulture farms.

2. Materials and Methods

2.1. Study Area

The Dimapur district of Nagaland is bounded by Assam state on the north and east, Kohima district on the east and Peren district in the south, with a total area of about 927 km^2 (Figure 1). It is the main commercially active district of Nagaland. A large part of this district is in the plains with an average elevation of 260 m above mean sea level, except for the Medziphema subdivision and a few villages of the Niuland subdivision, which are located in the foothills. The geographical extent of Dimapur district lies from 93°30′54″ to 94°01′16″ E longitude and from 25°38′53″ to 25°01′43″ N latitude. Loamy sand and clay loam soils are the two most prevalent soil types in the study region. Dimapur district falls under the humid subtropical agro-climatic zone (ACZ) and receives southwest monsoon rain during summer and northeast monsoon rain during winter.

The annual average rainfall is about 1504.7 mm, and the annual average maximum and minimum temperatures are 26 and 21 °C, respectively. The highest and lowest temperature recorded is 40 °C, and 10 °C with humidity up to 93% [9]. The entire region is notable for having a vast range of species of silkworms, such as mulberry, Eri, Muga and tasar. Eri and Muga sericulture has especially gained popularity in the region.

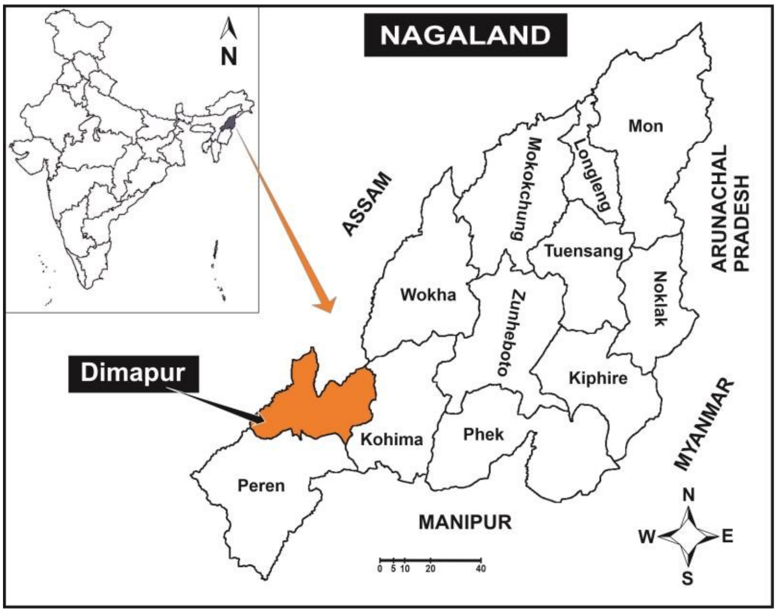


Figure 1. Location map of the study area showing Dimapur district of Nagaland.

2.2. Lithology of the Study Area

The district relies heavily on rain-fed irrigation for agriculture. The total cultivable area is 61,197 ha and 53,710 ha of it is classed as cultivable, with irrigated and rainfed areas making up 61.07 and 38.93%, respectively. Alluvial soil of recent origin and residual soils are the main landforms in the study region. The tertiary group of rocks are the main source of soil, and red clay soil is the most prevalent soil type in the area. The soils in Dimapur are taxonomically classified as Alfisols, Inceptisols, Ultisols and Entisols. Alfisols dominate the soils of the district area (50.5%), followed by Inceptisols (36.4%), Ultisols (10.2%) and Entisols (2.9%) [10]. The status of soil fertility in Dimapur district is medium with acidic pH [9].

2.3. Soil Sampling and Analysis

Systematic randomised sampling was carried out to collect georeferenced composite surface soil (0–15 cm) samples from 65 Muga farms and 79 Eri farms located in Dimapur district of Nagaland during 2018. The sampling point was cleaned, and all the debris on the soil was removed before sampling. A minimum of 10 samples from each field of a location were taken and combined to create a composite sample. Each composite sample was further divided into three parts, and every part was treated as a replica. The soil samples were processed, sieved using a 2 mm sieve and retained for examination after being air dried in the shade. A 0.2 mm sieve was used to filter soil samples in order to measure organic carbon.

Standard procedures were used to determine the soil's pH and electrical conductivity (EC) [11]. Soil organic carbon (OC) was analysed using the chromic acid oxidation method [12], available nitrogen (N) was measured using the alkaline potassium permanganate ($KMnO_4$) method [13], available phosphorus was measured using the method outlined in [14], available potash was measured using ammonium acetate [15], and available sulphur (S) was measured using the procedure laid down by Williams and Steinberges [16]. Among secondary macronutrients, only sulphur was studied, keeping in view the importance of this nutrient for plant growth and for rearing silkworm in order to harvest good cocoons [17]. Using 0.005 M DTPA extracts, the readily accessible metals zinc (Zn), copper (Cu), iron (Fe) and manganese (Mn) were extracted [18]. The sulphur availability index (SAI) was calculated using the formula outlined by Donahue et al. [19] as follows:

$$\text{SAI} = (0.4 \times \text{CaCl}_2 \text{ extractable SO}_4 \text{ in mg kg}^{-1} \text{ soil}) + \% \text{ organic matter} \quad (1)$$

According to the status of nutrient availability, the soil parameters examined for the Muga and Eri farms were divided into low, medium and high categories [20], as shown in Table 1.

Table 1. Categorisation for the studied soil parameters.

Parameters	Categories		
	Low	**Medium**	**High**
OC (%)	<0.4	0.4–0.75	>0.75
N (kg ha^{-1})	<280	280–560	>560
P (kg ha^{-1})	<34	34–68	>68
K (kg ha^{-1})	<110	110–280	>280
S (mg kg^{-1})	<10	10–20	>20
Zn (mg kg^{-1})	<0.6	0.6–1.2	>1.2
B (mg kg^{-1})	<0.5	0.5–1.0	>1.0
Fe (mg kg^{-1})	<4.5	4.5–9.0	>9.0
Cu (mg kg^{-1})	<0.2	0.2–0.4	>0.4

2.4. Nutrient Index

According to Motsara et al. [21], the nutrients index (NI) was calculated for surface soil samples as follows:

$$\text{Nutrient Index (NI)} = \frac{((N_l \times 1) + (N_m \times 2) + (N_h \times 3))}{N_t} \quad (2)$$

where

N_t = total number of samples analysed for a nutrient in given area;
N_l = number of samples falling in the low category of nutrient status;
N_m = number of samples falling in the medium category of nutrient status;
N_h = number of samples falling in the high category of nutrient status.

Additionally, the soil fertility level was classified as low (1.67), medium (1.67–2.33) or high (>2.33) on the basis of NI.

2.5. Data Interpretation in GIS Environment

Dimapur district level data from Eri and Muga farms were designed in MS Excel and generated as a point layer in ArcGIS 10.3 comprising all the nutrient availability information in the attribute table. The regularised spline interpolation technique was employed for the point data to create spatial distribution layers for soil pH; organic carbon; and available N, P, K, S, B, Fe, Mn, Zn and Cu in a GIS environment [1,8,22,23]. The layers were categorised with their threshold values. In order to estimate the area under each class, a reclassify operation in the ArcGIS Spatial Analyst tool was used. In the case of micronutrients, the layers were assigned new values in order to assess the spatial distribution of the micronutrients in the study area as these nutrients, except the available boron, are generally higher in the study region.

Using the layers created for the macronutrients (N, P and K), the priority zones for multinutrient management interventions were identified. Micronutrients were not taken into account because they had significant levels of composition in the research area. According to their nutritional content, the surfaces were first divided into three classes (low, medium and high). The medium and high categories received values of 2 and 3, respectively, while the low group was assigned a value of 1. The decision tree was used to create one layer after categorisation. By merging all of the macronutrient levels, a multi-macronutrient layer was created. All of the macronutrient surface layers were combined into one using the decision tree displayed in Table 2. The technique gave equal weight to each layer, and the value of each surface was assessed in a raster context.

Table 2. Decision tree for multi-macronutrient map (N, P and K).

IF	All the Layers Have Value of 1	High Priority Area
ELSE IF	Two layers have value of 1 and one layer has value of 2	High priority area
ELSE IF	Two layers have value of 2 and one layer has value of 1	High priority area
ELSE IF	All the layers have value of 2	Medium priority area
ELSE IF	One layer has value of 1, one layer has value of 2 and one layer has value of 3	Medium priority area
ELSE IF	Two layers have value of 2 and one layer has value of 3	Medium priority area
ELSE IF	All the layers have value of 3	Low priority area
ELSE IF	Two layers have value of 3 and one layer has value of 2	Low priority area

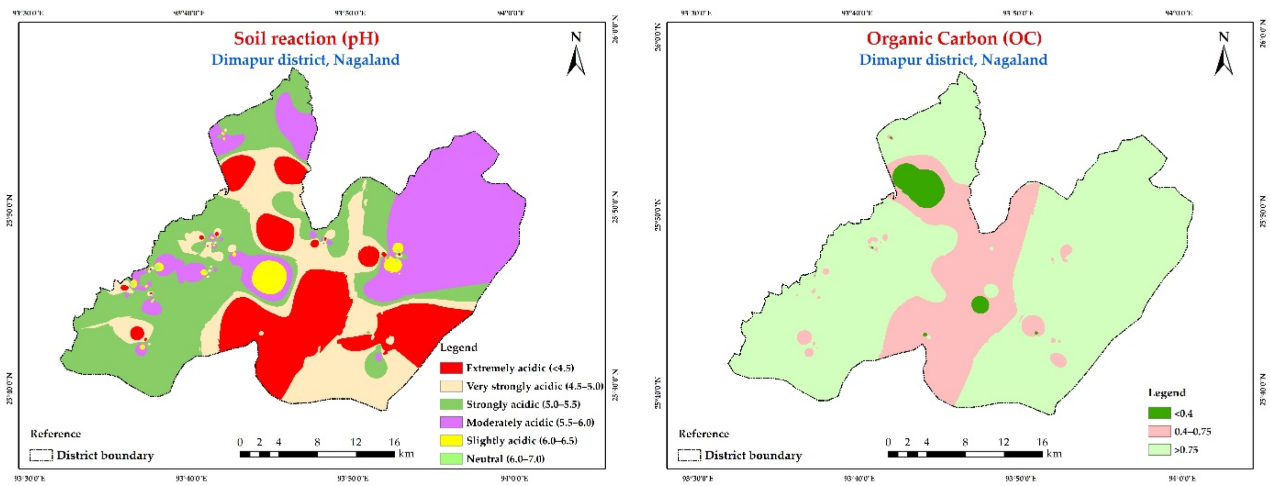
2.6. Statistical Analysis

The data analysis function of Excel 10.0 was used to carry out correlation analysis and descriptive statistical analysis. Combined information for surface soil samples from Dimapur district was employed to perform a correlation between important soil parameters and nutrient availability. Statistical measures were used to compare the average soil parameter values in the surface soil for Muga and Eri farms.

3. Results and Discussion

3.1. Soil pH and Organic Carbon Content

The measured physicochemical parameters of soils collected from Muga and Eri farms pertaining to Dimapur district of Nagaland are statistically summarised in Table 3. The pH values ranged from 3.06 to 6.84 with a mean value of 5.11, with the pH of 50% of soil samples found to be higher than 5.09. The map of pH showed variations from extremely acidic to neutral in the Sericulture farms in Dimapur district (Figure 2a). As the majority of plant nutrients are easily available in the pH range from 6 to 7, this range is often considered as the most optimal for plant development. However, the soil pH needed for Eri and Muga host plants was not in this range. Within the total geographical area (TGA), the maximum area, i.e., 31.62% (27389.28 ha), had a strongly acidic nature. As shown in Figure 2a, 19.91% of the area in Dimapur district of Nagaland, was found to be extremely acidic, 20.24% very strongly acidic, 26.42% moderately acidic, 1.75% slightly acidic and only 0.07% neutral.



(**a**) (**b**)

Figure 2. Spatial distribution of (**a**) soil pH and (**b**) organic carbon content in Dimapur district of Nagaland.

Table 3. Statistical outline of the measured soil parameters of sericulture farms (Muga and Eri farms) in Dimapur district, Nagaland.

Statistical Parameters	pH	EC	OC	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Available S (mg kg^{-1})	Available Zn (mg kg^{-1})	Available B (mg kg^{-1})	Available Fe (mg kg^{-1})	Available Mn (mg kg^{-1})	Available Cu (mg kg^{-1})	SAI	SNI
Min	3.06	0.01	0.24	179.80	2.68	6.24	0.00	0.43	0.46	10.20	4.50	2.71	0.26	1.66
Max	6.84	0.30	1.98	612.50	154.60	315.50	26.00	7.39	6.44	34.30	33.20	33.00	11.81	2.89
Mean	5.11	0.13	0.95	356.32	51.70	146.39	13.67	2.77	2.70	23.47	15.95	18.23	6.42	2.01
Median	5.09	0.13	0.91	347.15	42.50	138.35	13.50	2.45	2.57	23.10	15.70	17.80	6.36	1.86
SD	0.81	0.06	0.39	96.75	36.50	66.92	4.99	1.32	1.32	5.32	5.02	5.66	0.17	0.45
Kurtosis	−0.33	−0.25	−0.41	−0.38	−0.22	0.04	−0.14	0.62	−0.44	−0.69	0.37	−0.05	−0.16	0.92
Skewness	−0.10	0.35	0.40	0.44	0.75	0.51	0.24	0.69	0.36	−0.04	0.47	0.34	0.14	1.52
CV	0.13	0.01	0.06	15.94	6.01	11.02	0.82	0.22	0.22	0.88	0.83	0.93	0.34	0.32

The extremely acidic soil in humid subtropical environment is attributed to parent material and/or non-scientific chemical farming. The alkaline condition is generally attributed to waterlogged condition and low permeability of the soil [24].

The organic carbon observed in the studied region was high (>0.75%) in 65,580.89 ha, accounting for 75.71% of the TGA. The level of organic carbon was observed to be low (<0.4%) and moderate (0.4–0.75%) in 2.29 and 22.0% of the TGA of Dimapur district, Nagaland, respectively (Figure 2b). Two of the most dynamic features that are particularly responsive to crop and soil management are soil structure and soil organic matter (SOM) [25]. It is difficult to maintain amounts of organic carbon that might have a long-term beneficial effect due to the intensely shifting weather patterns, notably high temperatures and irregular or poor rainfall patterns [26]. While carbon is essential for soil fertility, productivity and quality, its reduction impacts the sustainability of agricultural production ecosystems and is crucial for sustaining the overall quality of the environment [27].

3.2. Electrical Conductivity

The high yearly rainfall in Dimapur valley and subsequent poor base saturation of the soil may be the reason for the acidic response of the soils. The EC uses soil texture, soil thickness, organic matter, cation-exchange capacity, salt concentration, nutrients (such as nitrate), water-holding capacity and drainage parameters as substitute measurements. Estimated electrical conductivity (EC) values in the soils of Muga farms in Dimapur district varied from 0.01 to 0.28 dS m^{-1}, with an average value of 0.13 dS m^{-1}, indicating an ion concentration and/or a content of dissolved particles (Table 3).

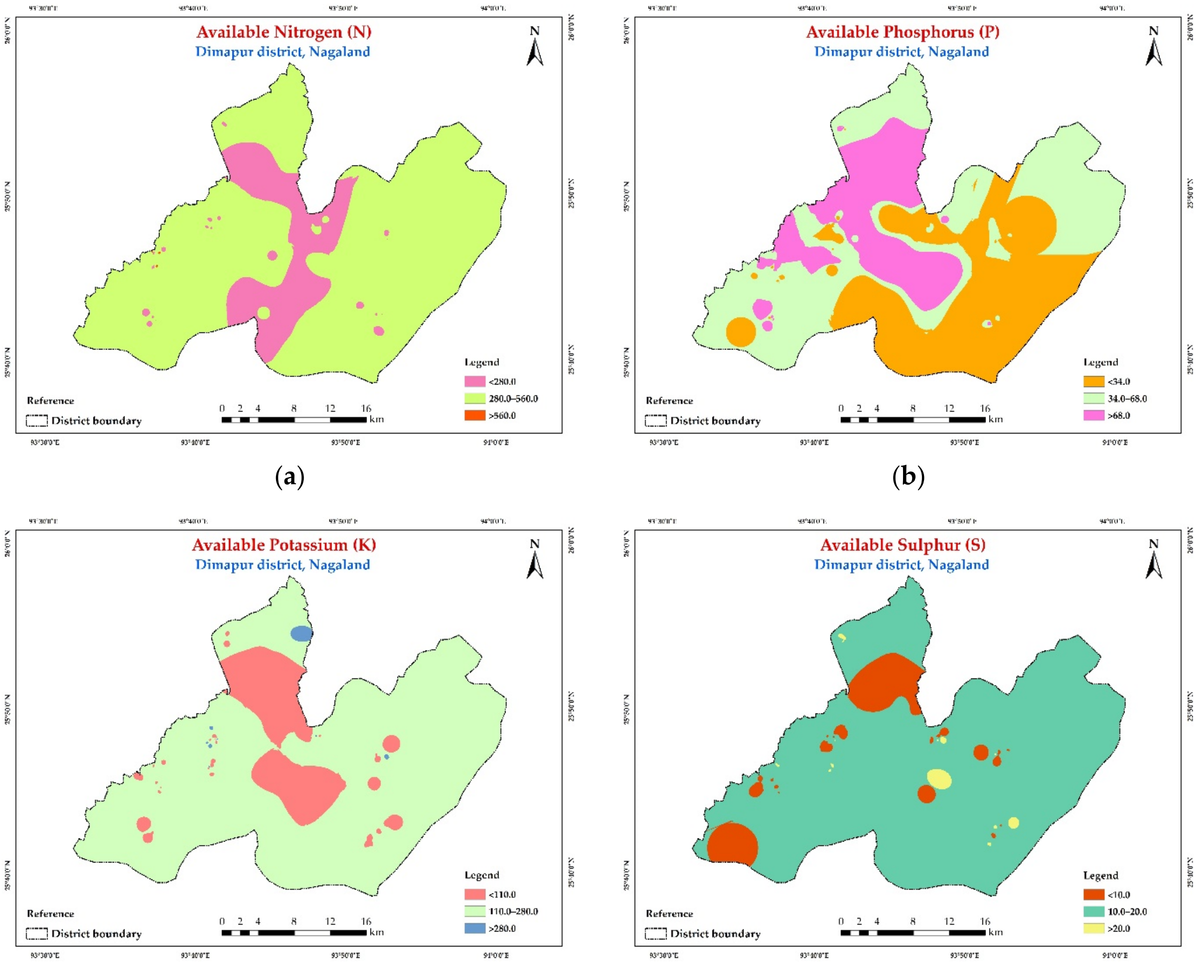
The spatial distribution of EC in Eri farms showed that the variation in soil EC values ranged from 0.03 to 1.98 dS m^{-1} (non saline soil), with an average value of 0.14 dS m^{-1}. EC values less than 2.0 dS m^{-1} indicate that the soils are free from salinity in all Eri farms in Dimapur district of Nagaland.

3.3. Macronutrients

Available macronutrients in the soil of sericulture farms (Muga and Eri farms) in Dimapur district are shown in spatial distribution maps in Figure 3a–d. For both the farm soils, spatial distribution maps were prepared for available N, P, K and S. The estimated available N value ranged from 179.80 to 612.50 (mean 356.32) kg ha^{-1}, available P value ranged from 2.68 to 154.60 (mean 51.70) kg ha^{-1}, available K value ranged from 6.24 to 315.50 (mean 146.39) kg ha^{-1} and available S value ranged from 0.05 to 26.00 (mean 13.67) mg kg^{-1} in the soils in Dimapur district of Nagaland.

A moderate level of nitrogen was observed in the studied region. The level of nitrogen was observed to be low in 16.55%, moderate in 83.44% and high in 0.02% of the TGA of Dimapur district of Nagaland. The available phosphorus in the studied region was moderate in 36781.02 ha area, accounting for 42.46% of the TGA. The level of available phosphorus was observed to be low in 36.44 % and high in 21.10% of the TGA. pH values below 5.5 (the average pH of Dimapur soil was found to be acidic in nature, i.e., pH of 4.84) limit P availability to plants due to fixation by aluminium, iron or calcium and are frequently associated with soil parent materials. Soils with pH values between 6 and 7.5 are ideal for P availability [28]. A moderate level of available potassium was observed in this study region. The level of available potassium was observed to be moderate in a majority of the area of the district (84.24% of the TGA), followed by low (15.27%) and high (0.49%) content of phosphorus in Dimapur district of Nagaland.

The available sulphur observed in the studied region was moderate in 78,396.77 ha, accounting for 90.5% of the TGA. The level of available sulphur was observed to be low in 8.64% and high in 0.86% of the TGA. Amendment of soil with biosolids, manures and agri-waste compost generally increase the available sulphur [29].



(**a**) (**b**)

(**c**) (**d**)

Figure 3. Spatial distribution of available (**a**) nitrogen (N), (**b**) phosphorus (P), (**c**) potassium (K) and (**d**) sulphur (S) in Dimapur district of Nagaland.

3.4. Micronutrients

Available micronutrients in the soils of Muga and Eri farms in Dimapur are shown in Figure 4a–e and Table 3. Extractable (0.005 M DTPA) B, Zn, Cu, Mn and Fe varied from 0.46 to 6.44 (2.70), 0.43 to 7.39 (average 2.77), 2.71 to 33.00 (average 18.33), 4.50 to 33.20 (average 15.95) and 10.20 to 34.30 (average 23.47) mg kg^{-1}, respectively, in the soils of Muga and Eri farms.

Results of available micronutrients revealed that sericulture farms soil are sufficient in available Fe, B, Zn, Mn and Cu. A moderate level of available iron was observed in the studied region. The level of available iron was observed to be below 15 mg kg^{-1} in only 0.83% of TGA, whereas the maximum area was in the range of 15–25 mg kg^{-1} of iron (70.43% of TGA), followed by >25 mg kg^{-1} (25.47% of TGA) in Dimapur district of Nagaland. A high level of zinc was observed in the studied region. The level of available zinc was observed to be below 1.5 mg kg^{-1} for 3817.95 ha of land (4.41%), under 1.5–3.0 mg kg^{-1} for 60,366.26 ha (69.69%) and under >3.0 mg kg^{-1} for 22,441.9 ha (25.91%). The level of available copper was higher than the threshold level in the studied region. Higher Zn and Cu level may be due to high organic content [30].

Available copper under <10 mg kg^{-1} was observed for 1720.65 ha of land (1.99%) and under >20.0 mg kg^{-1} for 34,312.78 ha (39.61%). The maximum proportion of the study area, accounting for 50592.68 ha (58.40%), had 10–20 mg kg^{-1} copper. The available boron observed in the studied region was high in 85378.86 ha of land, accounting for 98.56% of the TGA. The level of boron was observed to be low and moderate in 0.14 and 1.30% of the TGA, respectively. The level of manganese was high in the studied region.

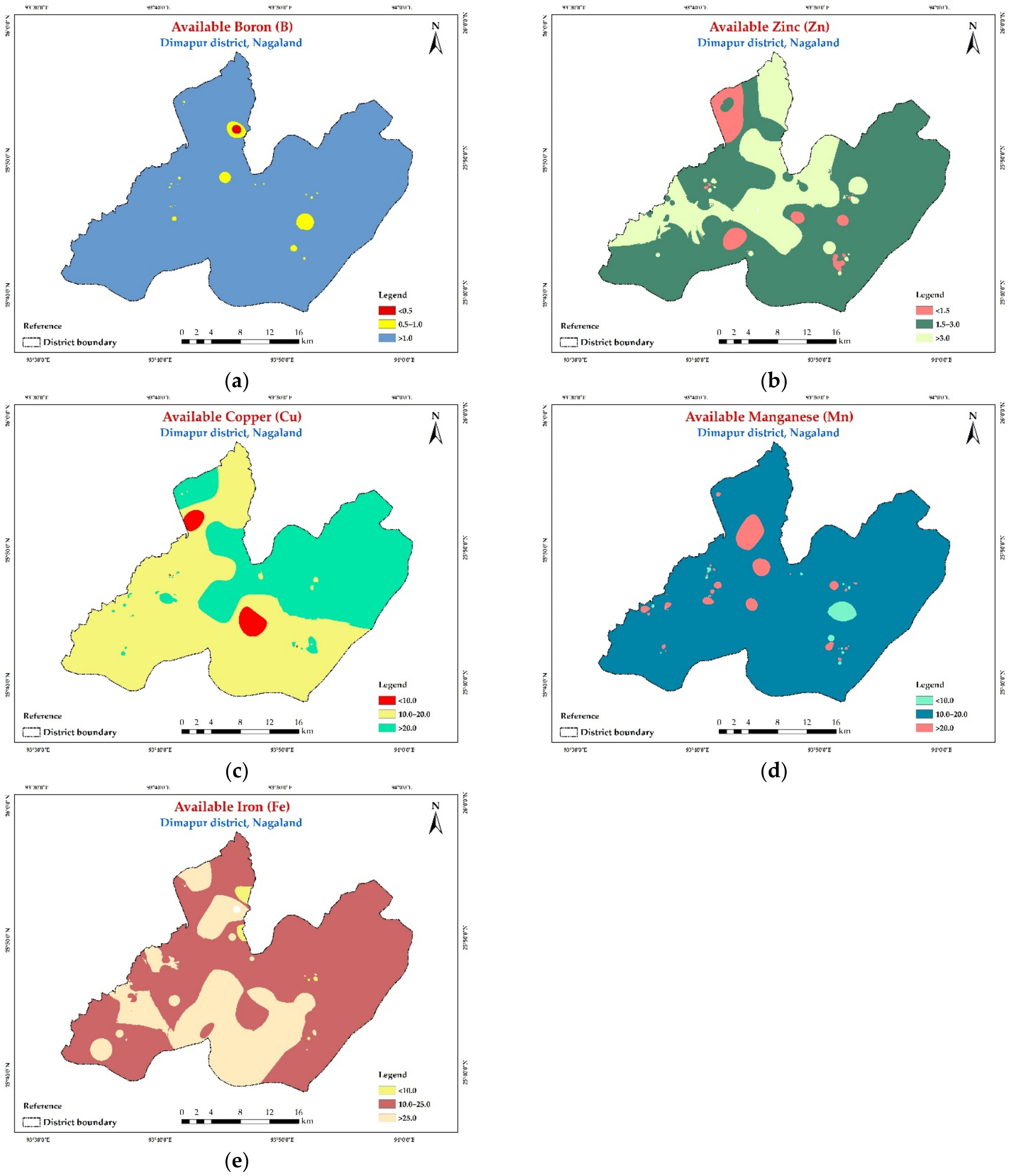


Figure 4. Spatial distribution of available (**a**) boron, (**b**) zinc, (**c**) copper, (**d**) manganese and (**e**) iron in Dimapur district of Nagaland.

The level of available manganese was observed to be <10 and >20 mg kg^{-1} in 1.16 and 3.20% of the TGA. A majority of the area, covering 82844.87 ha (95.63%) of Dimapur district, had 10–20 mg kg^{-1} manganese. However, Bandyopadhyay et al. [6] observed that 25.6% of the total surveyed area of Dimapur district was Zn deficient. This might be due to variation in the sampling locations as only vanya sericulture soil was sampled in the present investigation.

3.5. Multinutrient Deficiencies

By taking the macronutrients into account, a multinutrient map was created. These were not taken into account in the multinutrient map as most of the research region had high or medium levels of organic carbon and micronutrient content. Approximately 46.95% of the district's TGA showed deficiencies in one or more macronutrients in the multi-macronutrient map (N, P and K) (Figure 5). Due to intense cropping or leaching impacting the ability of soils to deliver nutrients, this region needs urgent attention in terms of nutrient management decisions [31]. While the fertility situation in the medium priority zone, which made up 53.01% of the TGA, was better than in the high priority regions, it still requires sufficient attention to halt the trend of declining soil fertility for agricultural production through wise resource management. Regarding the amount of available N, P and K, the remaining area of the district fell into the high nutrient status group. Only 0.04% of the area was a low priority zone, and it did not result in significantly increased crop yield or nutrient absorption [32].

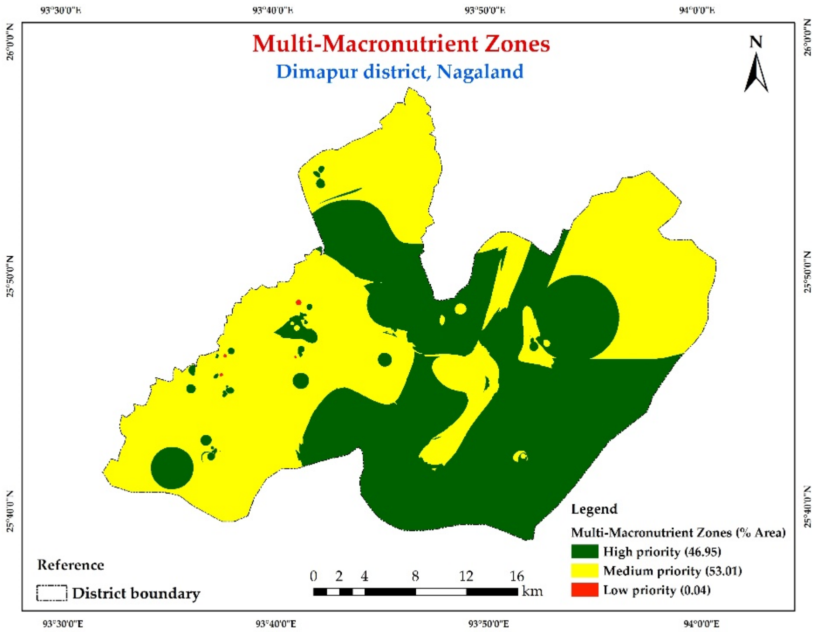


Figure 5. Multi-macronutrient map of Dimapur district of Nagaland.

3.6. Correlation Analysis of Available Nutrients in Muga and Eri Farms in Dimapur of Nagaland

Statistical correlation matrix of various nutrients and physicochemical parameters of the soils of Muga and Eri farms in Dimapur district are shown in Table 4. The pH showed significant positive correlation with phosphorus ($p < 0.05$). Organic carbon in the soil showed significant positive correlation with available nitrogen and SAI ($p < 0.05$) and available boron and manganese ($p < 0.01$).

The electrical conductivity showed positive correlation with OC, available nitrogen and SAI ($p < 0.05$) and with available potassium and available sulphur ($p < 0.01$). Available nitrogen was significantly positively correlated with available manganese and SAI ($p < 0.05$) and with potassium and boron ($p < 0.01$). Available sulphur was positively correlated with SAI ($p < 0.05$). Available zinc showed positive correlation with available boron ($p < 0.05$) as well as with available manganese and copper ($p < 0.01$) in Muga and Eri farms.

Table 4. Interelemental matrix of available nutrients in Muga and Eri sericulture farms in Dimapur district of Nagaland (n = 144).

	pH	EC	OC	N	P	K	S	Zn	B	Fe	Mn	Cu	SAI
pH	1												
EC	0.15	1											
OC	0.13	0.51 **	1										
N	0.13	0.51 **	0.98 **	1									
P	0.17 *	−0.14	0.07	0.08	1								
K	−0.00	0.19 *	0.14	0.16 *	−0.16	1							
S	0.06	0.17 *	0.15	0.14	−0.02	0.03	1						
Zn	0.15	0.03	0.14	0.16	0.21 *	−0.05	−0.08	1					
B	0.08	−0.06	0.19 *	0.19 *	0.31 **	−0.07	0.03	0.37 **	1				
Fe	−0.02	−0.03	−0.10	−0.11	−0.05	−0.13	−0.06	−0.06	0.06	1			
Mn	−0.03	0.10	0.21 *	0.23 **	0.12	−0.09	−0.016	0.19 *	0.17 *	−0.09	1		
Cu	0.07	−0.08	−0.03	−0.06	−0.03	−0.06	0.03	0.19 *	−0.13	−0.12	0.09	1	
SAI	0.08	0.26 **	0.33 **	0.32 **	−0.01	0.05	0.98 **	−0.05	0.06	−0.08	0.03	0.02	1

* Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

3.7. Nutrient Index and Sulphur Availability Index

The nutrient index (NI) value was calculated to assess the overall nutritional status of macro- and micronutrients of Muga and Eri farms in the present study area. The organic carbon, nitrogen, boron, copper, zinc and iron were high in soils, which indicated the fertile nature of soils based on the soil analysis of the Muga and Eri cultivated soils. It may be attributed to low surface run-off due to winter and surface enrichment with Muga litter due to active rearing. S, N, P and K indicated medium soil fertility status; however, soil sulphur and its fractions can be an effective measure for sulphur-deficient areas for better management practices in the future [33].

Donahue et al. [19] proposed the sulphur availability index (SAI) on the basis of con-tent of organic matter in the soil along with sulphate sulphur (SO_4^{2-} S) content. On the basis of SAI values, the soils were divided into three groups according to their level of sulphur availability: low (<6.0), medium (6.0 to 9.0), and high (>9.0). According to SAI values, values, the soil of 45.83% of the study area were categorised as deficient, 40.28% farms as medium category and only 13.89% of soils as high. Correlation coefficients of some important soil parameters with 0.15% $CaCl_2$ extractable S (i.e., available S) and SAI are presented in Table 3. The SAI showed positive correlation with EC, OC, available nitrogen and available sulphur content in the soils of sericulture farms in Dimapur district (Table 4). The creation of proteins, lipids, vitamins and flavouring chemicals in plants is well recognised for using sulphur. It is a component of three amino acids that make up protein, namely, methionine (21% S), cysteine (26% S) and cysteine (27% S) [34]. These amino acids comprise almost 90% of the plant sulphur [35]. The availability of sulphur is influenced by a number of soil conditions, and as a result, the status of various forms of sulphur in soils varies greatly with the soil type [36].

3.8. Contribution of Muga and Eri Silk Production to Soil Conservation

Massive deforestation and growing population are common in Nagaland, and about 20,000 ha of natural forest is felled every year in this state for jhum cultivation as well as for growing vegetables and other crops. According to the Indian Space Research Organization's Space Applications Centre (SAC) atlas, Nagaland is one of five Indian states where soil degradation is occurring at an alarming rate. Muga and Eri host plants are considered as multipurpose trees, which also play an important role in soil remediation. The host plants of Muga and Eri sericulture are trees that are transplanted at 3 × 3 m spacings and can be used for more than 25 years for silkworm rearing and cocoon production. Apart from cocoon production, sericulture practices produce silkworm litter, leaf jumble and root exudates, which may improve soil physical parameters and, above all, SOC [37]. Singh et al. [9] revealed that shifting to cultivation practices, mainly jhum cultivation in Dimapur district of Nagaland, has a negative impact on the environment. Nowadays, due to the consequences of development, effective resource conservation techniques, mainly zero tillage, minimum tillage, hedge crops, mulching and cover crops, need more attention to build up organic matter and therefore enhance soil health [9,37–39]. In this regard, Muga and Eri silk production is completely allied with these best practices. Thus, Muga and Eri sericulture will contribute to soil conservation and therefore to sustainable soil management in Dimapur district of Nagaland.

4. Conclusions

The results of this study, which highlight the significance of soil parameters of sericulture farms growing Muga and Eri host plants in Dimapur district of Nagaland, suggest that growing these host plants as crops may be beneficial for soil health and the sericulture farming community, along with corrective actions for nutrient deficiencies. Therefore, there is an urgent need to develop appropriate soil correction measures aimed at enhancing the soil pH. Judicious application of fertilisers, along with organic crop inputs, especially K, S and Zn, is needed in soils. This study allowed us to understand the spatial variability of soil fertility parameters in the sericulture zone in Dimapur district of Nagaland. Appropriate corrective measures will lead to enhanced quality of Muga and Eri cocoon production in Dimapur district of Nagaland. The long-term (perennial) existence of these silk host plants, except castor, also contributes to the soil conservation of the studied region. The cultural and commercial importance of silk will also contribute to reducing deforestation, jhum cultivation and soil degradation. Thus, silk production can motivate local inhabitants to conserve the soil in direct and/or indirect ways.

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References

1. Kumar, A.; Vinodakumar, S.N.; Tamuly, B.; Krishna, G.; Rai, A.; Shabnam, A.A.; Jigyasu, D.K.; Luikham, R.; Hazarika, U.; Ahmed, S.A.; et al. Assessment of Nutritional Status of the Acidic Soils of Manipur Vanya Sericulture: Levels and Spatial Distributions. *J. Soil Salin. Water Qual.* **2021**, *13*, 204–213.
2. Anonymous. *Seri-States of India 2019—A Profile*; Central Silk Board Ministry of Textiles—Government of India BTM Layout: Bengaluru, India, 2019; p. 180.
3. Choudhury, B.U.; Fiyaz, A.R.; Mohapatra, K.P.; Ngachan, S. Impact of land uses, agro-physical variables and altitudinal gradient of soil organic carbon concentration of north-eastern Himalayan region of India. *Land Degrad. Dev.* **2016**, *27*, 1163–1174. [CrossRef]
4. Choudhury, B.U.; Ansari, M.A.; Chakraborty, M.; Meetei, T.T. Effect of land-use change along altitudinal gradients on soil micronutrients in the mountain ecosystem of Indian (Eastern) Himalaya. *Sci. Rep.* **2021**, *11*, 14279. [CrossRef] [PubMed]
5. Seitinthang, L.H. Cropping pattern of north east India: An appraisal. *Am. Res. Thoughts* **2014**, *1*, 488–498.
6. Bandyopadhyay, B.; Ray, P.; Padua, S.; Ramachandran, S.; Jena, R.K.; Roy, D.P.; Dutta, D.P.; Ray, S.K. Priority Zoning of Available Micronutrients in the Soils of Agroecological Sub-regions of North-East India Using Geo-spatial Techniques. *Agric. Res.* **2018**, *7*, 200–214. [CrossRef]

7. Sarmah, M.C.; Neog, K.; Das, A.; Phukan, J.C.D. Impact of soil fertility and leaf nutrients status on cocoon production of Muga silkworm, Antheraeaassamensis (Helfer) in potential muga growing areas of Assam, India. *Int. J. Curr. Microbiol. App. Sci.* **2013**, *2*, 25–38.
8. Devi, S.A.; Sakthivel, N. Impact of Repeated Applications of Chemical Fertilizers in Mulberry Cropping System on Soil Health, Leaf Production and Rearing Parameters of Silkworm, *Bombyx mori* L. *Int. J. Plant Soil Sci.* **2018**, *23*, 1–11. [CrossRef]
9. Singh, S.K.; Kumar, K.S.; Aier, B.; Kanduri, V.P.; Ahirwar, S. Plant community characteristics and soil status in different land use systemsin Dimapur district, Nagaland, India. *Leoene Pract. Badaw. For. Res. Pap.* **2012**, *73*, 305–312.
10. Government of Nagaland. Nagaland State Action Plan on Climate Change: Achieving a Low Carbon Development Trajectory, Version 2012.2; 2012; p. 187. Available online: https://moef.gov.in/wp-content/uploads/2017/09/Nagaland.pdf (accessed on 16 April 2023).
11. Jackson, M.L. *Soil Chemical Analysis*; Prentice Hall of Indian (Pvt.) Limited: New Delhi, India, 1973.
12. Walkley, A.; Black, I.A. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sci.* **1934**, *37*, 29–38. [CrossRef]
13. Subbiah, B.V.; Asija, G.L. A rapid procedure for the determination of available nitrogen in soils. *Curr. Sci.* **1956**, *25*, 259–260.
14. Bray, H.R.; Kurtz, L.T. Determination of total organic and available forms of phosphorus in soil. *Soil Sci.* **1945**, *59*, 39–45. [CrossRef]
15. Chesmin, L.; Yien, C.H. Turbidometric determination of available sulphate. *Soil Sci. Soc. Am. Proc.* **1951**, *15*, 149–151. [CrossRef]
16. Williams, C.H.; Steinbergs, A. Soil sulphur fractions as chemical indices of available sulphur in some Australian soils. *Aust. J. Agric. Res.* **1959**, *10*, 340–352. [CrossRef]
17. Zhao, Y.W.; Cao, Z.H.; Hu, Z.Y.; Xu, C.K. Status of Sulfur in Mulberry Leaves–Silkworm Cocoon System of Typical Mulberry Gardens in the Lower to Middle Reaches of the Yangtse River. *J. Plant Nutr.* **2005**, *28*, 1801–1810. [CrossRef]
18. Lindsay, W.L.; Norvell, W.A. Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Sci. Soc. Am. J.* **1978**, *42*, 421–428. [CrossRef]
19. Donahue, R.L.; Miller, R.W.; Shiklune, J.C. *Soils—An Introduction to Soil and Plant Growth*; University of Wisconsin Madison: Madison, WI, USA, 1977.
20. Takkar, P.N. Soil fertility, fertilizer and integrated nutrient use. In *Hand Book of Agriculture*, 6th revised ed.; Rai, M., Agarwal, D.K., Sharma, R.P., Verma, S.A., Kumar, A.T., Prahan, S., Eds.; Indian Council of Agriculture: New Delhi, India, 2009; p. 516.
21. Motsara, M.R.; Singh, J.; Verma, K.P.S. Nutrients indexing system in soil fertility evaluation and fertilizer use in India. *Fertil. News* **1982**, *27*, 92–99.
22. Jena, R.K.; Duraisami, V.P.; Sivasamy, R.; Shanmugasundaram, R.; Krishnan, R.; Padua, S.; Bandyopadhyay, S.; Ramachandran, S.; Ray, P.; Roy, D.P.; et al. Spatial variability of soil fertility parameters in Jirang Block of Ri-Bhoi District, Meghalaya. *Clay Res.* **2015**, *34*, 35–45.
23. Padua, S.; Chattopadhyay, T.; Bandyopadhyay, S.; Ramachandran, S.; Jena, R.K.; Ray, P.; Roy, D.P.; Baruah, U.; Sah, K.D.; Singh, S.K.; et al. A simplified soil nutrient information system: Study from the North East Region of India. *Curr. Sci.* **2018**, *114*, 1241–1249. [CrossRef]
24. Bandyopadhyay, S.; Baruah, U.; Das, T.H.; Dutta, D.; Reza, S.K.; Padua, S.; Sarkar, D.; Sah, K.D.; Singh, S.K. *Assessment and Mapping of Some Important Soil Parameters Including Macro and Micronutrients for the State of Nagaland towards Optimum Utilization of Land Resources for Integrated and Sustainable Development*; NBSS Publication: Nagpur, India, 2014; p. 287.
25. Kumar, R.; Rawat, K.S.; Singh, J.; Singh, A.; Rai, A. Soil aggregation dynamics and carbon sequestration. *J. Appl. Nat. Sci.* **2013**, *5*, 250–267. [CrossRef]
26. GirijaVeni, V.; Srinivasarao, C.H.; Sammi, R.K.; Sharma, K.L.; Ashish, R. Soil Health and Climate Change. In *Climate Change and Soil Interactions*; Prasad, M.N.V., Pietrzykowski, M., Eds.; Elsevier: Amsterdam, The Netherlands, 2020; pp. 751–767. [CrossRef]
27. Baruah, R.; Medh, I.B.K.; Patgiri, D.K.; Bhattacharyya, D.; Deka, C.R. Soil organic carbon stock in agricultural land of Jorhat district of Assam. *J. Soil Water Conserv.* **2017**, *16*, 25–31. [CrossRef]
28. Thomas, J.L. Soil pH and the Availability of Plant Nutrients. *IPNI Plant Nutr. Today* **2010**, *2*, 1.
29. Miller, F.C. Minimizing odor generation. In *Science and Engineering of Composting: Design, Environmental, Microbiological, and Utilization Aspects*; Hoitink, H.A.J., Keener, H.M., Eds.; Renaissance Publications: Worthington, OH, USA, 1993; pp. 219–241.
30. Venkatesh, M.S.; Majumdar, B.; Kumar, K. Status of Micronutrient Cations under Various Land Use Systems of Meghalaya. *J. Indian Soc. Soil Sci.* **2003**, *51*, 60–64.
31. Havlin, J.L.; Beaton, J.D.; Tisdale, S.L.; Nelson, W.L. *Soil Fertility and Fertilizers*, 6th ed.; Prentice Hall: Upper Saddle River, NJ, USA, 1999; p. 499.
32. Smaling, E.M.A.; Braun, A.R. Soil fertility research in Sub-Saharan Africa: New dimensions, new challenges. *Commun. Soil Sci. Plant Anal.* **1996**, *27*, 365–386. [CrossRef]
33. Rai, A.; Singh, S. Available nutrients status in black soils of Varanasi district of eastern part of Uttar Pradesh. *J. Appl. Nat. Sci.* **2018**, *10*, 1238–1242. [CrossRef]
34. Sakal, R.; Singh, A.P. Sulphur in Balanced Fertilisation in Eastern India. In Proceedings of the Suphur Institute (TSI)/Fertiliser Association of India (FAI)/International Fertiliser Industry Association (IFA) Symp on Sulphur in Balanced Fertilisation, New Delhi, India, 13–14 February 1997; Volume SI-2, pp. 1–6.
35. Tandon, H.L.S.; Messick, D.L. *Practical Sulphur Guide*; The Sulphur Institute: Washington, DC, USA, 2002; p. 20.

36. Trivedi, S.K.; Bansal, K.N.; Tomar, R.A.S.; Verma, R.S. Vertical distribution of forms of sulphurinsome profiles of Morena and Bhind district of Madhya Pradesh. *J. Indian Soc. Soil Sci.* **2000**, *48*, 238–241.
37. Saha, R.; Chaudhary, R.S.; Somasundaram, J. Soil Health Management under Hill Agroecosystem of North East India. *Appl. Environ. Soil Sci.* **2012**, *2012*, 696174. [CrossRef]
38. Temjen, W.; Singh, M.R.; Ajungla, T. Effect of shifting cultivation and fallow on soil quality index in Mokokchung district, Nagaland, India. *Ecol. Process.* **2022**, *11*, 42. [CrossRef]
39. Ray, P.; Chattaraj, S.; Bandyopadhyay, S.; Jena, R.K.; Singh, S.K.; Ray, S.K. Shifting cultivation, soil degradation, and agricultural land-use planning in the northeastern hill region of India using geo-spatial techniques. *Land Degrad. Dev.* **2021**, *32*, 3870–3892. [CrossRef]