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Soil Physical Properties Enhancement via Native Tree Species in Northern Ethiopia

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Abstract

Dozens of chemical fertilizer is produced in factories to maintain and reclaim soil fertility, but the reliance on artificial fertilizer alone is not advisable due to environmental pollution. Thus, indigenous plant species can maintain soil fertility without any extra cost. The aim of this study was to examine the effect of indigenous tree species on soil physical properties. Three dominant indigenous trees species (*Croton macrostachuys, Cordia Africana and Albizia gummifera*) were considered. Soil samples were taken from different sampling points under crown of these tree species (mid of crown and edge of crown). One sampling point is included by far 30m from the selected tree as a control group. Soil sample was taken by using core sampler. Soil physical properties such as texture, structure, porosity, bulk density and moisture content were analyzed. Bulk density was determined as 0.73g/cm^3, 0.75g/cm^3 and 0.8g/cm^3 for *Albizzia gummifera, Croton macrostachuys* and *Cordia Africana* respectively. Bulk density was very small under crown of all trees as influenced by the amount of organic matter falling from trees leaf. The texture under crown of all tree species (silty loam, loam and loamy sand) is quite better for agriculture purpose than control point. Soil color under crown is in the range of brown to black color, which indicates high fertility level. Soil porosity was very high under the crown of all tree species as compared to the control site. It is determined as 72.5%, 71.6%, and 69.7% for *Albizzia gummifera, Croton macrostachuys* and *Cordia Africana* respectively. Soil consistence, porosity and moisture content were better under crown of the trees than control group. Soil properties under the crown of indigenous tree species were better than bare land soils. Therefore, indigenous trees are promising option to maintain soil fertility level and land owners ought to be aware of this miracle.

Key words: *Albizia Gummifera, Cordia Africana, Croton Macrostachuys*, Indigenous Tree Species, Soil Fertility, Soil Physical Properties

Introduction

Synthetic fertilizer applications like Urea and Diammonium Phosphate (DAP) is obviously an important strategy for alleviating nutrient depletion. However, fertilizers alone cannot guarantee sustainable long-term productivity due to some reasons like, financial stress and sustainability issues. Thus, inputs of organic materials are needed to maintain soil organic matter levels. In this respect, the utilization of tree and shrub species for soil fertility improvement is a viable alternative to enhance agricultural productivity [1]. Integration of soil fertility improving trees/shrubs in farming systems remains a plausible option to sustaining soil productivity under declining fertility [2]. Because, nutrient release from the tree/shrub litter fall is believed to be the major factor for transferring of nutrients and energy from living biological components to the soil.

Transfer of nutrients and energy from living biological components to the soil is closely related to litter fall and is the starting point for nutrient cycling. Litter fall constitutes a major portion of nutrient cycling between plants and soils, thus reflecting constraints on internal fluxes of Carbon, Nitrogen and Phosphorus at the ecosystem scale [1], [3], and it influences soil physical properties too.

Decomposition of litter fall which produces organic matter is an important factor for soil formation as well as nutrient cycling processes [4]. Decomposition is primarily influenced by the environmental conditions in which decay takes place, the chemical quality of leaf litter, and the nature and abundance of decomposing organisms present [5]. Previous studies have shown that there exist considerable variations in leaf litter decomposition rates among different tree species [2]. The process of litter decomposition plays a vital role in regulating ecosystem carbon storage and nutrient cycling [6]. The nutrient dynamics of litter related to the decomposition rates directly determine the nutrient status of an ecosystem, thereby exerting crucial control on vegetation productivity [7].

Under the traditional agro forestry system in Ethiopia, tree species such as *Cordia Africana* and *Croton macrostachyus* are commonly grown in association with crops. They have significant contribution in traditional agro forestry system in improving physical and chemical properties of soil and crop yield [8]. Tree-soil interactions and trees influence on soil fertility is complex; because trees affect all soil physical, chemical and biological properties. Soil physical properties strongly influence the fertility status and productivity of soils through their parameters such as structure, texture, bulk density, moisture holding characteristics and soil aeration. These physical properties of soils vary from place to place and even within a micro level as a result of natural and anthropogenic activities and existence of tree species. Land use systems and management influence several physical properties of soils. For instance, many soil physical properties change with cultivation, intensity of cultivation, the instruments used and the nature of the land under cultivation [9].

However in Ethiopia, tree species that are used for soil fertility improvement in the high altitude areas of Northern Ethiopia have not been given much research attention and are still lacking. Homesteads in the high altitude (> 2900 m.a.s.l) areas of central Ethiopia have a better tree and shrub species composition than farmlands [10]. The proportion and area coverage of indigenous species around the homesteads is also considerable as compared to exotic species. The increased proportion of indigenous species over the exotics is due to their adaptability to the local environmental conditions, resistance to pests and diseases, availability as sources of planting material and familiarity to the local farmers. Farmers grow indigenous tree and shrub species around homesteads to obtain various products (wood, food and feed) and services (live fence, shade and soil fertility improvement) [11]. Therefore, the general objectives of this research was to examine the role of indigenous tree species on some selected soil physical properties in the Lay Teda province.

Research Methods

Description of the Study Area

This study was conducted in province of lay Teda, Gondar zuria district, in Amhara region which is far from Gondar by 30 km in the north east direction. It is geographically located in $12^0$24'25''North latitude and $37^0$33'20'' East longitude. The altitude of the area ranges of about 1953-2500 meter above sea level. The mean annual rainfall is ranging from 995 to 1175 mm and the temperature ranges from 11^0C to 32^0C .The soil type in the study area comprise mainly "vertisoil" [12]. The dominant tree species include wanza, kachona, bisana, equalyptus and chibeha.

Identification of dominant tree species

The study area is endowed with various indigenous tree species. But for the purpose of this study tree inventory in representative area was conducted to select the first three dominant species. From the study area we had selected specific representative area which has area of 600m^2 (20m*30m). The density of each species was calculated and only the first three species considered for this study. Then, the tree species which is target of the study had approximately similar aged, same slope, had started leaf fall or litter fall to the soil and were having enough canopy. The land was not plough or not cultivated and the branch of the tree was not cut or pollarded in the past one year. The area belongs under canopy of tree had not been residential for animals and not place of fodder.

Soil sampling

The soil sample was taken from different sampling points under the canopy of the tree and one control group by far 30m from the tree. Composite soil samples were collected from three sampling points (mid of crown, edge of crown and control) for each tree. Three soil samples were taken for each tree species on top soil by using core samplers. Each three tree species had three soil samples and replicated three times and one sample for each tree species as a control group, which far 30 meters from tree species. Thus, totally we were collected 27 soil samples for our research purpose. Materials that are used during soil sampling were core sampler, spatula, hammer, sensitive balance, meter, plastic bag.

Soil Physical Properties Analysis

Bulk density

Soil bulk density was calculated by dividing the oven dry mass of soils to total volume of the soil using the formula stated as follows:

$$\text{Bulk density } (\rho b) = \frac{\text{Mass of ovendry soil (Ms)}}{\text{Total volume of soil (Vt)}}$$

Soil wetness

The amount of moisture found in the soil sample was calculated in two ways. It can be explained in terms of mass as gravimetric water and in terms of volume as volumetric water content. Thus, soil wetness was calculated in two ways as follows:

A. $$\text{Gravimetric water content } (\theta g) = \frac{\text{Mass of water (Mw)}}{\text{Mass of dry soil (Ms)}}$$

B. $$\text{Volumetric water content } (\theta g) = \frac{\text{Volume of water (Vw)}}{\text{Total soil volume (Vt)}}$$

Soil porosity

Soil Porosity is the spaces occupied by soil water and soil air. It was calculated by using formula stated as follows:
Porosity (f) =100- $(\frac{\text{Bulk density (Db)}}{\text{Particle density (Dp)}})$*100

Soil color

Soil color was described by using Munsell color chart notation coefficients in the Munsell color chart. Hue is the first notation in Munsell soil colour chart which represent dominant spectral colour, Value is the second notation which indicates lightness or darkness of colour and Chroma is the purity or strength of colour.

Soil consistency

Soil consistency refers to the forces of cohesion and adhesion exhibited by the soil. It was determined manually, by using finger feelings. And it was described as specified moisture levels (wet condition). The terms like plasticity and stickiness was used to explain consistency.

Soil Texture

Soil texture is the relative percentage of sand**,** silt and clay in a soil. It refers to the relative proportion of particles of various sizes in a given soil (i.e. it refers to the percentage by weight of each of the three mineral fractions: sand, silt and clay in the fine earth fractions i.e. particles <2mm in diameter). It can be determined in field by feeling method and in the laboratory by using the hydrometer method. We have used the first method to determine textural classes of the soil. By this method, a moist sample and wet soil sample were squeezed between the fingers. The presence of clay is indicated when the soil feels sticky at wet moisture content. Sand was indicated when the sample feels gritty, whereas the presence of silt produces a slick, soapy feeling.

Statistical Analysis

Quantitative soil properties like; soil bulk density, moisture content of soil and soil porosity was computed by using descriptive statistics. Others like soil color, textural name and soil consistency was analyzed by the researchers' judgment since they are qualitative. All these property was compared among trees species and within the control group.

Result and Discussions

Dominant Indigenous Tree Species

Based on the forest inventory made *Croton macrostachyus* stand first (14/600m^2). *Cordia africana* and *Albizia gummifera* ranked second and third by having density of 9/600m^2 and 6 /600m^2 respectively (Figure 1).

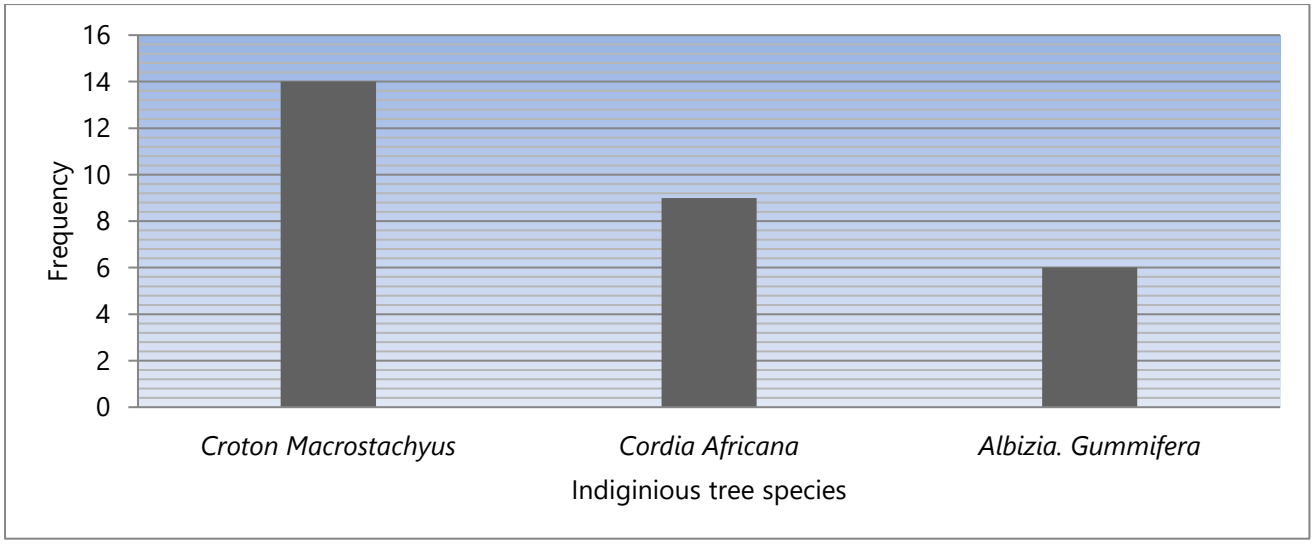

Figure 1: Dominant tree species in the study area

Soil Physical Properties

Bulk Density

Bulk density (ρb) of a soil is the oven- dried mass (Ms) per unit volume (Vt) of soil as a whole including pore space. The bulk density of a soil having high organic matter could have lower bulk density and it is preferable for agricultural purpose. As it is described in table one below bulk density is increased when we go far from each tree species. The bulk density of soils under crown is much lower than the control group. For example the density of soil under mid of crown of *Cordia A*. is 0.8 g/cm^3 while the control group bulk density increased to 1.07 g/cm^3 in the same tree species. Density of soil under mid crown of *Croton M*. is 0.75 g/cm^3 while the density in control group of the same species is recorded as 0.96 g/cm^3. In same fashion bulk density of soils under mid crown of *Albizia G*. were 0.73 g/cm3 while in same tree species the bulk density increased to 1.1 g/cm3 as we far 30m from the tree. In all tree species bulk density under crown is lower than the control group. This is probably happed by the effect of tree as they return litter falls to the ground. When we compare bulk densities of soil among tree species, the lowest bulk density (0.73 g/cm^3) was recorded under mid crown of *Albizia G.*, in contrary the highest bulk density (0.86 g/cm^3) was recorded under mid crown of *Cordia A*. (Table 1).

Table 1: Soil bulk density under different sampling point of selected indigenous tree species

Tree species	Sampling point	Initial wet(g)	Dry wet(g)	Particle density (g/cm^3)	Total volume	Bulk density (gm/cm^3)
	Mid crown	109.24	80.41	2.65	100	0.80
	Edge crown	113.08	85.67	2.65	100	0.86
Cordia A.	Control	128.6	106.64	2.65	100	1.07

	Mid crown	107.07	75.22	2.65	100	0.75
	Edge crown	109.86	79.31	2.65	100	0.79
Croton M.	Control	121.03	95.68	2.65	100	0.96
	Mid crown	100.57	72.91	2.65	100	0.73
	Edge crown	107.09	80.49	2.65	100	0.80
Albizia G.	Control	133.12	110.78	2.65	100	1.11

Soil bulk density measurements are often required as an input parameter for models that predict soil processes. Such models often use bulk density measurements to account for horizon mass when aggregating soil data. A normal range of bulk densities for proper root growth for different soil particle is found below (Table 2) [13].

Table 2: General relationship of soil bulk density to root growth based on soil texture

Soil Texture	Ideal bulk densities for plant growth (g/cm3)	Bulk densities that restrict root growth (g/cm3)
Sandy	< 1.60	> 1.80
Silt	< 1.40	> 1.65
Clayey	< 1.10	> 1.47

Soil porosity

A soil's porosity and pore size distribution characterize its pore space, that portion of the soil's volume that is not occupied by or isolated by solid material. The total porosity (f) is the volume occupied by pores (Vf) per unit volume of soil (Vt). It is an index of relative pore volume in soil and is generally expressed as a percentage. The basic character of the pore space affects and is affected by critical aspects of almost everything that occurs in the soil. It is affected by soil factors mainly texture and structure. The organic matter, bulk density, and management factors like tillage, cropping and irrigation, which affect soil structure, indirectly affect total porosity.

Porosity of soils under crown of all species is greater than the bare land which is definitely happened by the presence of the tree. For instance porosity under mid crown was 69.7%, 71.6% and 72.5% for *Cordia A., Croton M., Albizia G.*, respectively. And the highest and lowest porosity was recorded under crown of *Albizia G.* and *Cordia A* respectively (Table 3).

Table 3: Soil porosity under different sampling point of selected indigenous tree species

Tree species	Sampling point	Initial wet (g)	Dry wet (g)	Particle density (g/cm^3)	Total volume (cm^3)	Bulk Density (g/cm^3)	Porosity (%)
	Mid crown	109.24	80.41	2.65	100	0.80	69.7
	Edge crown	113.08	85.67	2.65	100	0.86	67.7
Cordia A.	Control group	128.6	106.64	2.65	100	1.07	59.8
	Mid crown	107.07	75.22	2.65	100	0.75	71.6
	Edge crown	109.86	79.31	2.65	100	0.79	70.1
Croton M.	Control group	121.03	95.68	2.65	100	0.96	63.9
	Mid crown	100.57	72.91	2.65	100	0.73	72.5
	Edge crown	107.09	80.49	2.65	100	0.80	69.6
Albizia G.	Control group	133.12	110.78	2.65	100	1.11	58.2

As it is described in the above table, the percentage of porosity is reduced when far away from mid crown of each tree to the control group. Which indicate that the presence of the tree have its own role in soil fertility improvement. Among all three tree species highest porosity was recorded under crown of *Albizia G.* (72.5%). Porosity is related to bulk density and particle density of the soil. The lower porosity is the highest organic matter content and ideal for optimum aeration, permeability, drainage and water retention; these also offer most favorable physical condition for optimum plant growth [14].

Soil wetness

Mass wetness (θg) is the mass of water (Mw) per unit mass of oven dried soil (Ms). It is often termed as gravimetric water content and expressed as a fraction or percentage as presented below (Table 4).

Table 4: Soil wetness under different sampling point of selected indigenous tree species

Tree species	Sampling point	Initial wet (g)	Dry wet (g)	Particle density (g/cm^3)	Total volume (cm^3)	Wetness (%)
	Mid crown	109.24	80.41	2.65	100	35.9
	Edge crown	113.08	85.67	2.65	100	32.0
Cordia A.	Control group	128.6	106.64	2.65	100	20.6
Croton M.	Mid crown	107.07	75.22	2.65	100	42.3

	Edge crown	109.86	79.31	2.65	100	38.5
	Control group	121.03	95.68	2.65	100	26.5
	Mid crown	100.57	72.91	2.65	100	37.9
	Edge crown	107.09	80.49	2.65	100	33.0
Albizia G.	Control group	133.12	110.78	2.65	100	20.2

The Mass wetness of soils under crown is much higher than the control group. For example Mass wetness of soil under mid of crown *Cordia A.* is (35%) while the control group Mass wetness decreased to (20%) in the same tree species, under mid of crown *Croton M.* (42%) while the control group Mass wetness decreased to (26%) and under mid of crown *Albizia G.* (37%) while the control group Mass wetness decreased to (20%).Within each three tree species Mass wetness of soils under mid crown of *Croton M.* is much higher than the *Albizia G.* and *Cordia A.* respectively. So, the study shows that the existence of tree has improved the moisture content of soil and micro climate of under the crown of soil. That indicates the highest organic matter content available under crown of tree due to litter fall.

Soil consistency

Soil consistency refers to the forces of cohesion and adhesion exhibited by the soil. It is the resistance of soil to deformation or rupture under applied pressure and expressed with reference to soil moisture content.The terms like plasticity and stickiness were used. It analyzes by using manually by finger feelings. Our study was made under wet condition as shown below (Table 5).

Table 5: Soil consistency under different sampling point of selected indigenous tree species

Species	Sampling point	Soil consistency		
		Stickiness	Plasticity	Remark
	Mid crown	Sticky	Plastic	Wet
	Edge crown	Sticky	Plastic	Wet
Cordia A.	Control	Very sticky	Slightly plastic	Wet
	Mid crown	Very sticky	Slightly plastic	Wet
	Edge crown	Very sticky	Slightly plastic	Wet
Croton M.	Control	Sticky	Plastic	Wet
Albizia G.	Mid crown	Slightly sticky	Non plastic	Wet

	Edge crown	Slightly sticky	Non plastic	Wet
	Control	Sticky	Slightly plastic	Wet

In this study soil consistency was determined by wet moisture condition. The stickiness of soil was sticky under mid crown of *Cordia A*. and very sticky at control group of same tree , very sticky for mid crown of *Croton M*. sticky at control group and also slightly sticky for mid crown of *Albizia G*. sticky at control group. The study showed that the stickiness was increased when it far from under crown of *Cordia A*. and *Albizia G*. tree species. But tree species of *Croton M*. soil Stickiness has shown reduced. For this case stickiness is affected through type of soil parent material. Soil plasticity also examined in our study. Based on the above table shows plasticity of soil is reduced from under mid crown of tree to control group of each tree species. So, that soil plasticity also affected through soil parent materials.

Soil Color

Soil color is described by using Munsell Color chart notation Coefficients in Munsell color chart was used as follows; Hue is the dominant spectral colour, Value is the lightness or darkness of colour and Chroma is the purity or strength of colour. Notations presented below (Table 6).

Table 6: Soil color under different sampling points of selected tree

Species	Sampling point	Soil color		
		Munsell Value	Color Name	Remark
	Mid crown	10R4/2	Weak red	Wet
	Edge crown	10R4/2	Weak red	Wet
Cordia A.	Control	2.5YR3/4	Dark reddish brown	Wet
	Mid crown	7.5YR3/4	Dark brown	Wet
	Edge crown	7.5YR3/4	Dark brown	Wet
Croton M.	Control	5YR4/3	Reddish brown	Wet
	Mid crown	2.5YR2.5/2	Very dusky red	Wet
	Edge crown	2.5YR2.5/2	Very dusky red	Wet
Albizia G.	Control	10R3/2	Dusky red	Wet

Soil color provides valuable information regarding soil conditions and some properties of soils. In our study shows the above table, color of soil increased in brightness from under mid crown of *cordia A*. to control group. From dark brown to reddish brown from under mid crown of *croton M* to control group. and very dusky red to dusky red from mid crown to control for *Albizia G*. when soil color is highly dark brown indicates have able to

absorb more solar radiation with the existence of available moisture have good conditions to activate microorganisms. And the dark brown color of the soil also indicates have organic matter content. So the existence of tree on land has slightly changes soil color as compared to control group or bare land.

In this study soil color under mid crown of *Cordia A.* recorded dark reddish brown, under mid crown of *Croton M.* was Dark brown and under mid crown of *Albizia G.* also recorded Very dusky red. So, that soil color under mid crown of *Croton M.* was good indicator for the presence of organic matter content. That is preferable to soil fertility as soil color is a manifestation of soil fertility. As mentioned in other studies before, dark colored soils absorb more solar radiation and warm up faster than lighter colored soil [15].

Soil Texture

Soil texture is the relative percentage of sand, silt and clay particles in a soil. It refers to the relative proportion of particles of various sizes in a given soil. The groups of different size range of mineral particles are known as soil separates or textural fractions, namely sand, silt and clay. The soil texture analysis result is presented below (Table 7).

Table 7: soil textural name of different sampling point of selected indigenous tree species

Species	Sampling Point	Textural Name	Remark1	Remark2
	Mid crown	Loamy sand	Coarse	Wet
	Edge crown	Loamy sand	Coarse	Wet
Cordia A.	Control	Silt/silt loam	Medium	Wet
	Mid crown	Loam	Medium	Wet
	Edge crown	Loam	Medium	Wet
Croton M.	Control	Sandi loam	Moderate coarse	Wet
	Mid crown	Silt/silt loam	Moderate	Wet
	Edge crown	Silt/silt loam	Moderate	Wet
Albizia G.	Control	Sandi loam	Moderate coarse	Wet

As presented in the above table, soil texture for *cordia A.* species in mid crown and control point becomes loamy sand to silt/silt loam. Whereas for *Croton M.* and *Albizia G.* indicates silt/silt loam and Sandy loam in mid of crown and control point respectively. In this case, when far away from the tree silt soil becomes coarse sand. So that, the existence of indigenous tree species *Croton M.* and *Albizia G* has improved soil structure through easily decomposable liter fall. But, under crown of indigenous tree species *cordia A.* reveres of *Croton M.* and *Albizia G.*, because, litter falls of *Cordia A.* may have a less rate of leaf decomposition in the soil.

Conclusion and Recommendation

Growing of indigenous trees species have a capacity to maintain soils fertility status through litter fall. Bulk density of soils under crown of tree is much lower than the bare land. Lower bulk density was recorded under mid crown of *Albizia G*. Porosity of soils under crown of all species is greater than the bare land which is definitely happened by the presence of the tree. For instance porosity under mid crown was 69.7%, 71.6% and 72.5% for *Cordia A., Croton M., Albizia G*., respectively. Soil stickiness was improved when it far from under crown of *Cordia A.* and *Albizia G*. tree species. Soil wetness under crown is much higher than the control group for each tree species. The study shows that the existence of tree has improved the moisture content of soil and micro climate of under crown of soil. The existence of a tree on land has slightly changes soil color as compared to control group or bare land. Within tree species under mid crown of *Cordia A*. recorded dark reddish brown, under mid crown *Croton M*. was Dark brown and under mid crown of *Albizia G*. also recorded very dusky red. Soil texture for each tree species from mid crown to Control becomes loamy sand to silt/silt loam except *Cordia A*. the existence of indigenous tree species *Croton M*. and *Albizia G.* has improved soil texture through easily decomposable liter fall.

From the selected indigenous tree species *Albizia Gumifera* and *Croton Macrostachuys* has a significant role to improve soil fertility. So, farmers should have to plant indigenous tree species in their own boundary of farm land to improve soil quality. Farmers should have to use agro forestry systems involving indigenous plants as a major tree component.

Moreover, the contribution of indigenous tree species for improving soil chemical and biological properties should be studied. So that, everybody can select a species, which can improve soil physical, chemical and biological properties simultaneously.

Availability of data and material

All raw and analyzed data are in the hands of the corresponding author and can be available based on reasonable request of publisher or any interested body.

Competing interests

There is no any competing interest regarding publication of this research result.

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