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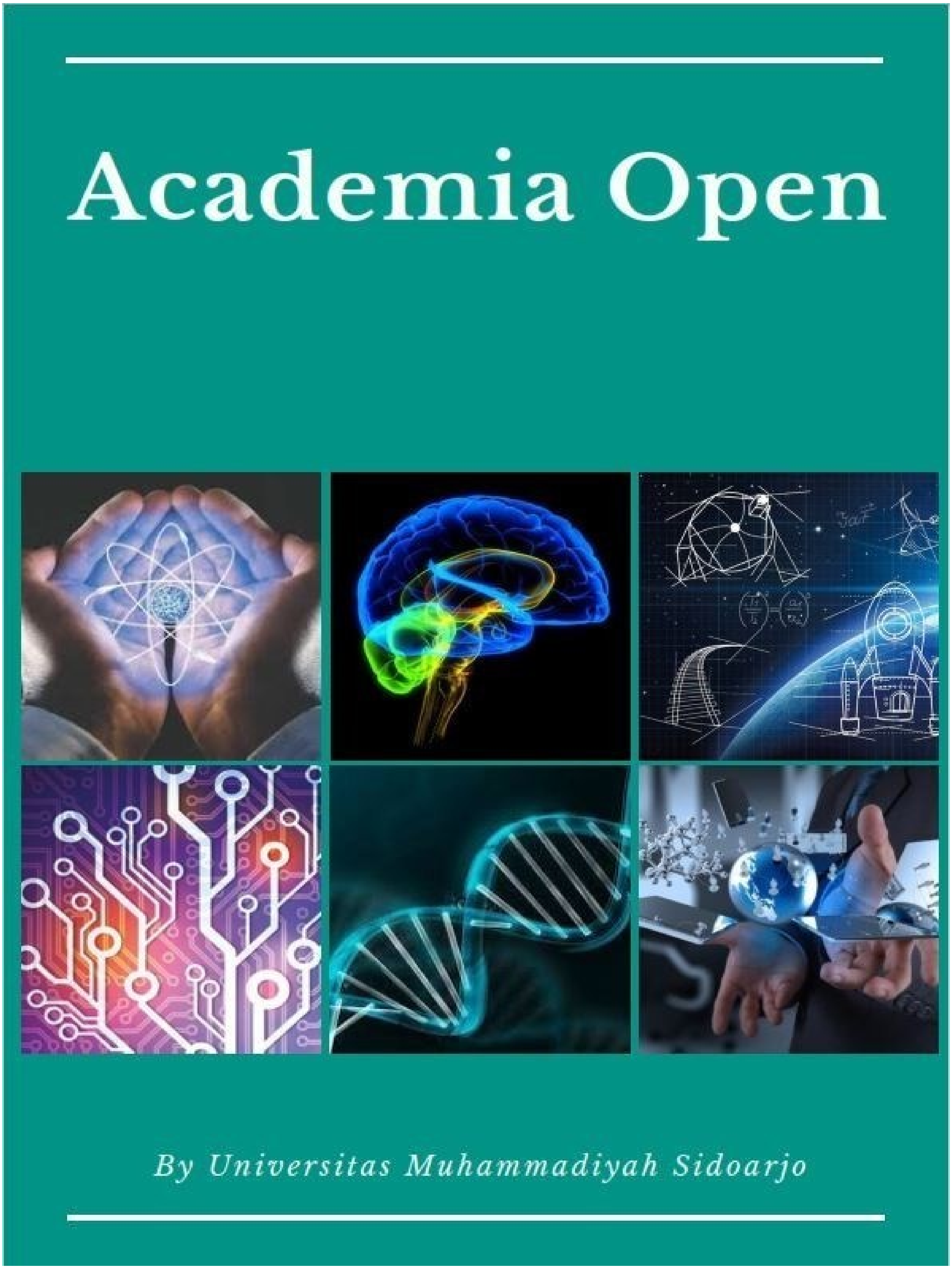

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Agrochemical and Microbiological Characteristics of Soils in Termez and Muzrabod Districts

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Abstract

General Background Soils in arid regions often experience declining fertility due to low organic matter, salinization, and intensive irrigation, which challenge sustainable agricultural productivity. Specific Background In the Surkhandarya Region of Uzbekistan, rice-growing areas of Termez and Muzrabod exhibit severely depleted humus levels, moderate salinity, and weak structural stability. Knowledge Gap Despite evidence that microalgae and cyanobacteria can improve soil fertility in arid environments, their potential for biorecultivation under the specific climatic and edaphic conditions of southern Surkhandarya remains insufficiently documented. Aims This study assessed key agrochemical properties and microbiological communities while evaluating the nitrogen-fixing activity and soil-ameliorating potential of native phototrophic microorganisms. Results Findings revealed low humus (1.0–1.5%), moderate salinity (EC 2.58–8.55 mS/cm), and active populations of Nostoc, Anabaena, Oscillatoria, Klebsormidium, and Chlorella with nitrogen fixation rates of 3.2–3.7 mg N g^{-1} day^{-1}. Klebsormidium inoculation increased organic matter by 20–25%, improved aggregate stability, reduced bulk density, and enhanced water-holding capacity by 12–15%. Novelty This work provides integrated chemical–biological evidence demonstrating the efficacy of locally adapted microalgae for soil restoration in BWk desert climates. Implications The results support microalgae-based biorecultivation as a viable strategy for rehabilitating degraded arid soils and strengthening sustainable land management in Central Asia..

Highlight :

- The content emphasizes that low humus levels and moderate salinization remain key factors reducing soil fertility in arid Surkhandarya regions.
- The role of cyanobacteria and microalgae is highlighted through their ability to fix nitrogen, strengthen soil aggregates, and enhance organic matter.
- Experimental findings show that microalgal inoculation, especially Klebsormidium, measurably improves soil structure and water retention, supporting its potential for sustainable biorecultivation.

Keywords : Soil, Humus, Agrochemical Analysis, Cyanobacteria, Microalgae

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Introduction

The increase of agricultural product during the past decades contributed to a substantial increase in world demand on mineral fertilisers and has thus become an important issue concerning the environment. It has been found that because of overuse, the physicochemical balance in soils was disturbed and the natural cycles of nutrients have become impoverished by an excessive application of N and P fertilizer. The Food and Agriculture Organization (FAO) and the United Nations Environment Programme (UNEP)'s 2015-2022 reported matter had speculated overuse of nitrogen to acidify these soils, decrease CEC and destabilize carbonate systems in arable non-calcareous soils. Likewise, insoluble forms of phosphorus should not be bioavailabile and can cause the eutrophication of neighbouring water bodies. Additionally, nitrate leaching and ammonia volatilisation can destabilise terrestrial and aquatic ecosystems as the same may exacerbate further existing environmental problems like climate changes at both local and global level.

The procedure is further complicated by some air and soil conditions in the arid parts of Central Asia, namely in the southern Surkhandarya Region (Uzbekistan). Beck et al. and Peel et al. categorize climate of two southern plains in the Amudarya and Sherobod rivers basin as BWk (cold desert), by Köppen-Geiger classification. Features of data on such points is that PDF: area has a large sum of annualy precipitations (110- 170 mm), summer temperature and \+42 - +47 °C, eva airing down rates are so high as to do the soil moisture lost fastly, leads to secondary salinization.[1] The high levels of irrigation are needed in paddy cultivation causing over-mineralisation, depletion of humus content and structure. Consequently, the soils from these areas are characterized by low aggregate stability, moderate salinisation, and low fertility that make the sustainable soil productivity more difficult.

In recent years, several studies in India and Kazakhstan as well as China, South Korea, and Japan have provided evidence that microalgae and cyanobacteria can be considered as useful natural bioagents for the rehabilitation of contaminated soils. The species of Nostoc, Anabaena and Klebsormidium could fix biological nitrogen and enhance soil organic matter content and stability of soil aggregates. These photoautotrophic-living organisms form biofilm layers on the surfaces of soil and also have been reported to act as both anti-erosive agents, and as water retention capacity increasers and restorers of microbials diversity in the land[es[2]. The use of these agents for biorecultivation purposes as an alternative to traditional fertilisation with chemicals is ecologically acceptable, especially in arid and salinised areas.

Systematic investigations of soil physicochemical properties and the distribution and activity of microalgae and cyanobacteria are necessary in the context of Surkhandarya region to manage the area in an ecologically oriented way. According to previous studies, the soils in Termez and Muzrabod are characterized by low-humus grey soil with moderate salinity and poor structural stability. A microalgae-based biotechnology for soil restoration could be built upon the discovery or selection of native phototrophic microorganisms adapted to these indigenous conditions-3]. Combining agrochemical evaluations with microbiological studies makes it possible to evaluate the intrinsic potentialities of self-rehabilitation and to plan targeted interventions aimed at increasing fertility with minimum impacts on the environment.

It is this that we focus on in the work: by a complex agrochemical and microbiological research of soil on rice fields in territories of Termez and Muzrabod district. The aims to be addressed would be: (i) determination of the content in humus and nutrients in soil, (ii) assessment of mechanical and electrophysical properties, (iii) determination of taxonomic composition and abundance of microalgae and cyanobacteria, as well as evaluation of their potential for nitrogen fixation. The aim of these studies is the scientific grounding for the development of biorecultivation technologies in view of local Southern Surkhandarya region natural and anthropogenic factors with sustainable land management functioning and ecological reconstruction (Gutov. 2004)[3]. The availability of such climatic, geographical and soil-related data allows for sophisticated explanation of processes in land degradation and the design of sustainable, effective biological interventions.

Materials and Methods

The present study was performed in the rice-growing regions of Termez and Muzrabod districts, Surkhandarya Region, Uzbekistan during 2024 and 2025. The Termez district is located in the south of the country, on the alluvium of the river Amudarya. This vast area is of great strategic importance, being adjacent to Afghanistan and acting as a significant border/transit zone. - Termez The district centre is the town of Termez, situated at an altitude between 287 and 313m above sea level at around latitude {{#invoke:Coordinates|coord}}{{#coordinates:37|229 |N|67|276|E|||| | |}}.

Of the Amudarya-Sherobodian plain, district Muzrabod is an other importaint agrozone of the republic. It is surrounded by the Sherobod and Qiziriq districts to the north, Angor district to the east and Termez district to the southeast. The seat of the district is the village Xalqobod which is situated at an altitude of 250-320 meters, at around Coordinates:. These geographical and environmental traits provide an appropriate environment for rice growing and agrochemical evaluation investigated in this research.

The two considered districts have arid continental climate, as described under the Köppen-Geiger system: BWk. This region has a desert climate, with hot, dry summer temperatures reaching maximums of between 42-47°C in Termez and between 37-42°C at Muzrabod, and cool winter temperatures dropping as low as -5°C in Termez and 0°C at Muzrabod. Average yearly rainfall is minimal (110–170mm), and falls mainly in winter and early spring. Fast evapotranspiration in the growing season can also fast release of soil moisture and induce a secondary salinization. The main drainage system is that of the Amu Darya River and its tributaries along with their irrigation and drainage canals, which are essential for providing agricultural water in an arid environment. Soils of alluvial meadows, sierozems, solonchaks and taqir zem are prevailing with a humus content reaching 1.0-1..5%. The low organic matter content is suggestive of poor buildup and is more responsive to salinization.

Soil samples were taken from the 0-30 cm layer at two observing points (P-1-Termez and P-2-Muzrabod). The sampling procedure followed standardized guidelines used to reduce the potential risk of contamination and maintain the representativeness. Samples were split into two: half was analysed for agrochemical properties and the other half for microbiological characteristics. Agrochemical properties were determined by traditional laboratory procedures. Humus was determined according to Tyurin, total nitrogen by Kjeldahl, mobil phosphorous and potassium according to Kirsanov, and mechanical composition based on the Kachinsky classification. Potentiometric method was used in measuring soil pH and electrical conductivity (EC), to evaluate the level of alkalinity and salinity.

The microbiological analyses consisted of allowing soil-inhabiting microalgae and cyanobacteria to grow on BG-11 medium, followed by microscopic examination for determinations on the basis of morphological characters. Nitrogen fixation activity of phototrophic micro-organisms was determined by the acetylene reduction assay (ARA) and their density by microscopic field counting. A number of model

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experiments have been carried out in the assessment of efficiency of bioreclamation on microalgae basis. The experiments were in inoculating Klebsormidium strains into soil and observing the effects on bulk density, aggregate stability, organic matter content and capacity for water retention. The methods described provide a comprehensive approach to evaluate the chemical and biological status of soils in southern Surkhandarya in certain hydrographic, climatic, and geomorphological conditions.

Results

This research was conducted in the Termez and Muzrabot districts southern of Surkhandarya region during the period 2024-2025. They are distinguished by the cold BWk desert climate type as well, characterised as high (+40-42 °C) summer temperatures and low annual precipitation (110-170 mm). The terrain at the study locations is lowland, alluvial plain both in alluvial plain and alluvial terrace between 287 m to 320 m above sea level. While the topography is suitable for irrigated a~riculture, soil salinization could occur due to lack of natural drainage coupled with high evapotranspiration[5-6]. The Amu Darya, including its surkhandarya and sherobod tributaries, is the main supplier of water to local irrigation canals. All these affect the effectiveness of the measures for irrigation and reclamation.

According to agrochemical analyses, soil of the districts Termez and Muzrabot have a low humus content—1.0–1.5%. The total nitrogen of the samples ranged from 0.10 to 0.13% and was identified as a limiting factor to biological activity. Note that the mobile potassium and phosphorus concentrations in any of these ED treatments were 1.5–1.7 mg/100 g and 8.3–8.5 mg/100 g, pointing to moderate nutrient availability levels. Localised salinization was suggested by the variation in soil EC values that ranged from 2.58 to 8.55 mS/cm. The said values had a range of 7.1 to 7.4, which showed that the environment was slightly alkaline environment with pH. An intermediate water retention and permeability, associated with fine sand fraction and silty proportion (38%36 43%). These conditions are favourable for phototrophic organisms and OM activity.

After a detailed microbiological examination of the soil samples, we identified phototrophic microorganisms from the genera Nostoc, Anabaena, Oscillatoria, Klebsormidium and Chlorella. These microorganisms significantly influence the biological stability of the soil. Cyanobacteria formed surface biofilms that increased resistance to soil erosion, ranging from 2.8 × 104 to 3.5 × 104 cells g−1 for phototrophic cells per gram of soil appearing in the test region. For the nitrogen fixation rate, values from 3.2 mg N/g dry soil/day to 3.7 mg N/g dry soil/day were obtained. This promotes the accumulation of organic matter and supports the concept of nutrient cycling[7].

Several favorable alterations of soil characteristics have been achieved by application of model experiments comprising inoculation with Klebsormidium species. Most importantly, soil organic matter increased 20-25%, aggregate stability improved, bulk density dropped sharply and water-holding capacity increased by 12-15%. Based on the results of this study, it is concluded that there exists strong empirical evidence in support of the proposed hypothesis: microalgae based bioreclimation technologies are very effective under the environmental conditions in Surkhandarya region.

The results of the study reveal that Termez and Muzrabot districts which contain experimental fields are typical for BWk cold desert climate zone. The major limiting factors of bioproduction are the soil's modestly salinized nature, low humus deposits and organic matter content 8(]. Nonetheless, the microbiological structure of soils contributes to restoration of eco-functions because nitrogen fixation activity, biofilm formation and soil aggregate stabilization have been found to increase.

Table 1 presents the quantitative evaluation of the soil microbiological and physico-chemical properties in the studied localities. Total N content varied from 0.10 to 0.13%, and SOM ranged from 1.0 ± 0% to I.olecules g of soil -1 (Table i). Phosphorus and potassium contents ranged between 1.5–1.7 mg/100 g and 8.3–8.5 mg/100 g, respectively. Electrical conductivity (EC) of the soil was betweent 2.58 and 8.55 mScm-1, and pH, which was between 7.1 and 7.4, indicated a slightly alkaline nature of the soil. These results indicate that there are localised areas of salinisation, particularly in low-lying poorly drained regions.

Table 1. Agrochemical properties of soils in Termez and Muzrabot districts

Parameter	Range	Unit
Humus content	1.0 -1.5	%
Total nitrogen	0.10 - 0.13	%
Mobile phosphorus	1.5 -1.7	mg/100 g
Potassium	8.3 -8.5	mg/100 g
pH	7.1 -7.4	-
Electrical conductivity	2.58 -8.55	mS/cm
Fine sand + silt fraction	38 -43	%

Table 2. In model inoculation tests with Klebsormidium strains the beneficial influences on soil structure are demonstrated. (2009) showed an organic matter increase of 20-25%, a decrease in soil bulk density of 0.12-0.15 g/cm³ and an increase in water-holding capacity of 12-15% (Table 2). 6.67, $p < 0.01$) with the MWD method (Table 4), which was increased from 0.52 mm to 0.68 mm after microalgal treatment.

Table 2. Effect of Klebsormidium inoculation on soil physical properties

Parameter	Control	Inoculated	Change (%)
Organic matter (%)	1.1	1.35	+22
Bulk density (g/cm³)	1.45	1.30	-10.3

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Parameter	Control	Inoculated	Change (%)
Water-holding capacity (%)	28	32	+14
Aggregate stability (MWD, mm)	0.52	0.68	+30.8

The relationships between the soil properties, environment impacts and bio-fixers in the Surkhandarya area are identified using agrochemical, microbiological and recultivating information. The study sites are situated in the valley of Amudarya river, which is characterized by low-relief terraces and alluvial plains. They are located in the southern part of Uzbekistan, or more specifically in Termez District (37.229°N, 67.276°E) and Muzrabot District (37.461°N, 66.920°E). Topography varies from 287 to 320 m a.s.l. and subtle undulations impact on the regional hydrological regime and soil salinity distribution.

The climate in the study site is an arid cold desert, or BWk type as per (Köppen-Geiger classification). The average annual temperature in Termez is about 19-20°C, somewhat lower – about 18-19°C – in Muzrabot, the lowest temperature values during winter being observed in places unprotected to weather, from -5°C and below, while the highest summer temperatures vary between 40 and 42 °C. During most of the year (in summer) it is dry, with a minimum precipitation occurring annually at an elevation of almost nothing (110–170 mm) in a lowland plane during winter-spring period. High evaporation in conjunction with little natural drainage systems has been the most prevalent thing associated with causation of salinized soils, some localised areas. These are confirmed by the EC measurements, that ranged between 2.58 and 8.55 mS cm –1.

As typical of dry land alluvial systems, the physicochemical characteristics of the soils that are low in humus (1.0-1.5%) and overall nitrogen (0.10-0.13%), indicate an inherently poor fertility factor. Although not severe, there are low levels of potassium (8.3-8.5 mg/100 g) and phosphorus (1.5-1.7 mg/100 g), indicating the need for mineral supplements over time to sustain agricultural production. Aside from desertic soils being predominantly fine sand with silt percentages between 38 and 43%, the retention is comensurately poor and stress worsened.

With cell density between 2.8×10^4 –3.5×10^4 cells/g, the assay revealed a diverse community of phototrophic bacteria dominated by Nostoc, Anabaena, Oscillatoria, Klebsormidium and Chlorella as shown in Fig. Natural soil fertility was significantly improved by the N fixation rates (which ranged from 3.2 to 3.7 mg of N g dry soil-1 d-1). Cyanobacterial biofilms, in particular those comprised of Nostoc and Anabaena, have been shown to enhance stability of aggregates, and reduce their susceptibility to erosion. Green algae such as Klebsormidium were found to be particularly promising for increasing soil organic matter and water retention in model recultivation experiments.

The interplay of bioclimatic and geographical factors indicates that diversified relief, high evapotranspiration, low precipitation amounts and a arid BWk subhumid climate negatively influence soil quality and the efficiency of bio-remediation. Wetland areas where water cannot drain effectively had the highest bioturbation activity and lowest EC values, whereas mounds (whose height was intermediate) resulted most suitable for nutrient cycling and microalgal colonization. Accordingly, on this basis it is proposed that site-specific interventions, e.g. controlled irrigation/ improved drainage /deliberate microalgae inoculation be applied to ensure long-term soil recovery in the Southern Surkhandarya plains.

The complete study also supports the view that recultivation techniques with microalgae is a plausible option for improving soil fertility and structure in the arid desert area, particularly under extreme savage conditions of Termez and Muzrabot regions [9]. The comprehension of the relationships between soil and ecosystems is achieved by the integration of environmental, microbiological and agrochemical information. This is the scientific underpinning for development of adaptive land management plans in similar dry regions worldwide.

Discussion

Results The current study elucidated the agrochemical and microbiological properties of soils in Surkhandarya at Termez and Muzrabod districts, Uzbekistan. These are arid to semiarid climate areas and frequently suffer great limitations in agriculture, chiefly concerning the low organic matter level and moderate salinization in soils. The soil organic matter of these soils varying from 1.0 to 1.5 per cent is low since it indicates less nutrient holding and biological activity in these soils. It is the general property of arid regions in which soil suitableness fertility is low and the accumulation of organic matter slow. Soil salinization is another cause that leads to the deterioration of soil texture, where EC content ranged from 2.58 to 8.55 mS/cm (Supplementary Table S I). In areas of excessive irrigation, such as the rice-growing regions of Termez and Muzrabod, the process is even more serious and a loss in land productivity may be experienced. Low OM highly saline and soil structure less which suppress the productivity of crop. Thus, knowledge of the mechanisms and factors that contribute to soil degradation in these regions is fundamental for proposing appropriate land management practices[9]. In this regard, it has been clear that a group of the phototrophic microorganisms including cyanobacteria and microalgae could mitigate these challenges through increasing soil fertility with stabilizing soil structure in biological methodology.

The microbiological results of this work provide a new approach to the use of soil-bacteria in arid land restoration. Nitrogen-fixing competencies of cyanobacteria and microalgae are well documented, being more pronounced in low nitrogen soils as the result of rows from Termez and Muzrabod. The values of nitrogen fixation obtained here were in mean 3.2-3.7 mg N2/g dry weight/day As γ-proteobacteria bacteria help enhancing nutrient cycle when the observed value is significant according to being a critical process for sustainable agriculture, on characterization new bacterial oligotrophic that mediated by soil interaction bearing nutritional resources from Ochlosoporous trichocarpus-γ.Hummed.& Convolvulaceae as well to such hestial agricultural practices. Nitrogen is an essential nutrient for plants and its availability is one of the limiting factors in dryland soils[10. Cyanobacteria can fix atmospheric nitrogen, therefore recharging the soil's natural levels of a crucial nutrient, thus decreasing the need for synthetic nitrogen fertilizers that can have harmful environmental effects (such as soil acidification and water pollution). Not only these microorganisms fix nitrogen, they are also known to enhance soil physical properties. Cyanobacterial biofilms detected on the soil surface lead to soil aggregation and enhance stability of soil to erosion. This is especially useful in regions where soil erosion is an important problem, since biofilms protect the soil against wind and water erosion[11]. These biofilms also improve the amount of water that soil can hold which is very important in a desert environment where there isn't much water to begin with. The increase in wet aggregated and water holding capacity found in this work highlights the potential of cyanobacteria and microalgae to improve soil resistance and fertility.

The inoculation of microalgae, in particular species of the genus Klebsormidium, showed advantages for soil properties in model experiments. These studies demonstrated 20–25% increase in organic matter, reduction in bulk density and also an enhancement of water-holding by 12–15%. These findings indicate potential of microalgal-based bio-recultivation for enhancing soil fertility, especially in soils with low organic matter level.

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Increased organic matter, in particular, is important because it contributes to soil fertility by enhancing nutrient availability, promoting good soil structure, and increasing water holding capacity of the soil[12]. Soil health is promoted by immobile organic matter, which provides plant nutrients and maintains soil structure for particles to bind. The lower bulk density value suggests higher soil porosity resulting in better root penetration and water infiltration. These enhancements are essential in dry areas, where the water is retention and soil stability constitute a big issue. The findings of the model experiments reinforce the concept that microalgaebased bioreclamation may provide an efficient substitute for expensive and environmentally destabilizing chemical fertilizers[13]. Through improving the content of soil organic matter and soil structure, microalgae may be a way to restore arid soils and promote sustainable agriculture in marginal areas.

However, there are still some difficulties to overcome before microalgae bioreclamation for the Termez and Muzrabod districts could successfully be applied. One of the problems that should still be addressed is the field-scale test of these results. Although significant improvements in soil properties have been observed for laboratory experiments of microalgae application, the long-term success of such applications needs to be evaluated in real agricultural conditions. Success of biorecultivation processes can depend (or may be influenced) on seasonal climate conditions, irrigation efforts and land soil type, for example. Thus, more examination is necessary to determine whether this method can be amplified for transformation of field applicable methods. Moreover, the economic feasibility of microalgae bio-recultivation should be evaluated in relation to conventional soil placement[14]. Even if microalgae provides an eco-friendly and sustainable alternative, inoculation cost as well as resources for cultivation and applied to the pond is a primordial factor. In addition, the persistence of microalgae inoculation in soil ecosystem and crop yield has to be followed in long-term perspective to check if profits overtake costs during time.

In conclusion, the present study has demonstrated a possibility of microalgae and cyanobacteria in restoring soil fertility and preventing soil erosion in arid zone regions such as Termez and Muzrabod within Surkhandarya region Uzbekistan. Results proved that these microorganisms are involved in nitrogen fixation, increasing the organic matter and stabilizing the soil aggregates. The positive effects on the soil structure and fertility in model cultivation experiments prove that use of microalgae-based biorecultivation is a competitive substitute for common chemical fertilizers[15]. This strategy brings a sustainable solution to the problem of soil depletion, which is particularly pronounced in areas with water and nutrient deficiency. Nevertheless, the efficacy of this approach under field conditions, its long-term sustainability and economic feasibility have to be established. Bio-cultivation A more sustainable farming Start-up Pioneering bioremediation using micro-algae, CGIAR-CSI reports that the successful practice could see soil quality kept intact, crop yields maintain optimal and environmental degradation reduced in arid areas through processes such as chemical pollution degradation.recipe The photobioreactor is equipped with kilos of algae-based bio-mass to clean wastewater used to irrigate farms in dry areas.

Conclusion

In this regard, the results of the present work are useful for studying physical-chemical and microbial parameters of soils in Termez and Muzrabod districts (Surkhandarya) communities. The low-humus (1.0–1.5%), partially saltified and weak gravel-aggregated soils are the main limiting factor for sustainable agriculture in arid BWk zones. However, in the course of such restoration with natural recovery, the photometric activity of microorganisms (Nostoc, Anabaena, Oscillatoria, Chlorella and Klebsormidium) will be a very important component. These micro-organisms play a role in enhancing nitrogen fixation and benefiting soil fertility and aggregate stability by the reduction of salt problem. Significant increase in organic matter (20-25%, Luthra et al. 1983), nutrient addition, water-holding capacity and reduction of bulk density (~50%) after inoculation with klebsormidium species has been reported by several workers in different experimental fields which would obviously enhance the sustainability of farming.

These results demonstrated the great potential of microalgae-based biotechnologies for improving soil quality and enhancing agricultural productivity in the region. These ameliorating methods applied in arid soil will achieve sustainable soil regeneration, which is attributed to improvement of the soil structure, nutrients availability and water retention. The promotion of biological ways of soil regeneration in the regional land use planning is able to secure environmental and socio-economic benefits, which defines its importance for sustainable agriculture in difficult natural conditions of Surkhandarya oblast.

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