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Role of soil biota in the formation of soil fertility in agricultural landscapes of Akmola region, Kazakhstan

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ABSTRACT
Biofertilizers are needed to restore soil fertility. Long-term use of chemical fertilizers causes soil degradation and affects crop yield. Biofertilizers increase the soil's water-holding capacity and add nutrients like nitrogen, vitamins, and proteins to the soil. This article, with the topic of agricultural land use, deals with the impacts of control operations on the living part of the soil and its processes that play a role in the biological fertility of the soil. This article evaluated the effect of cultivation rate and biota on the fertility of agricultural lands in the Akmola region, Kazakhstan using soil analysis under different conditions. Although physical, chemical, and biological factors are generally recognized as the most important factors of soil fertility, more attention has been paid to the management of the physical and chemical parts of the soil compared to the biological part. The results show that soil microbial biomass causes many chemical changes in the soil. Therefore, microorganisms have a major controlling role in the cycling and loss of nutrients from the soil. They also regulate the availability of nutrients and many other transformation processes in the soil.

Keywords: Soil fertility, Soil analysis, Soil biota, Soil biology, Akmola region.
Article type: Research Article.

INTRODUCTION
Over 40% of the world's land is arid and semi-arid (Churkina *et al.* 2012). These areas are mostly spread in parts of North and South Africa, the Middle East, North and South America, and Australia. Considering the problem of water scarcity in Kazakhstan, over 80% of its area is semi-arid. Areas with an average annual rainfall of 100 to 250 mm are considered arid, and those with 250 to 600 mm semi-arid (Derpsch *et al.* 2010). Many challenges in arid and semi-arid soils lead to reduced production. Among other things, soils usually have a light and sandy texture in these areas with low organic matter and nutrients, soil biological activity and aggregation are weak, and the soil is susceptible to water and wind erosion (Barrios 2007). Secondary minerals such as calcite and gibbsite are usually high in these soils, and the presence of these minerals in large quantities can significantly reduce soil fertility (Ponge *et al.* 2013). Carbonated and sulfated parent materials and low leaching lead to the accumulation of carbonates, sulfates, and other dissolved salts, leading to the salinity of these soils (Ishenin *et al.* 2021). Other limitations of arid and semi-arid soils include salinity sodicity, low depth and development, the presence of hard limiting layers, and lack of soil moisture. However, among all these challenges, the lack of organic matter, especially in soils with low clay content, can be considered one of the most important and main limitations of soils in arid and semi-arid regions (Sudarmilah & Maelani 2021) because soil organic matter is known as the gateway to soil fertility. By increasing the amount of organic matter, biological activity can be improved. The substrate can be provided to increase soil fertility. Today, various methods are used to increase soil organic matter, including returning plant residues to the soil, using appropriate crop rotation and minimum tillage or no-till, adding various types of organic fertilizers such as livestock and poultry manure, compost, sewage sludge or green manure.

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Organic matter has direct and indirect positive effects after being added to the soil, and while directly adding some nutrients, it improves soil fertility by increasing organic carbon. However, due to their high rate of decomposition and degradation, many organic materials do not have a long life and durability, have few residual effects, and must be continuously added to the soil to maintain their positive effects. In addition, some organic materials contain weed seeds, and others contain living (microbe types) and non-living (organic pollutants and heavy metals) pathogens. The unpleasant odor of some of these compounds also limits their use (Grosu *et al.* 2021). In recent years, the technology of converting various organic waste materials into a solid, carbon-rich, coal-like material called biochar has attracted the attention of agricultural and environmental scientists. Biochar is produced by heating organic biomass in the absence or limited oxygen at temperatures of 300 to 700 ℃ and, due to the presence of aromatic carbon, remains stable in the soil for hundreds to thousands of years. Also, due to its porous structure, high specific surface area, and various functional groups, it has unique properties that add to the advantages of its use in soil (Starodubtsev & Bakai 2021; Rosalina *et al.* 2024). The technology of converting biomass into biochar is called thermal decomposition. The rate of increase in the maximum temperature and the duration of heating at the maximum temperature are considered to be the most important thermal factors of thermal decomposition, which, together with the type of biomass used, determine the characteristics of the produced biochar. In the thermal cracking process, the lower the oxygen content of the biomass tank and the higher the gas emissions, the higher the quality of the biochar produced. Suppose the hydrothermal carbonization process is used to heat the biomass instead of the thermal cracking process. In that case, the product produced is called hydrochar, a solid carbon material with more industrial and environmental uses. The biomass is heated in a mixture with water inside a sealed tank during this process. As the temperature increases, the pressure also gradually elevates, and heating continues for several hours at a specific and constant temperature and pressure. The maximum temperature and pressure, the duration of heating at the maximum temperature, the biomass-to-water ratio, and the type of biomass are the most important factors affecting the characteristics of the produced hydrochar (Patra *et al.* 2023). Biochar can improve fertility and increase crop growth and yield by directly adding some nutrients and affecting the soil's physical, chemical, and biological properties (Sofo *et al.* 2022). For example, (Sofo *et al.* 2020) reported that adding biochar produced from sugarcane bagasse at temperatures of 200 to 500 ℃ in an amount of 1 and 2% by weight to a calcareous soil increased the cation exchange capacity, organic carbon and absorbable phosphorus and potassium of the soil. Also, microbial respiration, substrate-induced respiration, microbial biomass carbon, and the activity of dehydrogenase and catalase enzymes increased, and the intensity of these changes elevated by upraising the amount of biochar used. In addition, during the thermal decomposition process, the biomass is converted into an almost sterile material (biochar), and weed seeds, then pathogens, and the unpleasant odor of some biomass, are removed. Beneficial soil bacteria, including *Bacillus, Pseudomonas, Streptomyces,* etc., are producers of secondary metabolites that can act against plant-pathogenic fungi and human pathogenic bacteria (Van Mansvelt 2017; Kooch *et al.* 2021; Kussainova *et al.* 2023). Earthworms in nature are the farmer's helper and nature's plowman. Earthworms are able to ingest and crush soil and debris particles along with their associated bacteria, leading to elevated availability of vermicompost nutrients with the help of aerobic and anaerobic microbes. The type of land cover in the land use is one of the main factors affecting the microbial community of soils in forest areas. The soil microbial community can cause differences in topsoil's physical and chemical properties under different land uses. Most previous studies have referred to changes in the physicochemical characteristics of soil in different land covers, and soil microbial activities have been less studied. Despite the decrease in fertility and extensive changes in land use in the Akmola region, a proper assessment of its consequences, especially the effect of seasonal and depth changes on soil microbial and enzymatic characteristics in agricultural land uses, has not been carried out. Therefore, this study addressed two important issues: (i) The effect of various factors on soil microbial activities; (ii) The dynamics of soil enzymatic activities in different land covers in Akmola, Kazakhstan.

MATERIALS AND METHODS

Studied area: Akmola Region is a north-central region of Kazakhstan beside Russia. Its climate has four seasons, with the lowest temperature in winter reaching -12 ℃ and the highest in summer (25 ℃). This region is suitable for agriculture due to its climate, the river passing through it, and its dry vegetation. The study area is located between latitude 36°37'30" to 36°4'52" and longitude 51°7'50" to 51°12'51". The minimum altitude above sea level is 45 meters, the maximum is 145 meters, and the area's slope is between 1%. According to the meteorological station located in the Akmola region, which is the closest meteorological station to the study area, the average annual temperature is 17 ℃, the average annual rainfall is 1300 mm, and the dry season is from June to August (based on the ten-year period 2010-2020). The soil texture is loam-silty-sandy.

Fig. 1. Akmola region location.

After visiting and carefully identifying the land uses, an area of 2 hectares (100 × 200 m) with physiographic conditions (slope, geographical direction, and altitude above sea level) and similar parent materials was selected from six land uses. Soil samples were collected from a surface of 25 × 25 cm (beginning, middle, and end) located on five transects parallel to the center of the land uses. It should be noted that each transect's length was considered 100 m. Initially, fifteen samples were taken from each land use from two depths of 0-5 and 10-5 cm, and finally, three samples were mixed in each transect, resulting in five composite samples from each land use. Sampling was conducted four times a year, in the middle months of each season (Giller *et al.* 1997). 250 soil samples (6 land uses × 2 depths × 4 seasons × 5 repetitions) were taken from the land uses and transferred to the laboratory. To reduce boundary effects, the margins of the land used for sampling were not considered, and sampling was directed towards the central part of each land use. Part of the soil samples were kept at 4 °C until the experiment to measure microbial characteristics, and another part was kept at -20 °C to measure enzyme activities.

RESULTS

Akmola is a grain-growing region in the north-central part of Kazakhstan. It produces about 30% grain, 6% milk, 20% poultry meat, 15% eggs, and 10% flour. The climatic conditions of the studied region during a year are shown in Fig. 2.

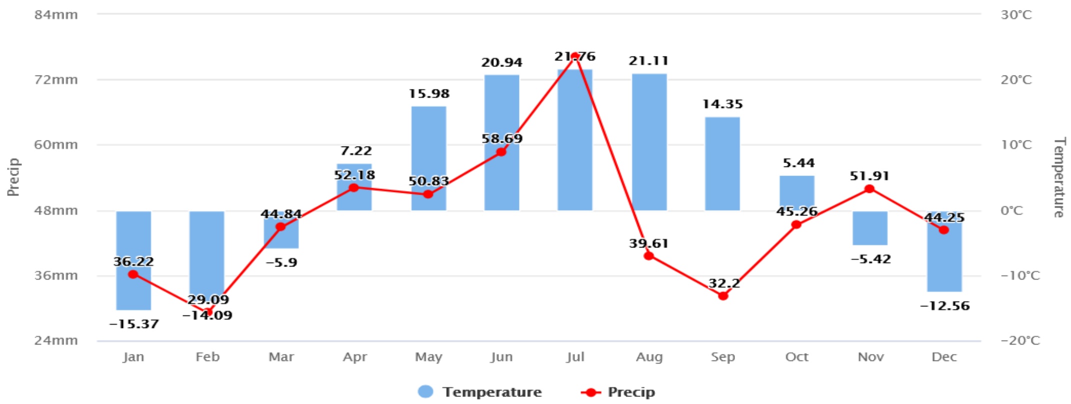

Fig. 2. Climate Graph.

As shown in Table 1, the factors affecting soil analysis are presented and the effect of each on soil biota is evaluated. The factors studied in this study include crop rotation, returning plant residues instead of burning, tillage operations, irrigation based on rainfall and moisture, land drainage, application of pesticides and fungicides in the soil, application of nitrogen fertilizer, organic soil improvement, liming of acidic soil, and the results of their effects on microbial biomass, mineralization and soil nitrification, denitrification, CO_2 and methane emissions.

Table 1. Effects of agricultural management practices on soil analysis (Cr and nitrogen)

	Microbial biomass	Mineralization	Nitrification	CO_2 emission	Methane	Denitrification
Crop rotation	+	+		+		
Returning plant residues instead of burning	+	+		+		
Tillage operations	+	-		-	-	+
Irrigation based on rainfall and humidity	+	+	+	+		+
Land drainage		+	+	+	-	-
Application of pesticides and fungicides to soil	-					
Application of nitrogen fertilizer			+			+
Organic soil improvement	+	+		+		+
Limization of acidic soil	+	+	+	+		+

Microbial biomass presence is higher in rotational cropping systems than in monoculture systems (Hartemink *et al.* 2008; Flohre *et al.* 2011). This is probably because, in rotation systems, the wide range of plant residues added to the soil increases the diversity of the microbiota. Elevating the proportion of legumes in a rotation increased total soil nitrogen, microbial biomass nitrogen, and the cumulative seasonal gross mineralization rate of nitrogen (Table 2).

Table 2. Soil nitrogen storage values (kg ha^{-1}) at different wheat cropping times.

	Continuous wheat cultivation	Lupin-wheat rotation	Continuous clover cultivation
Total organic nitrogen storage	1102	1098	1544
Microbial biomass nitrogen	70	73	81
Gross nitrogen mineralization	289	126	102
Gross nitrogen organicization	159	57	51
Net nitrogen mineralization	131	62	48
Nitrogen via microbial biomass	52	44	31

Carbon resources often limit microbial activity in agricultural soils. Therefore, returning crop residues is a practical solution to increase microbial communities without adding organic matter outside the soil. Crop residue management alterations in soil temperatures, soil humidity, and the distribution of plant residues and soil organic matter, all of which affect the place and action of microorganisms. Mulching the soil surface with crop residues has increased the population of bacteria, actinomycetes, and fungi by 2 to 6 times compared to uncovered soils. In contrast, burning straw and stubble reduces the organic matter introduced into the soil. It causes elevated soil temperature and water deficit after harvest, dropping the population and activity of soil microorganisms. In (Menta 2012), burying straw and stubble instead of burning it can upraise microbial biomass by up to 45%, although total carbon increased by only 5% in this experiment. Complete information on land uses (characteristics of different land covers and some soil properties) is reported in Table 3.

Table 3. Characteristics of different land covers and some physical and chemical properties of soil.

Soil properties	Continuous cultivation	Crop rotation	Non-agricultural land
Density	1.28	1.24	1.52
Humidity	24.12	26.67	21.56
pH	6.69	6.91	6.34
Electrical Conductivity	0.72	0.78	1.01
Carbon	1.53	1.52	0.51
Nitrogen	0.19	0.36	0.12
Phosphorus	6.27	6.52	5.98
Potassium	189.34	281.23	198.67

The higher the energy intensity introduced to the soil by tillage, the faster the rate of decomposition (Hartemink *et al.* 2008; Flohre *et al.* 2011), which tunes the microbial percentages (Fig. 3). Mixing plant residues with soil has a greater effect on bacterial populations than on fungi and can alter residue decomposition pathways and soil predator networks. Minimal tillage and no-tillage procedures can result in alterations in various environmental parameters that regulate microbial action and residue decomposition. Despite the higher microbial biomass populations of no-tillage systems, in temperate regions and early in the season, high moisture levels, low oxygen concentrations, and low soil temperatures reduce microbial activity and nitrogen mineralization. Today, it is important to pay attention to managing municipal and hospital waste cheap, simple, convenient, low-risk, and healthy. By biological composting, beneficial alterations and transformations occur in waste, and while organic materials become stable, the risk of contamination and transmission of pathogens is minimized (Meng *et al.* 2022). However, evidence shows that the vermicomposting process surprisingly significantly reduces pathogens, including *Salmonella*, intestinal coliforms, and pathogenic larvae in biological waste. The vermicomposting process reduced intestinal coliforms to zero (Montoya Sánchez *et al.* 2023). Vermicomposting of municipal waste eliminated coliforms and *Salmonella* from 39,000 MPN/g (most probable number per gram) and 3 MPN/g to zero and one, respectively.

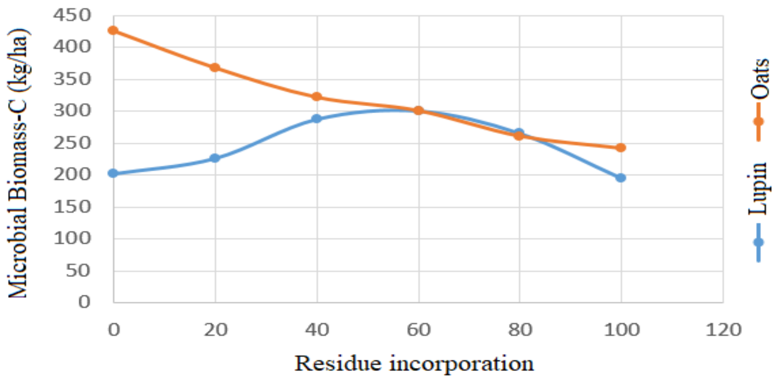

Fig. 3. Impact of residue mixing (lupine or oat) using tillage operations on the amount of microbial biomass at different depths.

On the other hand, in the sewage sludge vermicomposting process, the number of *Salmonella* and *Escherichia coli* was initially 17×10^3 CFU/g and 14×10^2 CFU/g, respectively, and was eliminated after 70 days of the vermicomposting process. Earthworm activity in the sewage sludge reduced the amount of pathogens and its unpleasant odor and made it stable. There is a high correlation between the bacteria in the earthworm gut and their ability to absorb these microbes (Morris & Blackwood 2024). Many researches results indicate the inhibitory role of thermophilic compost in controlling diseases and various phytopathogens such as *Rhizoctonia*, *Phytophthora*, and *Fusarium*. The positive effects of microbes may be one of the reasons for disease control because adding organic matter to the soil increases the population and diversity of microbes in the soil and enhances antagonistic effects (Raupp *et al.* 2024). Application of 10 to 30% vermicompost in greenhouse and orchard growing medium significantly reduced *Pythium* and *Rhizoctonia* in greenhouse conditions. Cabbage rot caused by *P. brassicae* was controlled when the cabbage roots were treated with clay and vermicompost. Potatoes grown with vermicompost treatment were also more resistant to *P. infestus* than those grown with chemical fertilizers. Vermicompost extract inhibited the growth of *Corticium, Sclerotinia Sclerotiorum*, and *B. cineria* in beans as well as *F. oxysporum, R. solani*, and *S. rolfsii* under field conditions (Huang - 2024). Adding organic matter to the soil and growing medium stimulates the population of various fungi and bacteria, including *Pseudomonas*, *Trichoderma*, and chitinolytic bacteria, and predatory nematodes of other nematodes, such as the insect-like nematode *Collumbola, Hypoaspis calcuttaensis*, and other arthropods that specifically feed on pathogenic nematodes. The use of vermicompost, on the one hand, increases the population of nematode-predatory fungi that destroy nematode cysts and, on the other hand, elevates the population of growth-promoting rhizobium bacteria that produce toxic enzymes for pathogenic nematodes. Adding vermicompost to soils under tomato, pepper, strawberry, and grape cultivation significantly reduced the population of pathogenic nematodes. It increased the population of fungivorous and bacterivorous nematodes compared to chemical fertilizer treatment. Living factors, including the production of nematicide compounds including hydrogen sulfide, ammonia, nitrate, and organic acids that are released during the vermicomposting process, also reduce the C/N ratio, have a direct negative effect, as well as physical and chemical properties of the soil, including soil bulk density, porosity, soil water holding capacity, EC, CEC, pH, and nutrition, have indirect adverse effects on plant pathogenic nematodes.

CONCLUSION

Soil conservation and management are essential to increase soil fertility, manage tillage schemes to restore degraded land use, and increase specific fertility. Efficient application of nutrients needs a balance of the elements added to the soil and those released over the biological decomposition of plant and animal residues added to the soil or organic matter present in the soil. The biological actions of soil that play a role in disease prevention and plant nutrient uptake are also important in environmentally beneficial cropping systems. Although control actions must be proper to soil and climate conditions, soil fertility cannot be achieved until soils are in a suitable condition in terms of biological activity. This bacterial diversity plays a significant role in soil fertility and plant growth, increasing quantitative yield (at least 20 to 70%) as well as qualitative yield and product health (up to 50%), along with producing growth-stimulating and regulating hormones. Combining chemical fertilizer with at least 20% vermicomposting increases growth indices and the effectiveness of chemical fertilizer in soil fertility.

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