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The Impact of Shelterbelts on the Nutrient Regime as Well as Enzymatic and Biological Activity of Soils

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ABSTRACT

Background: The creation and maintenance of highly productive, ecologically sustainable agricultural soils in accordance with modern conditions is impossible without shelterbelts. The studies were carried out under shelterbelts of the dry steppe zone of the Republic of Armenia, as well as under individual tree species. The changes in the content of organic matter, mobile nutrients, microbial processes and enzymatic activity in the soil and their influence were revealed.

Methods: In order to identify the impact of the shelterbelts, as well as individual tree species, on changes in organic matter, mobile nutrients, as well as microbial processes and enzymatic activity in soils, soil sampling was carried out (from 0-10, 10-20, 20-30 cm layers). Microbiological studies were carried out by sowing on solid and liquid nutrient media. The activities of invertase, urease and catalase were investigated from enzymes.The research was carried out in 1988 (the year of the shelterbelt establishment) and 2023 under the shelterbelts based on kastanozems of Kotayk region.

Result: Under the shelterbelts, over the course of 35 years, the amount of humus and mobile nutrients increases by 0.8% and 26-32%, respectively, which gradually decreases as they go farther away. During this time, the amount of bacteria and bacilli increases by 1.6-3.4 times and the content of oligonitrophiles, actinomycetes and nitrifiers decreases by 1.2-2.3 times. The activity of enzymes increases by about 14-67%. The establishment of shelterbelts in the conditions of global climate change is of great importance for the implementation of long-term programs for combating soil degradation and environmental protection.

Key words: Fermentative and biological activity, Humus, Mobile micronutrients, Shelterbelts, Tree species.

INTRODUCTION

In the context of soil degradation and global warming, it is necessary to develop and implement integrated approaches to ensure the efficiency of modern agricultural production. The creation of the shelterbelts system plays a unique role in the system of such measures, which is confirmed by numerous scientific studies and practical experience (Tkachuk, 2022).

Having an important environmental significance, the creation of the shelterbelts system is especially justified on degraded lands with low productivity (Sollen-Norrlin *et al.,* 2020; Taryono *et al.,* 2023; Sheetal *et al.,* 2024).

Numerous studies have been conducted on various aspects of the impact of shelterbelts on soil properties, crop yields and the environment. It has been established that they have a great impact not only on preventing erosion processes but also on improving the hydrological regime of soils, environmental microclimatic conditions, the efficiency of agricultural soils and increasing crop yields (Li *et al.,* 2022; Dinh and Shima, 2024; Katariya *et al.,* 2025).

The role of shelterbelts in agrolandscapes is important mainly due to its impact on soil organic matter and nutrients, as well as biological activity (Jiang *et al.,* 2022; Koshelev *et al.,* 2024).

Shelterbelts protect the soil from water and wind erosion and reduce the leaching of nutrients and biogenic substances, due to which the amount of humus in arable lands increases by 5.2-18.0% (Proezdov *et al.,* 2016).

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The main source of organic matter and essential nutrients (P, K, Ca, Mg, *etc*.) entering the soil in shelterbelts is the litter of trees, shrubs and undergrowth, as well as dying roots and parts of plants (Dhillon and Van Rees, 2017).

Some studies confirm that the effect of shelterbelts on the content of available potassium and mobile phosphorus is felt up to 100 cm depth and it decreases with depth. Thus, if at a depth of 0-20 cm the content of available

potassion increases by 117.4%, then in deep layers it increases by 24.6-39.2%. The amount of mobile phosphorus increases by 28.3% and 0.2-6.1%, respectively (Carnovale *et al.,* 2019).

The accumulation of organic matter and nutrients under the influence of shelterbelts on agricultural lands contributes to the increase in microbial biomass, their metabolism and diversity in these soils. Moreover the study of soil bioactivity allows us to identify patterns in the processes of transformation of organic matter, taking into account that microorganisms strongly respond to changes in climate and anthropogenic influences (Carnovale *et al.,* 2019; Trivedi *et al.,* 2022).

In the general process of decomposition of organic matter in soils, enzymes play a key biochemical role (Cele and Maboeta, 2016).

Soil enzyme activity, on the one hand, is characterised by high sensitivity to external influences (climatic conditions, land use, agricultural activities) and on the other hand, provides a clear picture of the ecological state of such a complex natural system as soil (Trivedi *et al.,* 2020; Perminova, 2023). That is why enzyme activity in soil is considered the best indicator of changes in the soil under the influence of natural and anthropogenic factors, which is used when applying new forms of land management and land use to assess soil qualitative changes (Khaziev, 2018).

The microbial and biochemical properties of soils are also largely determined by the tree species used in shelterbelts, which is of particular interest from the viewpoint that the amount of organic matter and physicochemical properties produced under different tree species differ significantly. This is seen when comparing the microbiota present in soils under coniferous and broadleaf tree species (Gartzia-Bengoetxea *et al.,* 2016; Trivedi *et al.,* 2020).

The study of the composition and functions of soil microbiota is essential for gaining a complete understanding of the mechanisms by which agroforestry ecosystems respond to environmental changes (Grosso *et al.,* 2018). The diversity of soil microbiota in forest areas reflects their direct relationship with vegetation cover, soil characteristics and land use types (Tripolskaja *et al.,* 2022).

In the kastanozem zone of the Republic of Armenia, a large area is occupied by eroded soils with rugged relief, located on steep slopes, unsuitable for agriculture, characterized by very low fertility and biological activity (Galstyan, 1974). In such areas, forest reclamation measures play an important role in regulating surface runoff, preventing soil erosion and restoring fertility.

It should be noted that in the Republic of Armenia, afforestation activities are very fragmented and limited and the establishment of shelterbelts is almost non-existent (Khurshudyan *et al.,* 2021). There is almost no scientific research on the impact of shelterbelts on soil and environmental microclimatic conditions.

Taking into account the aforementioned, this study was undertaken to determine the impact of shelterbelts on soil organic matter, mobile nutrient accumulation and biological activity.

MATERIALS AND METHODS

Research site

Mountain kastanozems are generally characterised by satisfactory physical properties and have a medium and heavy clayey granulometric composition. The reaction of the soil solution is alkaline. The amount of organic matter varies within 2.0-4.5%. The soils of the experimental site are poorly provided with available nitrogen and mobile phosphorus and well provided with potassium (Babayan, 2007).

The zone of formation of kastanozems is characterized by the following climatic conditions: the annual precipitation is 400-470 mm. The average yearly temperature varies within 9°C, in summer it is +20-22°C, the maximum air temperature reaches up to 38°C and the absolute minimum drops to -30°C in winter. The sum of temperatures above 10°C is 3176°C. (Babayan, 2007; Agroclimatic resources of Armenia, 2011).

The effect of shelterbelts was studied in forest strips planted 35 years ago in the Dzoraghbyur forestry area of Kotayk region, with a length of 300 m and a width of 60 m. *Amygdalus fenzliana (Frich.) Lipsky* was planted in the stand.

The effect of individual tree species was studied in the Jrvezh Forest Park, located in the northeast of Yerevan and occupies an area of 300 ha. The study was carried out under different tree species of the same age (20 years): Scots pine (*Pinus sylvestris* L.); Birch Litvinova (B*etula litwinowii Doluch.*); Oriental beech (*Fagus orientalis Lipsky*) and a mixed stand of Common ash (*Fraxinus excelsior* L.) + Alpine maple (*Acer Trautvetteri Medv*.).

Soil sampling and analysis

Soil sampling was carried out in the study areas to identify the impact of shelterbelts on changes in soil organic matter, mobile nutrients, as well as microbial processes and enzymatic activity. In order to identify the impact of the shelterbelts on changes in organic matter, mobile nutrients, as well as microbial processes and enzymatic activity in soils, soil sampling was carried out in the study areas, with three replications, from the following experimental treatments:

Treatment 1 (T1) under the shelterbelts.
Treatment 2 (T2) 30 m below the shelterbelts.
Treatment 3 (T3) control-1 forestless slope adjacent to the shelterbelts.
Treatment 4 (T4) 30 m below the shelterbelts.
Treatment 5 (T5) control-2.

Grazing is prohibited in control areas of T3 and T4. And to have a complete picture, we selected another control area T5, which is grazed and subject to direct anthropogenic

impact. Soil samples were taken from the 0-10 cm, 10-20 cm and 20-30 cm layers. Before sampling, plant litter (about 1 cm) was removed from the top layer of the soil. To study the effect of tree species composition, soil samples were taken from the areas under the foliage of each tree. Sampling points were located 0.5 m from the tree trunk. Surface litter was removed from under the foliage of standard trees, at the base of the roots. After removing litter, soil samples were taken from three locations at 0-10 cm, 10-20 cm and 20-30 cm and mixed according to the layers to obtain an average sample. Immediately after sampling, the soil samples were divided into two equal parts. One part (in a wet state) was used for microbiological and biochemical analyses and the second part for physical and chemical soil analyses.

Fresh soil samples used for microbiological and biochemical studies were sieved through a 2 mm sieve and stored at 4°C until analysis, while samples for physicochemical analyses were brought to a state of aeration and sieved through the same sieve.

The reaction of the soil solution in these samples was determined potentiometrically with a glass electrode. Humus was determined according to Tyurin, hydrolyzable nitrogen according to Tyurin and Kononova, mobile phosphorus according to Machigin and exchangeable potassium according to Maslova (Arinushkina, 1970).

Quantitative studies of various microbial groups were carried out by the soil dilution method with sowing on solid and liquid nutrient media. Sowing was carried out from fresh soil samples by the depth method. The following groups of microorganisms were observed: bacteria and actinomycetes on starch-ammonia agar (SAA) and oligonitrophiles on Ashby's modified agar. Bacilli on a mixture of meat-peptone agar and malt agar (MPA +MA) in equal proportions (according to Mishustin), nitrifiers on a liquid medium with Winogradsky chalk. For aerobic microorganisms that decompose cellulose, we used Hutchinson's modified medium. The number of fungi was determined on malt agar (MA) with lactic acid and Chapek's agar. The number of microorganisms was expressed in millions per 1 g of dry soil.

Bacteria and actinomycetes were identified using Krasilnikova's (1949) and Buchanan and Gibbons (1974) determinants and fungi were identified using Litvinov's (1967) determinant.

Among the enzymes, the activity of invertase, urease and catalase was investigated using the methods of A. Sh. Galstyan (1974).

All statistical analyzes were performed using R software (version 4.5.0). The experimental design was a two-way factorial design with treatment (T1-T5) and soil depth (0-10 cm, 10-20 cm, 20-30 cm). Prior to analysis, the data set was checked for outliers and the assumptions of the ANOVA were tested for normality of residuals (Shapiro-Wilk test) and homogeneity of variances (Leveney test).

Two-way ANOVA was used to analyze the main effects of treatment and depth as well as their interactions on the activities of invertase, urease and catalase. In cases where the ANOVA showed significant differences, treatment means were separated using the least significant difference (LSD) test at a significance level of 5% ($p<0.05$).

RESULTS AND DISCUSSION

Our research shows that shelterbelts, along with age, have a certain effect on the content of humus and mobile nutrients in slope soils. Under shelterbelts (T1), over 35 years, the amount of humus in the upper 10 cm layer of kastanozems increases by 0.5% compared to the control (grazed area). The content of mobile nutrients also increases, in particular hydrolyzable nitrogen by 0.8 mg, mobile phosphorus by 0.62 mg and exchangeable potassium by 9.9 mg per 100 g of soil. It should be noted

Table 1: The effect of shelterbelts on the nutrient content of kastanozems.

Treatments	Depth, cm	Humus, %	mg per 100 g soil		
			N	P_2O_5	K_2O
T1	0-10	3.0	3.8	2.54	44.3
	10-20	2.7	3.0	1.91	17.5
	20-30	1.9	1.9	0.83	14.0
T2	0-10	2.8	3.2	2.57	41.3
	10-20	2.6	2.0	1.0	18.4
	20-30	1.7	2.1	0.86	12.2
T3	0-10	2.9	3.9	2.60	34.0
	10-20	2.7	2.3	0.80	14.6
	20-30	1.8	2.0	1.30	8.2
T4	0-10	2.8	4.2	2.31	38.4
	10-20	2.8	2.1	1.21	16.3
	20-30	1.9	2.3	1.00	10.2
T5	0-10	2.5	3.0	1.92	34.4
	10-20	2.2	2.4	1.31	17.2
	20-30	1.2	1.5	1.00	14.4

that the content of biogenic elements (NPK) is also high below the forest (T2) and on the slopes adjacent to it (T3), which is explained by the fact that under grasses, as a result of the prohibition of grazing animals, all nutrients present in the biomass return to the soil, while in shelterbelts only those present in the leaf mass do (Table 1).

The increase in the amount of organic matter and mobile nutrients in the soil creates favourable conditions for biochemical processes.

The shelterbelts with broad-leaved tree species (Fenzlian almonds) over time also contributed to the restoration of soil enzyme activity. In particular, the activity of the invertase enzyme increases 34.7-35.8 mg glucose per 24 hours (T1; T2), approaching the level of natural enzyme activity of kastanozems of the given zone. Moreover, their positive effect on enzyme activity is felt even at a distance of 30 m from shelterbelts (Table 2, Fig 1).

As for the activity of catalase and urease enzymes in shelterbelts (T1), under them, these indicators are higher by 13.5-86.1% and 5.2-66.7%, respectively, compared to other variants. The latter is also due to the biochemical changes occurring in the soil under the influence of shelterbelts.

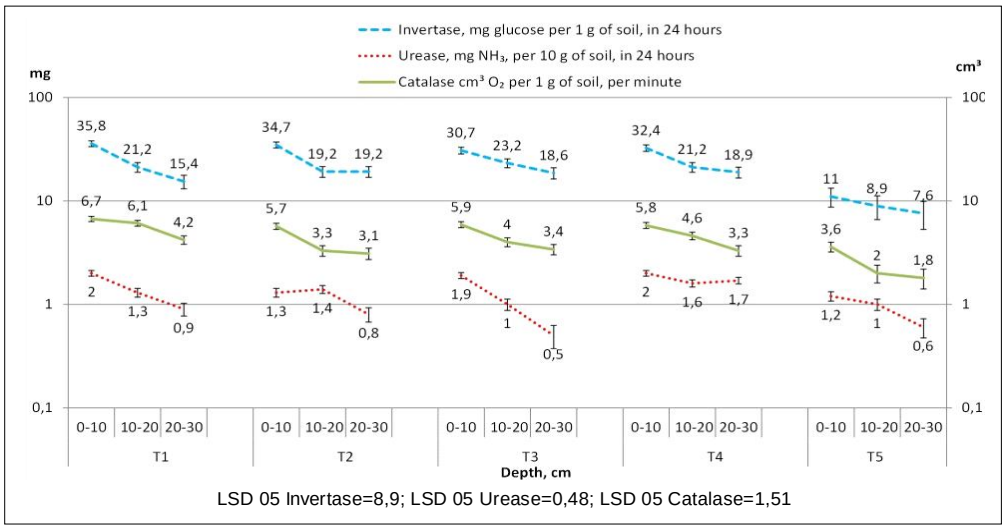
Under shelterbelts, favorable conditions are created for microbial activity and the formation of certain microbial groups in forest soils. In particular, the number of fungi under a 35-year-old Fenzlian almond reaches 1.2 million/g (T1); in the control (T3), it is 0.41 million/g (Table 3).

The number of bacteria (bacilli) that assimilate mineral nitrogen under shelterbelts (T1) reaches 17.04 million/g of soil; in the control variant (T3; T4), it is only 4.04-4.89 million/g of soil. The number of oligonitrophiles, on the contrary, decreases by about 27.6%. The number of actinomycetes also decreases, reaching 2.42 million at a distance of 30 m below the forest, which is typical of kastanozems used under grassland.

The changes occurring in the soil under shelterbelts are also determined by the species composition of the trees used in these plantations. In this direction, we

Table 2: Effect of shelterbelts on the enzyme activity of kastanozems (1988).

Variants	Depth, cm	Invertase, mg glucose per 1 g of soil, in 24 hours	Urease, mg NH_3, per 10 g of soil, in 24 hours	Catalase cm^3 O_2 per 1 g of soil, per minute
T1	0-10	26.7	1.1	6.4
	10-20	13.2	0.7	5.7
	20-30	12.6	0.5	3.5
T2	0-10	25.3	1.2	4.4
	10-20	9.0	1.1	3.5
	20-30	8.0	0.6	2.1
T3	0-10	16.5	1.1	4.3
	10-20	9.3	1.3	2.9
	20-30	6.1	1.1	1.7
T4	0-10	18.1	0.9	4.3
	10-20	9.2	0.7	3.2
	20-30	7.5	0.6	1.9



LSD 05 Invertase=8,9; LSD 05 Urease=0,48; LSD 05 Catalase=1,51

Fig 1: Effect of shelterbelts on the enzyme activity of kastanozems (2023).

conducted our research in shelterbelts consisting of different tree species (pine, birch, beech, ash and maple). The conducted studies show that under different tree species of the same height, compared to the control, the humus content increased by 0.22-0.55% over 20 years, easily hydrolysed nitrogen by 1.8-2.6 times, mobile phosphorus by 1.8-2.3 and exchangeable potassium by 1.2-1.8 times (Table 4). It should be noted that although the indicators highlighted an increase under pine compared to the control, they are inferior to the indicators recorded under broad-leaved tree species.

This is explained by the fact that conifers decompose slowly because they contain compounds that are difficult for bacteria to access.

In addition, the evergreen foliage of pine, as it gradually thickens, shades and hinders the development of vegetation in the forest layer, which ultimately affects the content of nutrients (Table 4).

We also studied the effect of different tree species on soil enzyme activity. In the Jrvezh forest park, conifers (pine), broadleaf trees (birch and beech) and mixed plantings of ash and maple were selected (Fig 2).

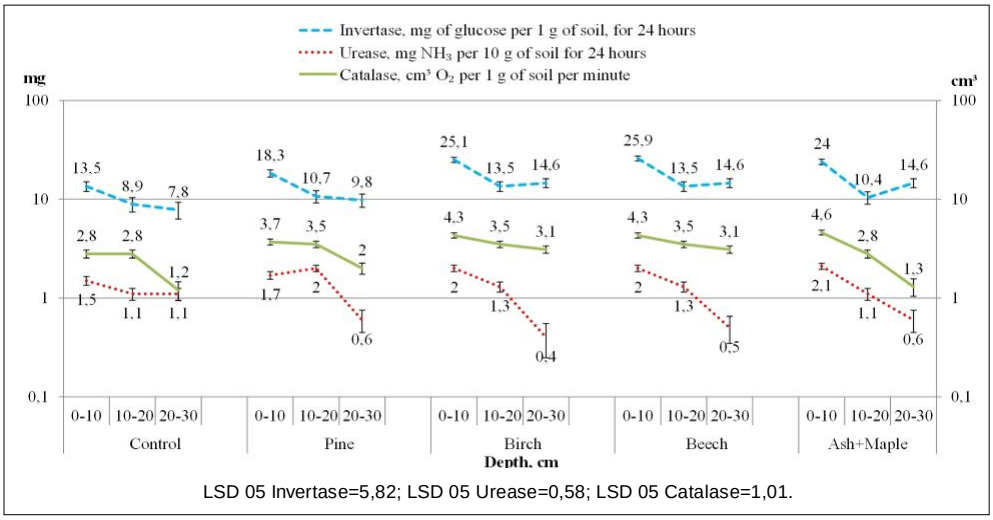
Observations show that the changed vegetation cover affects not only the content of organic matter and nutrients in the soil but also the biochemical processes taking place in the soil (Fig 2). Under broad-leaved tree species, compared to the control, the activity of the invertase enzyme increases by 1.7-1.9 times, urease by 33-40% and catalase by 53-78%, approaching the level of enzyme activity of kastanozem. Under pine, the enzyme activity, although quite high compared to the control (by 13-82%) is still significantly lower compared to broad-leaved tree species; in particular, the activity of invertase is lower by 31-41%, urease by 18-23% and catalase by 16-24%. Such indicators of enzyme activity indicate that these soils, over time, can acquire characteristics typical of forest soils.

Table 3: Effect of shelterbelts on microbial activity of kastanozems (million/g soil).

Variants	Depth, cm	Bacteria					
		Bacteria	Bacilli	Oligonitrophiles	Actinomycetea	Nitrifiers	Fungi
T1	0-10	9.92	17.04	5.11	0.34	1.25	1.2
	10-20	2.29	9.22	3.00	0.15	1.25	0.36
	20-30	2.08	6.05	2.61	0.05	1.22	0.27
T2	0-10	5.14	13.19	17.00	2.42	1.24	0.68
	10-20	2.94	5.62	8.43	1.24	1.21	0.45
	20-30	2.48	3.92	4.80	0.53	1.15	0.38
T3	0-10	6.29	4.89	6.52	1.30	1.20	0.41
	10-20	4.50	2.06	5.18	0.30	1.20	0.33
	20-30	1.96	1.52	2.17	0.0	1.20	0.16
T4	0-10	3.91	4.04	6.18	0.79	1.32	0.8
	10-20	2.3	2.49	3.40	0.34	1.26	0.35
	20-30	1.61	2.42	2.07	0.17	1.24	0.27
LSD 05		2.41	4.80	4.10	0.70	0.04	0.28

Table 4: The effect of different tree species on the humus and nutrient content of kastanozems.

Variants	Depth, cm	Humus, %	mg per 100 g soil		
			N	P_2O_5	K_2O
Control	0-10	2.15	2.1	1.24	18.0
	10-20	1.89	1.1	0.83	13.2
	20-30	0.93	0.8	0.51	6.3
Pine	0-10	2.37	3.8	2.31	22.4
	10-20	2.14	2.0	1.24	13.5
	20-30	1.22	0.8	0.62	8.0
Birch	0-10	2.57	4.3	2.61	30.6
	10-20	2.14	3.1	1.83	21.2
	20-30	1.22	1.4	1.00	8.6
Beech	0-10	2.70	5.4	2.83	32.1
	10-20	2.43	3.9	2.06	24.1
	20-30	1.64	1.3	1.31	9.7
Ash+Maple	0-10	2.60	4.5	2.54	28.2
	10-20	2.37	2.6	1.76	17.0
	20-30	1.56	1.2	1.12	8.3



LSD 05 Invertase=5,82; LSD 05 Urease=0,58; LSD 05 Catalase=1,01.

Fig 2: The effect of different tree species on the enzymatic activity of kastanozems.

Correlation analysis

Pearson correlation analysis revealed strong positive correlations between humus content and enzyme activity, both under the forest layer and by individual tree species.

- Humus content and Invertase enzyme (r=0.64-0.71).
- Humus content and Urease enzyme (r=0.74-0.79).
- Humus content and Catalase enzyme (r=0.78-0.81).

The correlations were calculated using R (cor.test function) and visualized using the ggpubr package.

CONCLUSION

The impact of shelterbelts, as well as different tree species in them, is significant on the nutritional regime of soils both under them and in the adjacent areas. Under 35-year-old shelterbelts, humus in the 0-10 cm layer increased by 0.8 and mobile nutrients by 26-32%. Depending on the tree species, over 20 years, these indicators increased by 0.2-0.5% and the amount of mobile nutrients increased by 1.2-2.6 times. This effect is felt up to 30 m below the forest edge.

Over 35 years, the number of bacteria and bacilli increased by 1.6-3.4 times and the number of oligonitrophiles, actinomycetes and the content of nitrifiers decreased by 1.2-2.3 times. Under shelterbelts an increase in enzyme activity of about 14-67% is also recorded. These differences are also significant due to tree species, under which the activity of enzymes increases by 0.3-2.5 times. It should be noted that under pine, although it increases compared to the control, it is still 16-41% less than under broad-leaved tree species. Pearson correlation analysis revealed strong positive correlations between humus content and enzyme activity (r=0.64-0.81).

The results obtained are applicable to the effective organization and management of agricultural activities, which, in the context of global climate change, will be a great contribution to combating land degradation and environmental protection.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

All authors declare that they have no conflict of interest.

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