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Establishment of Windbreaks in Semi-Arid Zones as a Method to Ensure the Sustainability of Agroecological Transformations

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ABSTRACT

In the context of ongoing global climate change, establishing protective forest layers that enhance the stability of agroecosystems has become increasingly essential. This issue is particularly pressing in arid regions such as Armenia. Prior to the 1990s, the creation of protective forest layers was a widespread practice across the Republic of Armenia, primarily aimed at reducing wind intensity and preventing the intrusion of cold air masses into agricultural and residential areas. In addition to serving as windbreaks, these forest layers played a vital role in regulating the soil's water regime and creating a favorable microclimate for the growth and development of both plant and animal life. Despite their proven importance, most of these protective forest layers have been removed across the country—including in semi-desert zones—due to shortages of fuel and energy resources. As a result, no new protective layers have been established since.However, agro-ecological transformation now presents an opportunity to develop sustainable agro-food systems, making the restoration of windbreaks in the Ararat Valley not only desirable but necessary. Such practices will support environmental sustainability while also delivering substantial socio-economic benefits. This study presents an analysis of agroecological indicators, based on which a model for the establishment of windbreaks in the study area has been developed.

Introduction

Until the 1990s, protective forest belts were established in the Republic of Armenia. However, due to shortages of fuel and energy resources, particularly in semi-desert regions, these belts were largely removed, and no new ones were planted. In the Ararat Plain, where the effects of climate change are becoming increasingly evident, implementing and maintaining strategies to enhance the stability of agroecosystems is essential. Such measures can help mitigate drought, prevent biodiversity loss, and contribute to long-term socio-economic benefits. Two representative locations were selected for the establishment of protective forest belts: roadside and mid-field sections. The proposed models serve as exemplary frameworks for designing protective belts in semi-desert zones. Agro-ecological transformations based on this approach can contribute to mitigating wind intensity, reducing the penetration of cold air currents, and regulating the soil water regime. These improvements foster a favorable microclimate, enhancing the growth and sustainability of plant and animal life.

Materials and methods

The research methodology is based on a comprehensive analysis of the literature on protective forest layers, the selection and examination of representative sites, and insights gathered from group discussions with residents. The identification of typical sites and comparative analyses were conducted using topographic maps, including Google Maps and Google Earth applications. Additionally, the vegetation cover was assessed using the route method, which involved documenting the presence of trees and plant communities within the selected sites (Harutyunyan et al., 2010). As a result of the research and analysis, representative models for establishing protective forest layers in the semi-desert zone have been developed. These models incorporate plant species native to the region, which also possess the potential to mitigate existing environmental challenges.

Results and discussions

The selected sample areas are situated in a human-induced pollution zone, resulting from industrial activities conducted by enterprises in the surrounding areas. Additionally, these locations are traversed by the Yerevan-Ararat and Yerevan-Armavir highways, further contributing to environmental stress in the region.

Picture 1. The selected sample areas at the Yerevan-Ararat highway.

The research was conducted within the agroecosystems of the Vedi community, selected due to their increased vulnerability to the aforementioned impacts. The restoration and establishment of forest belts in these areas is essential, as they play a dual role in reducing emissions from highways and mitigating the adverse environmental impacts of nearby industrial activities, particularly those associated with "Araratcement" CJSC and "Geopromining Gold" LLC (Ararat Gold Extraction Factory). Furthermore, the newly established forest belts are expected to serve multifunctional purposes, contributing to both ecological stability and landscape improvement.

Picture 2. Example of a Protective Forest Belt (www.glavagronom.ru).

In the main zones of the studied areas, the land cover is predominantly homogeneous, characterized by mountainous gray semi-desert landscapes and cultivated, irrigated soils. The mountainous gray semi-desert soils prevalent in the aforementioned zone are characterized by a chalk-rich, pulverized structure, with humus content typically not exceeding 1–2 %. However, in cultivated areas, these soils have gradually become enriched with humus, developed a silty texture over time, and transformed into fertile cultivated-irrigated soils. The geological structure of the studied areas is predominantly composed of sedimentary sandstone, gravel and gravel formations, as well as tuff formations, which serve as the parent rocks. The groundwater table is relatively high, which significantly influences the soil quality indicators, leading to increased salinization.

Table 1. Results of the soil sample analysis conducted in the agroecosystems of the Vosketap settlement (2024)*

N	Soil sample	pH	The concentration of water-soluble salts, %	$CaCO_3$, %	Hummus, %	Organic content, %	Barium concentration (mg/100g soil)		Plant-available nutrient concentration (mg/100g soil)		
							Cu	Zn	NO_3-N	P_2O_5	K_2O
1	Sample 1	7,1	0,222	13,83	2,45	6,51	0,133	-	8,4	9,42	39,9
2	Sample 2	7,9	0,069	12,37	2,57	6,82	0.118	0,214	3,06	5,27	32,0
3	Sample 3	8,0	0,075	10,51	2,55	6,63	0.040	0,158	0,83	3,97	24,5
4	Sample 4	8,0	0,039	11,44	2,62	6,72	0.037	0,045	1,77	3,92	28,8

*Composed by the authors.

In soil samples 1 and 2, the soil pH is weakly basic, while in the other two samples, it is predominantly strongly basic. The concentration of water-soluble salts in soil sample 1 surpasses the recommended threshold, with the optimal range being 0.05–0.2 %, whereas in the remaining samples, the levels of water-soluble salts are within the acceptable range for optimal plant growth.

The analyzed soil samples are calcareous. Overall, the study area demonstrates a moderate to adequate availability of key macronutrients, with phosphorus (P) and potassium (K) being relatively abundant. In contrast, nitrogen (N) is generally found in limited to moderate amounts (Table 1) (Forest Restoration and Climate Change in Armenia – FORACCA Project, Plan for the Establishment of Protective Forest Layers, 2024).

The results of the soil sample analysis from the study sites also indicated that the soils are predominantly light clay in terms of their texture and mechanical composition. Additionally, these locations are traversed by the Yerevan-Ararat and Yerevan-Armavir highways, further contributing to environmental stress in the region. I n the observed areas, specifically within the agroecosystems adjacent to the Yerevan-Ararat highway, studies conducted between 2008 and 2010 revealed that the concentrations of Cu and Pb in vineyards and vegetable crops exceeded the acceptable limits for various soil types. In contrast, the levels of other heavy metals (Zn, Mn, Ni, Cd) remained within permissible limits. This contamination is primarily attributed to emissions from motor vehicles and industrial activities, particularly from the Ararat Cement Plant.

It is important to note that the analysis of yield indicators for tomatoes, eggplants, and peppers cultivated in the studied areas revealed that crops grown within 150-200 meters from highways exhibited weaker growth and development compared to those grown at distances of 500 meters or more. Additionally, the plant density per unit area was 5-10% lower in the former group (Table 2). Based on the findings, it can be concluded that the concentrations of certain heavy metals in the soils do not pose a significant threat to the ecological safety of agricultural products (Galstyan, et al., 2010).

Windbreaks offer many direct effects on agricultural production with maximum benefits of ecosystem biodiversity. Despite the indisputable advantages and favorable effects of permanent linear vegetation elements, their representation in the agricultural landscape is not as frequent as it used to be (Podhrázská, et al., 2021).

Table 2. Yield indicators of vegetable crops in agroecosystems adjacent to the Yerevan-Ararat highway (average data for 2008-2010)*

Name of the highway	Distance from the highway (m)	Average yield (c/ha)		
		tomato	eggplant	pepper
Yerevan-Ararat	500 (checker)	410	354	285
	250	400	341	280
	50	352	330	250
	25	326	310	230

*Composed by the authors.

Table 3. Results of heavy metal concentrations in soil samples collected from the agroecosystems of the Vosketap settlement (2024)*

Soil sample	**Studied elements (mg/kg)**											
	Cr	**+/-**	**Pb**	**+/-**	**As**	**+/-**	**Mo**	**+/-**	**Zn**	**+/-**	**Mn**	**+/-**
Sample 1	1350	140	11	7	0	0	4	4	8	6	3200	120
Sample 2	1090	140	0	0	0	0	0	0	9	5	2930	110
Sample 3	2630	170	0	0	0	0	13	13	0	0	3620	120
Sample 4	2080	150	0	0	0	0	10	10	0	0	2310	100

*Composed by the authors.

In 2024, studies conducted in the same areas revealed a significant increase in heavy metal contamination. The concentration of chromium (Cr) in soil samples exceeded the threshold limit value (TLV) by approximately 15 to 37 times, while molybdenum (Mo) levels were exceptionally high, surpassing the TLV by 3 to 10 times. Additionally, manganese (Mn) concentrations were at least twice the TLV, whereas the levels of zinc (Zn) and arsenic (As) remained within acceptable limits. These findings indicate that the selected sites are directly impacted by severe anthropogenic pollution (Table 3).

The analysis of data from the Urtsadzor meteorological station for the period 2019-2023, provided by the Hydrometeorology and Monitoring Center of the RA Ministry of Environment, reveals that climate change has contributed to an increase in wind currents and intensity in the studied region. Local residents report that this change has adversely affected both the qualitative and quantitative characteristics of the crops. (This is a recommendation which is not relevant for this chapter, you would rather move it to the conclusion part).

Windbreaks are often created by leaving existing trees in strips or by planting trees between fields, inside fields, and near farm buildings (Dawid, 2021). Windbreaks play a significant role in minimizing soil erosion and reducing evapotranspiration, while also contributing to improved crop yields and offering a range of additional on-farm benefits. Notably, their establishment and maintenance require relatively low investment, and they can be integrated into agricultural landscapes without occupying substantial land area (University of Florida IFAS, 2017; Center for Agroforestry, 2024).

By significantly decreasing wind speed, windbreaks contribute to the modification of the microenvironment within crop fields, thereby influencing factors such as evapotranspiration, soil moisture retention, and temperature regulation. Depending on the crop, the type of soil, and the local climate, various benefits to crop growth and development occur (Hevs, 2019).

Based on the studies, considering the characteristics of the zone, the agrochemical properties of the analyzed soil samples, and input from local residents and government authorities, models for the establishment of protective forest belts were developed through collaborative design (Tables 2 and 3).

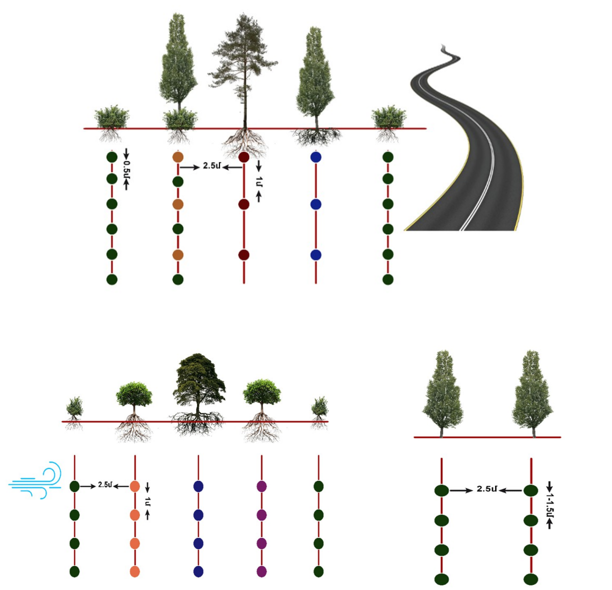

Figure. Proposed roadside and auxiliary protective forest layer models (*composed by the authors*).

Picture 3. 3D model of the proposed primary protective forest belt.

The proposed protective forest belts—comprising roadside, main, and auxiliary belts—incorporate plant species characteristic of the region (Table 4). These species are selected not only for their suitability to the local environment but also for their potential to mitigate prevailing environmental challenges. Such practices, widely implemented and recognized as successful in global green agriculture initiatives, contribute to the long-term sustainability of these systems (Ghazaryan, et al., 1974).

Table 4. Proposed plant species for the protective forest belt models*

Arboreal species	Populus deltoides (Canadian poplar) E. orientalis (Elaeagnus) Salix alba (Willow) Morus alba (Mulberry) *Zízíphus jujúba* (Jujube) Armeniaca vulgaris Lam. (Apricot tree) Ulmus pumila "Pinnato-ramosa" Dieck (Pinnate-branched elm) Gleditsia triacanthos L. (Honey locust) Pyrus caucasica Fed. (Caucasian pear) Salix alba L. (White willow) Acer ibericum M.Bieb. (Georgian maple) Elaeagnus angustifolia L. (Narrow-leaved oleaster) Sorbus torminalis (L.) Crantz (Wild service tree, sometimes called Eastern apple tree)
Shrub species	Caragana arborescens Lam. (Siberian peashrub) Ribes aureum Pursh (Ribes) Rosa canina L. (Rosehip)

*Composed by the authors.

Conclusion

To establish an optimal agroecosystem structure in the semi-desert zone, protect soils from anthropogenic impacts and vehicle emissions, and facilitate agro-ecological transformations, it is essential to restore and establish protective forest belts. These belts hold significant ecological value, as they contribute to the creation of a microclimate that fosters plant growth and development, enhances crop yields, and improves their quality. As phytoameliorants, forest belts will also positively influence the ecological safety of agricultural products derived from agroecosystems adjacent to highways. Thus, to ensure the stability of agro-ecosystems, enhance the production of ecologically safe agricultural products in areas adjacent to the Yerevan-Ararat highway, and mitigate the adverse effects of wind, we propose the restoration and establishment of protective forest belts (www.armstat.am/file/article/eco_book_2023_1ent).

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Declarations of interest

The authors declare no conflict of interest concerning the research, authorship, and/or publication of this article.

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