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The Influence of the Depression Zone of Forest Shelterbelts on the Productivity and Profitability of Winter Wheat

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ABSTRACT

Background: The article presents the results of a study which is characterizing the impact of a forest shelterbelt on the productivity and profitability of winter wheat of the dry steppe zone of Volgograd region (Russia). The relevance of the problem was due to the fact that most of the agriculture is used to be concentrated in the steppe and forest-steppe natural zones. It is known that these territories were used to be forest reclamation facilities in the form of a network of protective forest belts. Also it touched the research aimed n need to evaluate the efficiency of winter wheat production within depression zones. The hypothesis means that the soil and climatic conditions of dry steppe regions, were utilizing these depression zone for arable land which significantly reduced the productivity and profitability of winter wheat cultivation.

Methods: The work presents the biological productivity which was taken into account by using the method of meter-long plots in triplicationand a soil moisture was determined by the thermostat-weight method and grain quality was determined by using an infrared analyzer “InfraLUM FT-12”. The territory was visualized by using an unmanned aerial vehicle and chemical analyzes of soil samples were performed in the soil analysis laboratory of the FSC of Agroecology RAS by using generally accepted methods in soil science.

Result: The research determined that depression zones arise in the steppe and dry steppe zones on the territory of agroforest landscapes near protective forest plantations. The areas of these zones occupy 4-8% of the total arable land area. Observations have shown that soil moisture in the depression zone in the meter-long layer is lower than in the inter-strip space. At the same time, the lack of mineral nutrition elements leads to a significant decrease in biometric indicators and the quality of winter wheat grown.

Key words: Agroforestry area, Arable land, Depression zone, Productivity, Winter wheat.

INTRODUCTION

Agroforestry, which originated in Russia in the mid-19th century, is a scientific discipline that develops a set of measures carried out in agro landscapes (C'akir, 2020). The purpose of agroforestry measures is to create protective forest plantations for the rational management of agricultural activities in arid steppe areas.

In the steppe and dry steppe zones, there is a need for forest reclamation which is obvious and dictated primarily with the needs for effective and stable protection of agricultural lands from droughts and dry winds (Elabbadi *et al*., 2024). Therefore, the agro-landscape is almost completely bare, ecologically depleted and unstable, as well as the harvests. Thus, depression zones can form the border of forest belts and agricultural fields (Vavin *et al*., 2006). A depression zone in agricultural fields is an area of low productivity of agrocenoses, which is located in close proximity to forest belts (from 0 to 15 m) and has the shape of a narrow elongated strip, stretching along the forest belt. It is common problem with weeds. They often grow in depression zoneand the overall yield of agricultural crops in such areas is 40-60% lower than the average one. (Godunov *et al*., 2012; Manaenkov *et al*., 2015; Obshchiya *et al*., 2018; Manaenkov *et al*., 2023)

The relevance of the problem is due to the fact that most of the agriculture is concentrated in the steppe and forest-steppe natural zones. There is an insufficient moisture, the presence of dry periods and the design of the forest belts themselves often lead to the formation of a depression zone in the agro-landscape, which must be adapted to increase the profitability of agricultural production (Yang *et al*., 2011; Jia *et al*., 2017). In pursuit of the harvest, farmers strive to use the entire field area, ploughing close to the forest belt, which creates unfavorable agro-ecological conditions for the agrocenosis and leads to significant crop losses. The presence of an obvious depression zone necessitates the alienation of part of the arable land for a

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neutral zone that will not be sown. At the same time, the area of the depression zone in the agroforest landscape occupies about 4-8% of the total area of arable land. The involvement of the depression zone leads to crop loss and is unprofitable from an economic point of view (Konstantinov *et al.,* 1974).

The research aims are striven to evaluate the efficiency of winter wheat production in the depression zones. The hypothesis says that in the soil and climatic conditions of dry steppe regions, utilizing these depression zone for arable land significantly reduces the productivity and profitability of winter wheat cultivation.

MATERIALS AND METHODS

The studies were carried out at the Federal Scientific Center of Agroecology of the Russian Academy of Sciences in the period 2021-2024. in the framework of the state assignment No. FNFE2022-0007 “Theory and principles of formation of adaptive agroforestry reclamation complexes of the dry steppe zone of the south of the Russian Federation in the context of climate change.

The area of the Kachalino test site is 3950 hectares (Fig 1), the actual area of the of protective forest plantations is 1501.861 hectares at the moment. The shelterbelt forest cover of the territory is 10.7%, the width of the inter-strip field is 250-500 m for a length of 1250 m. Special forest reclaimed soils are formed under forest plantations. Planting of field protective forest belts was carried out in 1985-1992. The crop rotation link of the research object is a combination of fallow followed by cultivation of winter wheat.

The soils of the research plots are represented to a large extent by developed chestnut shallow heavy loamy soils on medium and light non-saline loams. According to agro-climatic zoning, the area is favorable for agricultural production such as farming, grain production, forage production, melon growing, gardening and livestock farming. In geomorphological terms, the study area is gently undulating gully-ravine.

Experimental design

The research program included field and cameral work. The field stage consisted of the following works:

i. The taxation and ameliorative assessment of the adjacent forest belt by laying sample areas which are being (25×12 m) in accordance with the methodology of forest taxation in agroforestry ameliorated areas (Kretinin, 2009).

ii. Material photography using an unmanned aerial vehicle (UAV).

iii. Soil samples to a depth of 1 m with a step of 10 cm in the forest belt and inter-strip space at a distance of 2, 5, 10, 15H (H is the height of the forest belt) which is need to determine the dynamics of soil moisture Studies to determine the dynamics of soil moisture were carried out according to the established experimental design (according to the method of V.M. Kretinin) to a depth of 100 cm with a step of 10 cm in the forest belt and inter-strip space (2H, 5H, 10H, 15H) (Kretinin, 2009; Methodological Guidelines for Conducting Comprehensive Monitoring of Soil Fertility of Agricultural Lands, 2003; Mineev, 2004).

iv. Soil sampling to the depth of the root zone (0-30 cm) to determine fertility indicators.

v. Mowing sheaves of winter wheat (*Triticum aestivum*) using a 50×50 cm agronomist’s field ruler at a distance of 2, 10, 15H from the forest belt (Fig 1).

Data analysis

The office stage included determination of biometric parameters of winter wheat sheaves from (*Triticum aestivum*), soil moisture by the thermostat-weight method, calculation of economic profitability and statistical processing of the obtained results using Microsoft Excel and STATISTICA 7.0. The quantity of given data on plant height and ear length were being tested for normality using Q-Q plot analysis and the one-sample Kolmogorov-Smirnov

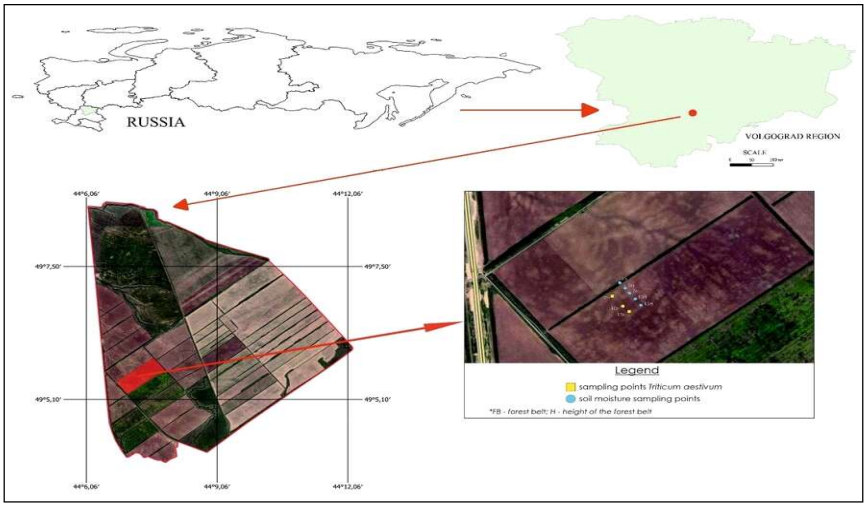


Fig 1: Map of the object of study.

test. For all data (forest stands, 2H, 10H and 15H), the p-value was < 0.05. In the soil analysis laboratory of the Federal Scientific Center of Agroecology of the Russian Academy of Sciences, using the infrared analyzer INFRALUM FT-12, a qualitative assessment of the grain was carried out forprotein, moisture, gluten and vitreousness. Chemical analyses of soil samples was also carried out in the soil analysis laboratory by using generally accepted methods in soil science.

RESULTS AND DISCUSSION

According to the research program, the taxation and meliorative characteristics of the forest shelterbelt were determined there. The age of the forest stands at the time of the research was 35-40 years. The forest stands are located on the northwestern side of the field and have the following geographic coordinates: N 49°05′28.2″, E 44°06′51.1″. The forest belt has 4 rows, 2 rows of which are represented by the main species (*Utmus laevis*), 2 outer



Fig 2: A-depression zone near the forest belt (UAV); B-general view of the agricultural landscape with UAV; C-depression zone near the forest belt.

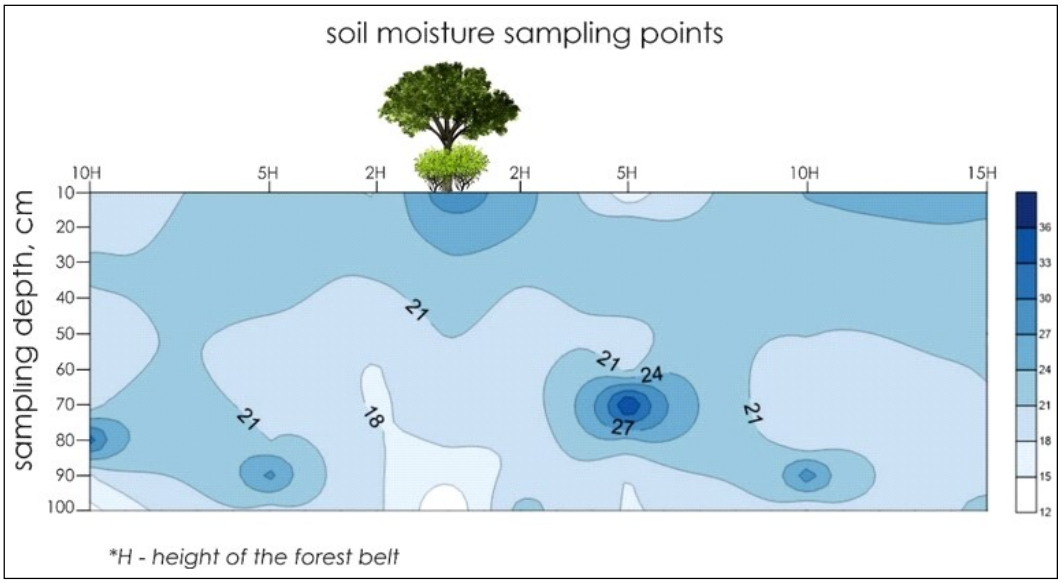


Fig 3: Soil moisture (%) in the agroforest landscape.

rows (*Ribes nigrum*), the width between rows is 3 m, the width of the forest belt is 12 m (*Rosa canina*) is found singularly. The forest belt has an openwork structure, on average, the open surface along the profile was 23.3%. The average height of the stands is 9 m, the average trunk diameter is 17 cm (Fig 2).

Based on the results of aerial photography of the agricultural landscape, the presence of a depression zone near the forest belt was confirmed (Fig 2). The depression zone extended up to 2H or 20 m.

As a result, data were obtained by characterizing the change in moisture in the 100 cm soil layer (Fig 3). Thus, the soil layer from 10 to 20 cm is characterized by significant variability in moisture. The soil under the forest belt has the highest moisture. In the zone up to 10H, there is a decrease in soil moisture which was noted, which is explained by the opposite situation - the impact of direct sunlight. It was also suggested that forest stands had the greatest impact on the microclimate in the zone up to 5H, by creating stronger winds that accelerate the evaporation of water from the surface soil layer. The influence of the root system of forest stands was also great. In the soil layer at a depth of 30-40 cm, a uniform distribution of moisture was noted throughout the test site. At a depth of 40 cm, a slight decrease in moisture was observed under the forest strip up to 5 H from it. A sharp and significant decrease in moisture under forest stands was obvious. This was explained by the peculiarities of the root system of the Siberian elm. It was powerful and extensive and consisted of the main and lateral roots that form a network in the soil. The main root of the elm usually grows vertically downwards and can penetrate to a depth of 10 meters. Lateral roots branch off from the main root and grow horizontally to the sides, forming an extensive root system. They can extend up to 30 meters from the tree trunk, which provides it with stability and support. Lateral roots are involved in the absorption of water and nutrients from the soil. The effect of elm roots on reducing soil moisture is noted at a depth of below 50 cm. At a depth of 100 cm, the moisture content in the soil under forest plantations is minimal (Fig 3) (Kretinin, 2009; Koshelev *et al.,* 2024).

The results of the analysis of soil sample shave been shown that the soils of the experimental site vary from slightly alkaline to moderately alkaline. In the depression zone, the content of macronutrients and organic matter is lower than in the forest belt and at a distance of 10H, 15H. The lack of mineral nutrition elements in plants growing at the depression zone affects the yield and the quality of the products (Table 1). Observations have shown that due to the lack of moisture and mineral nutrition elements in the depression zone, winter wheat shoots are significantly lower than in the rest of the inter-strip space. The vernalization period for such plants occurs later and, as a result, they go into winter without going through the entire phenophase cycle. In early spring, such plants lag significantly behind in development, the growth and development phases are delayed from other winter wheat plants. The research program included the analysis of

Table 1: Chemical analysis of soils in the study area.

Distance from the forest belt	Humus, %	Total nitrogen, % / ±Δ	Total phosphorus, % / ±Δ	Potassium mobile, mln^{-1} / ±Δ	pH	Dense residue, % / ±Δ
Forest belt	2.42	0.087±0.016	0.19±0.05	601±123	8.17±0.20	0.17±0.048
Depression zone	1.47	0.053±0.010	0.18±0.06	288±56	8.11±0.20	0.11±0.033
10H	1.99	0.086±0.013	0.20±0.06	551.7±111	7.70±0.20	0.23±0.070
15H	1.77	0.072±0.014	0.19±0.07	423±81	7.99±0.20	0.27±0.082



Fig 4: Sheaves of triticum aestivum at different distances from the forest belt.

biometric indicators, such as the number of stems on one plant, the number of productive stems, plant height and ear length (Table 2, Fig 4).

A statistical analysis on the growth functions of winter wheat was presented in Table 3.

Laboratory analysis of grain on Infralum FT-12 has shown that the quality of the obtained products grown in the depression zone differed significantly from the quality of grain grown outside this zone. Thus, the protein content was reduced by 21-28%, gluten by 62-72%, vitreousness by -47%. At the same time, the yield in the depression zone was 2 t/ha, outside the zone 5-6.7 t/ha, which indicates a decrease in yield by 60-70% (Table 4).

The agricultural technology of winter wheat cultivation in the Kachalino experimental farm includes a number of technological operations determined by the season. The technological map of winter wheat cultivation is a detailed plan that describes all stages of production, from field preparation to harvesting. So, in the autumn, the soil is prepared for sowing, including plowing to a depth of 10-12 cm, cultivating fallow land to a depth of 8-10 cm and harrowing in one track. After sowing winter wheat, complex fertilizers are applied in the research. In the spring, after the resumption of vegetation, farmers also add fertilizers. Plant protection includes treating arable land with pesticides. After harvesting the grain, post-harvest treatment of the arable land follows (Table 5).

The cost of one ton of grain, taking into account general business expenses, labor costs and depreciation, was $332.9. The calculation of economic efficiency has showed that growing winter wheat in the depression zone is unprofitable. With the same cost of production, the selling price of grain grown in the depression zone is lower, which is due to its quality. Due to the low yield, the profitability was about 16%, while this indicator for the rest of the agrocenosis was 226% for 10H and 144% for 15H (Table 6). The advantage of 10H over 15H in yield and profitability is due to soil fertility (Table 1).

The results of the study showed that along the forest belts there is a depression zone (from 0 to 2H, where H is the height of trees in the forest belt) with significant suppression of agricultural plants. Removing the low-productivity depression zone from the field turnover from the agricultural point of view (*i.e.* changing its use) can increase the average yield of each hectare of the field while achieving high profitability of the crop (Esaulko *et al.,* 2016;

Table 2: Biometric indicators of winter wheat in the ear ripening phase (frame 50×50 cm).

The distance from forest belt	The height of the plant, cm	The lenght of the plant a, cm	Number of stems per plant, pcs	Number of stems per plant, pcs	Number of productive stems on one plant, pcs	Weight of 1000 grains, g	Sheaf weight, g
The phase of development	Ripening of the ear			Milk ripeness			
2H (depression zone)	65	8	2	4	1	34.63	189.19
10H	99	10	5	16	3	35.77	606.05
15H	85	10	5	13	3	37.36	491.24

Table 3: Statistical analysis of the obtained results.

Distance from forest belt	n	min	Q1	med	Q3	max	M	s	V, %	x±m
Plant height statistics										
2H Depression belt	62	36	61.5	71	76.7	87	69.3	10	14.7	1.31
10H	176	70	106	110	113	120	109	7.1	6	0.53
15H	145	82	107	111	114	122	109	6.6	6	0.55
Ear length statistics										
2H Depression belt	62	3	7	9	10	13	8.6	1.9	22	0.24
10H	176	2	9	10	10.5	12	10.6	1.25	11	0.09
15H	145	4	9	10	11	12	9.96	1.2	11	0.09

Table 4: Qualitative characteristics of winter wheat and yield.

Sampling points	Protein, %	Moisture, %	Gluten, %	Vitreousness, %	Yield, t/ha
Depression belt	8.41	11.43	4.38	29.00	2.0
10H	11.73	11.73	15.78	55.00	6.7
15H	10.59	10.71	11.46	55.00	5.0

Table 5: Technological map of winter wheat cultivation in the Kachalino experimental farm.

№ t/t	Name of carried work	The volume of work	Fuel consumption, l/ha	Costs, $	Total costs, $/ha
Autumn	Plowing (10-12 cm)		16	0.49	7.8
	Fall-crop cultivation (8-10 cm)	5	10	0.49	24.3
	Harrowing in one track		10	0.49	4.9
	Sowing with application of complex fertilizers		20	0.49	9.7
	Ammophos fertilizer. kg/ha		100	0.30	30.1
Spring	Early spring application of fertilizers		10	0.49	4.9
	Ammonium nitrate fertilizer		100	0.23	23.2
	Treatment of arable land with pesticides		10	0.49	4.9
	Pesticides				7.8
	Grain harvesting		30	0.49	14.6
	Winter wheat seeds kg/ha		160	0.40	64.9
	General business expenses	7%			13.8
	Wages	20%			39.4
	Post-harvest treatment of arable land	30%			59
	Depreciation	12%			23.6
Total					332.9

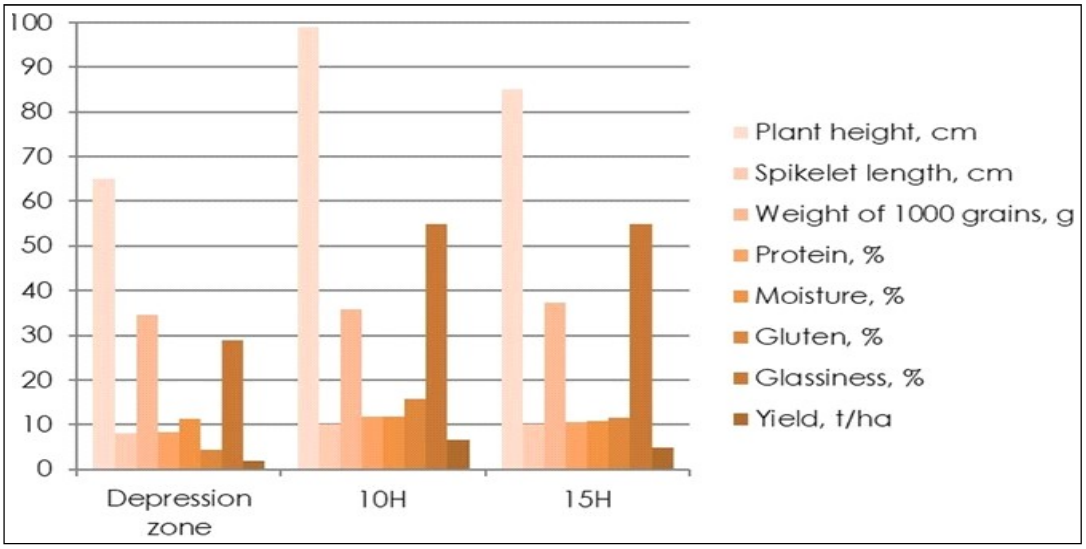


Fig 5: Winter wheat grain quality.

Table 6: Economic efficiency of winter wheat production.

	Economic efficiency of winter production		
	2H	10H	15H
Yield, kg/ha	2000	6700	5000
Cost of 1 ton of product, $.	332,9	332,9	332,9
Selling price, $/kg	0,14	0,16	0,16
Sales revenue, $.	278	1 086,5	810,8
Profit, $.	-54,8	753,7	478
Profitability, %	-16	226	144

Jia *et al.,* 2017; Zhang *et al*., 2018). Germination and condition of winter wheat crops directly depended on soil moisture. Lack of moisture leads to a decreasing of seed germination, to weak development of the root system of crops, which does not allow assimilating with a sufficient amount of nutrients from the soil. As a result, plants develop more slowly, their productivity decreases.

Observations have shown that in the depression zone, a significant decrease in the biometric indicators of winter wheat was noted than. Thus, the number of stems per plant in the depression zone is 60% lower than in the rest of the agrocenosis, the maximum number of stems per plant is 70% lowerand productive stems are 30%. During the ear ripening phase, the length of the winter wheat stem in the depression zone is 24-34% is lower than outside the zone, the ear length is 20% lower, the weight of 1000 grains is 3-7% lowerand the weight of a sheaf from a 50x50 mowing is 61-69% lower, respectively. The most important indicators of wheat quality are the protein and gluten content in the grain stem. High-protein grain (17-18%) is used to make pastaand from 10 to 14.5% - in baking. It is with this protein content, as well as from 18.0 to 32.0% raw gluten, that soft wheat grain can be used in baking and for food purposes. The final grain quality characteristics are shown in Fig 5.

CONCLUSION

Result of the research established that in the steppe and dry steppe zones on the territory of agroforest landscapes near protective forest plantations depression zones arise. The areas of these zones occupy 4-8% of the total area of arable land. Depression zones are unproductive and unprofitable when used to grow agricultural crops, in particular winter wheat. In this zone, there is a lack of soil moisture, a decrease in the biometric indicators of plants, a decrease in the quality of the resulting grain. Winter wheat production in the depression zone did not justify the costs and is generally unprofitable.

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Disclaimers

The views and conclusions which were expressed in this article are only those of the authors‘ works and do not really represent the views of their applied institutions. The authors are responsible for the accuracy and completeness of the information which is provided in this article, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

The authors are declaring that there are no conflicts of interest by regarding the publication of this article. No funding or sponsorship was influenced on the design of the study, data base, analysis, decision to publish, or preparation of the manuscript.

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