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Research Paper

Influence of protective forest belts on snow accumulation in agricultural landscapes of Volgograd region, Russia

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ABSTRACT

In semi-arid climate conditions of South of Russia (Lower Volga region), where farming is complicated by a lack of atmospheric moisture, the preservation of snow in an agroforest landscape serves as an additional source of moisture for the growth and development of tree and shrub vegetation. The paper investigates the role of forest belts of a combined structure on the nature of snow deposition depending on different patterns of shrub placement (along the top edge, along the lower edge, on both sides) during the winter of 2020-2021 in Volgograd region, Russia. The results of the conducted snow surveys show that experimental sites with shrubs along the top edge were characterized by the highest level of snow accumulation both in the forest belt and in the adjacent field. The snow-retaining function in the forest belt zone was weaker in the presence of shrubs on both sides. It has been established that the values of snow density increase with approaching the forest stand. The highest values were recorded in the forest belt with shrubs along the top edge (up to 0.5 g cm^{-3}). The accumulation of snow and its density eventually affected the amount of snow reserves. The highest values of snow reserves were observed in the forest belt with shrubs along the top edge with a row width of up to 1 m. This contributed to the accumulation of 82-203 mm of snow in the forest belt area (at 43 mm of snowfall). Shrub placement along the lower edge provoked a loss of moisture in the forest belt itself, which made this pattern ineffective. The results obtained can be applied in the design of protective forest belts in the areas with insufficient moisture.

Keywords: Forest belt, snow accumulation, snow reserves, snow density, arid climate.

Forest reclamation measures in the water catchment area contribute to increasing the stability of agricultural ecosystems and ensure their productive development. The effectiveness of forest belts has been studied by many researchers (Esaulko *et al.*, 2016; Iwasaki *et al.*, 2021; Kučera *et al.*, 2020; Trubacheva *et al.,* 2021; Rodina, 2021; Zomer *et al.*, 2009). Against the backdrop of climate aridization (especially with the appearance of long dry periods), the safety of forest belts began to deteriorate sharply. The possibility of growing trees and shrubs under such conditions is limited by a number of factors (Allen, *et al.,* 2010; Bertrand *et al.*, 2011; Chang *et al.*, 2015; Manaenkov, 2017; Repo *et al.*, 2021; Thuiller *et al.*, 2005) including precipitation. Creating the necessary conditions for moisture accumulation in forest belts can provide these areas with an additional supply of moisture. The winter period is a favorable time for creating such conditions by preventing the loss of snow into the hydrographic network and providing the conditions for its preservation. Owing to rapid climate change and global warming, study of snow accumulation and snowmelt runoff is considered very important for forecasting the availability of water, its management and for planning of safe and long-term water allocations (Kumar *et al.*, 2022).

The main structures of forest belts used in the practice of agroforestry are dense, permeable, openwork (Agroforestry, 2006). Their effectiveness in snow accumulation and snow distribution over the catchment area has been well studied (Barabanov and Kulik, 2017; Esaulko *et al.*, 2016), but in addition to the positive aspects, they have a number of drawbacks. For example, forest belts of a permeable structure contribute to a more uniform deposition of snow cover on the inter-belt space, but in the forest belt itself, snow is almost completely blown out. At the same time, the permeable structure increases the risk of deep freezing of soil, reduces the infiltration of melt water into soil and the moisture supply of a forest stand. This affects its safety and resistance to diseases and pests.

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The studies on the effects of openwork structure of forest belts on wind protection functions (Magid and Diab, 2014) and that of forest belts on snow distribution (Peterson and Schmidt, 1984) revealed that with an increase of permeability in the lower part of the belt's vertical profile, the snow accumulation function extends to a greater distance than with a dense forest belt structure. This creates strong whirlwinds during snowstorms, which leads to the formation of two snowdrifts on the leeward side. Barabanov *et al.*, (2005) patented a new structure of forest belts – a combined one. Its vertical profile is different in the degree of openwork. The combined structure of forest belts has been studied at the runoff-erosion station of the Federal Scientific Center of Agroecology of the Russian Academy of Sciences for more than 20 years proved to be quite effective in distribution of snow over the catchment surface, in reducing the depth of soil freezing, as well as in reducing the surface runoff of melt water (Barabanov *et al*., 2018; Kulik and Gordienko, 2022). Over the last decade, special attention has been paid to investigation of the impact of shrubs placement in combined forest belts on the nature of snow distribution in the agroforest landscapes. Depending on the shrub placement, speed of the wind flow changes, which affects the accumulation of snow.

The purpose of the present work is to identify the role of shrubs and their placement on the characteristics of snow deposition in protective forest belts of a combined structure.

MATERIAL AND METHODS

Research object

The studies were carried out in Volgograd, Volgograd region, Russia (48°37'59''-48°37'55'' N, 44°24'12''-44°24'56''E) on the runoff-erosion station «Amfiteatr» (Fig. 1). The object is located on a 934 m long slope of eastern exposure located on the southern end of the Volga Upland at an altitude of 45-105 m above sea level. The base level of erosion from the watershed to the foot of the slope is 58 m. The maximum angle of the slope is 7.4°. The climate of the area is hot steppe (semiarid) (BSh (McKnight and Hess, 2000)), with an average annual temperature of +7.6°C and an average annual rainfall of 350 mm, of which 34% (118 mm) falls during winter period (December-March) (Sazhin *et al.*, 2010). In the zone of dry steppes, to which the study site belongs, winter precipitation is a necessary additional source of moisture accumulation not only on agricultural land, but also in forest belts.

The soil cover at the site is characterized by heterogeneity, due to its location on the border of two gully catchments, as well as the convex-curved topography. Thus, on the northern part of the slope, soil-forming rocks are represented by light yellow carbonate sands and sandy loams, due to which Calcic Kastanozems (Loamic, Aric) and Eutric Cambisols (Siltic, Aric, Protocalcic) are widespread here. The soil-forming rocks of the southern part of the slope are represented by binomial deposits of melletic greenish-gray highly saline clays of the Kharkov stage, alternating with layers of sand, sandy loam, light and medium loams up to 0.2-0.6 m thick. Lithological heterogeneity, as well as a high degree of soil erosion contributed to the formation of Eutric Cambisols (Siltic, Aric, Raptic), as well as Calcic Kastanozems (Loamic, Aric, Densic, Raptic) (Gordienko and Ivantsova, 2021; Guidelines for Soil Description, 2006; IUSS Working Group WRB, 2014).

The study area was an experimental station for studying the factors that form the surface runoff of melt water in the agroforestry landscape. Five contour runoff-regulating forest belts of different species composition are located on the territory of the station. They were placed at different distances from each other (160-200 m). The experimental plots were located in the second forest belt from the watershed on a slope of 3-4º. The forest belt was clean and consists of green ash (*Fraxinus lanceolata Borkh.*). The forest belt had three rows of trees with spacing of ۳×1 m. The average height of the stand was 6.8 m, the average diameter of the trunk at chest height was 9.8 cm. The age of the forest belt was 41 years.

Experiment scheme

There were three main shrub placement patterns in the forest belt: along the top edge, along the lower edge and on both sides of the forest belt (Fig. 2 (a-c)). These plots were compared with the control site, which is the area without shrubs (Fig 2 (d)). There were two plots with the shrub placement along the top edge. The shrub on the first plot was represented by spirea (*Spiraea hypericifolia L.*), and on the other one – by golden currant (*Ribes aureum L.*). The shrub was 50-60 cm high and was formed by pruning. The currant had a denser vertical profile than the spirea in terms of permeability and was characterized by greater bushiness, having a row width of about 1 m. The length of plots with the same placement of shrubs was 20 m. There was a zone without forest belt maintenance (up to 30 m) between them to prevent the lateral influence of different placement patterns on each other.

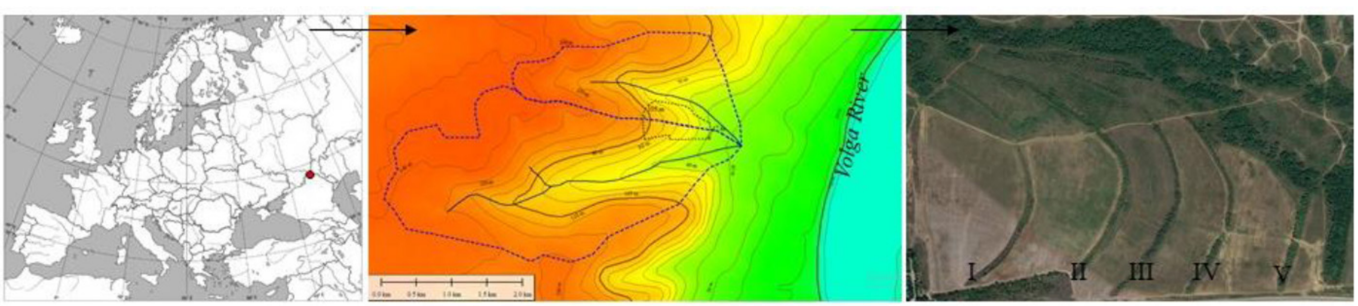

Fig. 1: Research object. I-V numbers of forest belts

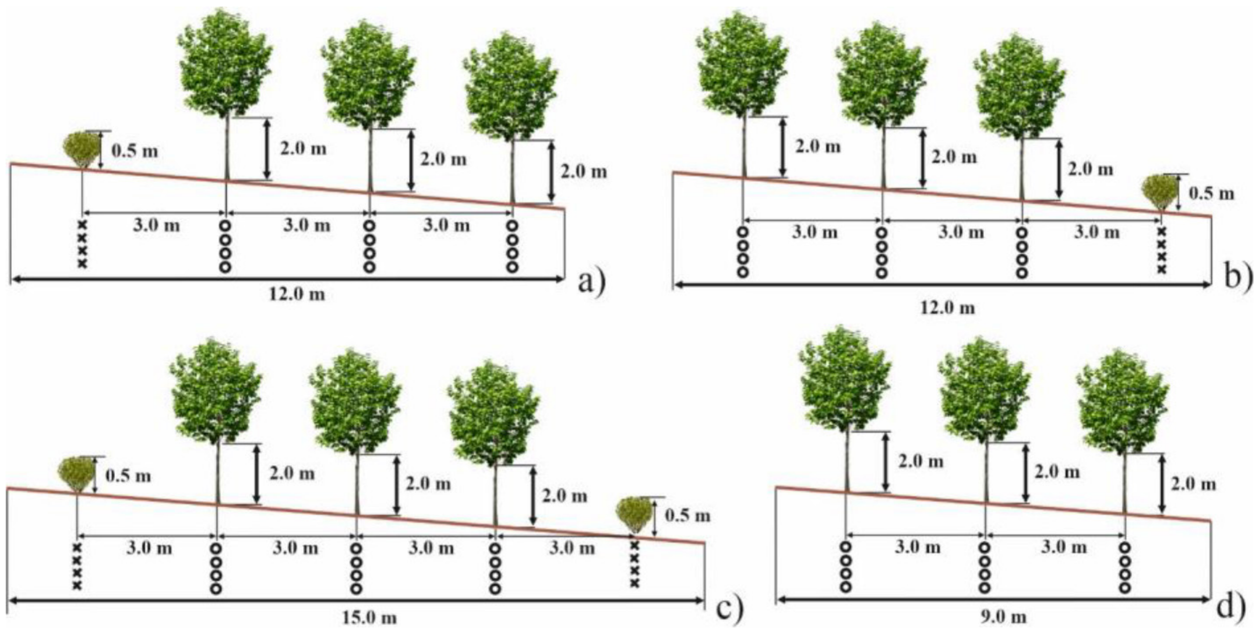

Fig. 2: Diagram of experimental plots of the forest belt with different patterns of the shrub placement. Shrub placement: a – along the top edge, b – along the lower edge, c – on both sides; d – without shrubs (control variant)

Research methodology

In the winter of 2020-2021, before the beginning of the third ten-day period of January, 54.7 mm of precipitation fell during active snowdrift, which made it possible to assess the effectiveness of the shrub influence on the nature of snow deposition to the greatest extent. Snow measurements were carried out along the profiles from top to bottom along the slope in the direction perpendicular to the runoff-regulating forest belt. The snow cover height was measured with a snow gauge three times: in the inter-belt space (in the field part) every 4 m; in the trails of the forest belt – every 2 m; and in the forest belt – every 1 m. The snow cover density was measured three times using a VS-43 weight snow gauge at a distance of 14H (where H is the height of the forest belt), 7H and H, in the first and third rows of the forest belt. Statistical processing of research results was carried out using XLstat.

The extent of wind-breaking influence of forest belts accepted in Russia is 25-30H on the leeward side and 3-5H on the windward side. At the same time, an increase in the snow accumulation function is noted at a distance of up to 10-20H (Agroforestry, 2006). According to foreign studies, the total effect of forest belts extends over a distance of up to 25H, with the wind regulation effect extending up to 20H, and protection against wind erosion (blowing) only up to 10H (Anonymous, 2007). It is can be concluded that, the wind break influence of forest belt extends up to 10-15H on average. The space between belts where observations were carried out was 200 m wide. Determination the studied parameters along the profiles in the direction of the forest belt in the following points: the middle of the field, the zone of depression and inside the plantation was a mandatory requirement during the observations. The distance between the border points was 100 m, which is very much for these studies, so it was decided to lay one more between them. Thus, the generalization of the data obtained was carried out by zones of influence: top (14H), middle (7H), bottom (H); in the forest belt itself. As snow deposition in the forest belt has a bright heterogeneity, for a more detailed consideration of snow cover density, zones of 1-st and 3-rd rows of trees were singled out separately.

Weather conditions

The weather in winter within the city of Volgograd is characterized by great volatility – the presence of thaws, followed by a sharp cooling. The first snow fell on November 22, 2020 and formed a low snow cover (up to 5 cm) in the field, which completely melted by the end of the month. In the first decades of December, no precipitation was observed, and only by the 20th day of the month snow fell (6 mm). Subsequent thaws, which lasted until January 10, 2021, contributed to the complete disappearance of the snow cover. In the second decade of January, when the air temperature dropped to -15-22ºC, snowfalls were observed. Over the period from January 12 to January 22, 2021, 43.3 mm of precipitation fell in the form of snow, contributing to the formation of a stable snow cover.

RESULTS AND DISCUSSION

Assessment of the forest belt location in relation to the direction of snowstorms

Location of the forest belt on the slope in relation to the prevailing chart of snowstorms has a great impact on the efficiency of the belt's snow retention capacity. An analysis of the location of the forest belt under study found that east winds approached it at a 90º angle, with the plantation contributing most to snow retention (Fig. 3). In the studies Anonymous (2007) and Jiao-jun *et al*., (2002), it is proved that when the forest belt is located perpendicular to the prevailing wind, the range of its influence practically does not change.

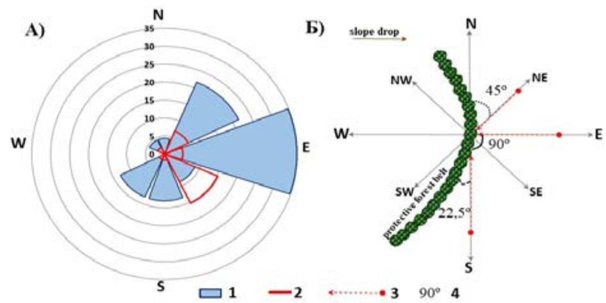

Fig. 3: Snowstorm frequency chart and location of the forest belt in relation to the snowstorm's prevailing directions. 1 – snowstorm frequency, %; 2 – amount of precipitation, mm; 3 – snow drift direction; 4 – angle of approach of the snowstorm to the forest belt

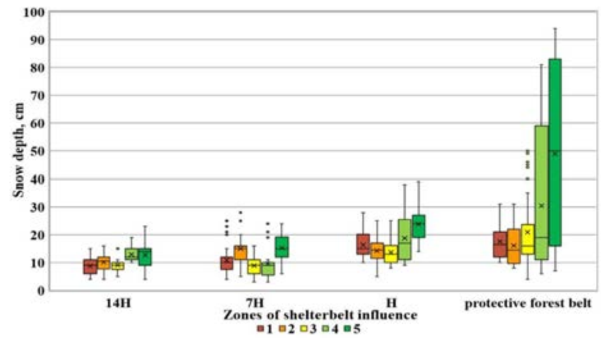

Fig. 4: Dynamics of snow cover height in different areas of the forest belt influence. 1 – without shrubs; shrub placement: 2 – along the lower edge, 3 – on both sides, 4 – along the top edge, 5 – along the top edge (shrub's row width – 1 m)

A decrease in snow accumulation function occurred during snowstorms of northeast and south directions. The angle of their approach to the forest belt was 45.0 and 22.5º, respectively, which reduced its efficiency by more than 30%. Garshinev (2002) found that at a deviation of ±10-20° from perpendicular, the range of wind breakage changes by 2-6%, and at ±30-45° up to 20-30%. When analyzing precipitation patterns, it was found that the greatest amount of precipitation (15 mm in one day) was recorded in southeasterly winds. The wind flow approached the plantation at a 45° angle, so the forest belt was not able to contain all the snow. Some of it was lost and carried out of the field into the adjacent landscapes.

The degree of openness (number of gaps in the forest belt, %) also has a strong influence on the character of snow deposition. The studied forest belt had a combined vertical profile. The main mass of snow was transported in the surface air layer (up to 50 cm), where shrubs were located, which had about 50-60% openness in a leafless form and promoted sufficient snow accumulation. According to Vasiliev (2003) at 40-50% openness and deviation of the angle of approach of the wind flow to the forest belt from perpendicular, the range of influence decreases to 10%, and at 13-31% openness to 55-20%. For a complex assessment of the forest belt effect on the character of snow distribution and accumulation, we used the formula of the total range of wind breakage effect by Garshinev (2002). It was found that the efficiency of the forest belt based on the analysis of the snowstorm wind rose was 68.7%, and the plantation should theoretically provide retention of 71.3% of the snowfall.

Characteristics of snow deposition

The results of snow measurements showed that the forest belt with the shrub placement along the top edge was the most effective pattern affecting a snow cover height (Fig. 4). At the same time, other experimental plots demonstrated the results similar to those of the control variant (without shrubs), but they were characterized by a more uniform distribution of snow in the inter-belt space. The forest belt with the shrub placement on both sides proved to be the least effective of all the patterns studied. Under its influence, less snow was deposited in the field part along the entire length than in the area without shrubs.

In the areas with the shrub placement along the top edge (shrub's row width – 1 m), the average snow cover height increased gradually from 12 to 23 cm when approaching the forest belt. In the forest belt itself, the cover's thickness increased sharply to 49 cm. At the same time, in the field part, at a distance of up to 14H, the standard deviation index varied from 4.9 to 4.1 cm, and in the forest belt it exceeded 30 cm. The characteristics of snow deposition directly depends on the aerodynamic properties of forest belts (Jiao-jun *et al.,* 2002; Wu *et al*., 2018). As a result of a long-term study of the combined structure of forest belts, it was found out that forest belts have some peculiarities due to the heterogeneous structure of their vertical profiles. On the leeward side, the belt's zone of impact was about 5H, and snow accumulation took place due to the presence of low-growing shrubs in the first row. When approaching close to the forest belt, the snowstorm stream is divided into two parts: top and lower. At the same time, the speed of the lower flow in front of the shrub decreases, which leads to additional snow deposition between the shrub and the first row of the forest belt. When eastern snowstorms predominate, snow is blown out of the zone of the lower trail, but the different placement of shrubs in the forest belt contributes to the distinctive distribution of snow cover (Fig. 5).

Thus, the shrub placement on both sides forms two zones of snow deposition. With the shrub placement along the top edge, snow is deposited between the shrub area and the first row of trees. Further down the slope, a sharp decrease in the depth of the snow cover was observed, and after the second row of the shrub, it increased again. The shrub placement only along the lower edge also forms two zones of snow deposition. The first one is formed due to a general decrease in the speed of the snowstorm as it approaches the forest belt. At the same time, snow is deposited up to the first row of trees. The second one is naturally formed in the shrub area as in the previous variant.

The shrub placement only along the upper edge ensures snow accumulation between the shrub area and the first row of the forest belt. The height of the snow cover reaches its maximum values with an increase in the shrub's row width. If we consider the

Table 1: Distribution of snow reserves under the influence of forest belts of a combined structure with different shrub placement patterns, mm

Zone of the forest belt influence	Shrub placement in the forest belt				
	along the top edge	along the top edge (row width – 1 m)	along the lower edge	along both sides	without shrubs
14H	35	35	29	19	24
7H	34	46	46	17	35
H	75	94	51	37	49
1st row of the forest belt	201	283	80	115	121
3rd row of the forest belt	53	56	66	124	72

Note. The maximum values of snow reserves, characteristic for each zone of the forest belt impact, are highlighted in the Table.

Table 2: Accumulation and loss of snow water under the influence of forest belts with different shrub placement patterns, mm

Zone of the forest belt influence	Shrub placement in the forest belt				
	along the top edge	along the top edge (row width – 1 m)	along the lower edge	along both sides	without shrubs
14H	-19.7	-19.7	-25.7	-35.7	-30.7
7H	-20.7	-8.7	-8.7	-37.7	-19.7
H	+20.3	+39.3	-3.7	-17.7	-5.7
1st row of the forest belt	+146.3	+228.3	+25.3	+60.3	+66.3
3rd row of the forest belt	-1.7	+1.3	+11.3	+69.3	+17.3

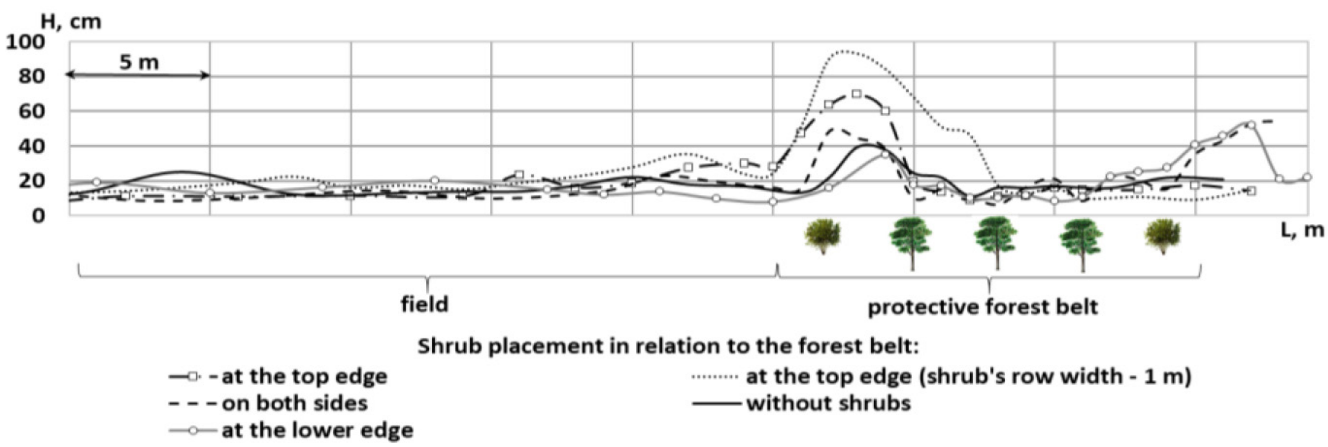

Fig. 5: Characteristics of snow deposition in the forest belt with different shrub placement patterns

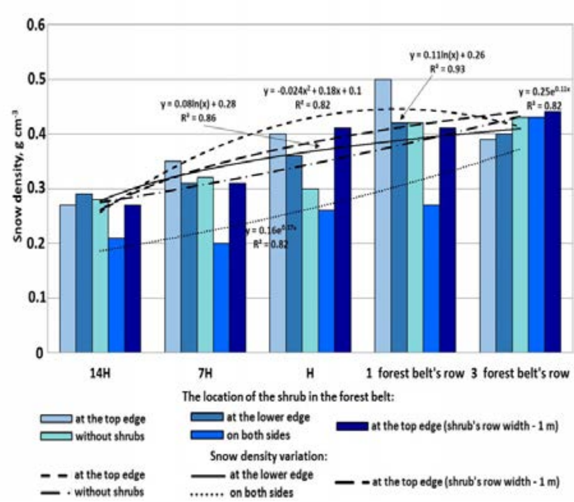

Fig. 6: Change in the density of snow cover depending on the distance from the forest belt and on different shrub placement patterns

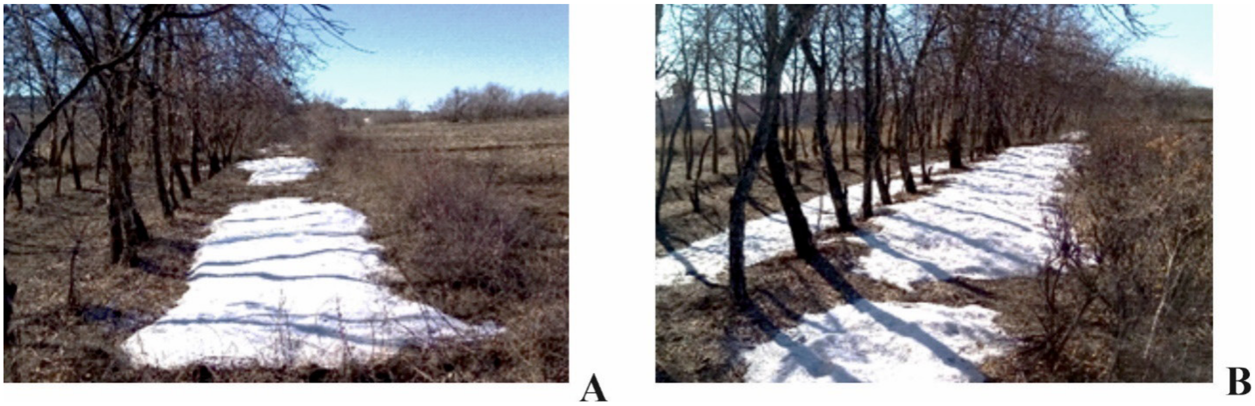

Fig. 7: Characteristics of snow melting in forest belts of a combined structure with shrub placement along the top edge with a row width of 0.5 m (A) and 1 m (B)

forest belt as a porous medium, then the force of resistance to the wind flow is determined not only by its surface area, but its volume as well (Jiao-jun et al., 2002). In our studies, with an increase in the shrub's row width to 1 m, the height of the snow cover reaches 94 cm, and with a width of about 50 cm – 81 cm.

Snow density

Forest belts not only affect the characteristics of snow deposition in the zone of their influence, but also contribute to a change in the microclimate, which was traced in the dynamics of snow cover density (Fig. 6). The shrub placement on both sides of the stand increases the snow density gradually from 0.20 g/cm^{-3} in the top part of the field to 0.43 g/cm^{-3} in the third row of the forest belt. The presence of shrubs only along the upper edge caused a greater warming effect in the zone of the first row of the forest belt, where the value of snow density reaches its maximum (0.50 g/cm^{-3}). At the same time, in the third row of plantings, the snow density sharply decreased to a minimal value as compared to other shrub placement patterns. In this area, the snow cover height was sharply reduced, the process of snow blowing was constant and the snow did not compress and thicken due to time constraints.

Snow reserves

The characteristics of snow distribution and the values of snow density determines the formation of snow reserves of the following values (Table 1). In the field part, throughout its entire length, the maximum values corresponded to the area under the influence of the forest belt with the shrub placement along the top edge with a row width of 1 m (up to 94 mm). The forest belt also accumulated the maximum amount of snow (283 mm). The shrub placement on both sides provoked snow water losses in the field part, but at the same time the snow was deposited in the third row of the forest belt.

Efficiency of the combined forest belts with different patterns of low-growing shrub placement

During the observation period, 54.7 mm of precipitation fell. The minimum losses of snow moisture in the field part were observed under the influence of forest belts with the shrub placement along the top edge (Table 2). At the same time, the accumulation of additional snow reserves was noted in the area of the first row of the forest belt. Heavy snow trails were formed in the area. During the snowmelt period, after the complete melting of the snow cover in the field, snow still remains in the forest belt (Fig. 7). Its gradual melting contributes to the infiltration of melt water into the thawed soil, while reducing losses to surface runoff.

CONCLUSION

The highest level of snow accumulation in the forest belt was revealed in the experimental plots with shrubs along the top edge. With an increase in the width of its row, the height of the snow cover also increased by an average of 25 cm. A gradual increase in the height of the snow cover in the field from 14H to the forest belt was observed. The shrub placement influenced the change in the aerodynamic properties of the forest belt, which was reflected in the characteristics of snow accumulation. In the presence of shrubs on both sides of the forest belt, two zones of snow deposition were formed. The same characteristics were observed in the area with shrub placement along the lower edge, but the snow-retaining function in the forest belt zone was weaker. The values of snow cover density naturally increased with approaching the stand. At the same time, the highest values corresponded to the forest belt with shrubs along the top edge (up to 0.5 $g\ cm^{-3}$). The characteristics of snow accumulation and the dynamics of its density ultimately affected the amount of snow reserves. Thus, the forest belt with shrubs along the top edge with a row width of 1 m is characterized by the best performance in almost all zones. It contributed to the accumulation of 82 to 203 mm of snow in the forest belt, which served as a reserve of additional moisture in the zone with insufficient moisture. In the forest belts with shrubs along the lower edge, moisture loss was observed in almost all zones, except for the field area, so it was not effective for improving the growth conditions of tree and shrub vegetation.

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of Soil Erosion.\

Conflict of Interest Statement: The author(s) declare(s) that there is no conflict of interest.

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