Snow-regulating role of forest belts depending on the field area

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Abstract. The article analyzes the five-year experience of observing the distribution of snow cover and moisture accumulation in snow. It has been made in the system of protective forest belts with different field areas. The studies have been conducted on the basis of the Stone-Steppe oasis. A brief description of climatic conditions, ameliorative role of protective plantings is given. It is noted that the height of snow cover is different in various field areas. At the same time the amount of moisture in snow does not change, which indicates different density. It is established that the larger the area of the field, the higher the density of snow. In spring, the highest moisture content is observed in the forest belts themselves and in the zones adjacent to them on both sides, where the snow trails were located. The length of the zone with increased moisture reserves in spring coincides with the length of the trails. It has been noted that the greatest effect of forest shelter belts was obtained in fields of 90–95 hectares. Such a system of forest belts occupies a smaller area of arable land, without reducing the protective effectiveness of plantations.

1. Introduction

The Stone Steppe is one of the famous unique objects for restoring the nature of the steppes. The creation of reclamation systems reduces the adverse effects of droughts. It provides reliable conditions for obtaining high sustainable yields of agricultural crops. The object of the research is located in the Voronezh region in the watershed between the Bityug and Khoper rivers. The object coordinates are: 51°6´ N and 40°2´ - 41°37´ E.

The plantations of the Stone-Steppe oasis are currently the best-preserved landings of the expedition by Professor V V Dokuchaev (among all the other expedition landings). A unique experiment has been carried out to combat drought and preserve the fertility of black soil on the basis of these plantings over a period of 127 years in the Stone Steppe.

The oasis of the old-growth forest belts created in the period from 1893 to 1908 counted 179.3 hectares (92 forest belts) of different types of plantings in the first 15 years. Oak was the main species during creation of these lanes in the years of the expedition. Its participation did not exceed 10% in the landing schemes of that time. The last planting points were given to the oak admixtures: European and green ash, maple, linden, birch, pine, acacia and shrubs. Elm family trees were planted as adjustment species [1].

Forest belts play a leading role in the optimization of agricultural landscapes. They evenly distribute snow on arable land, retain moisture in the soil, increase the humidity of the air, protect the
soil from water and wind erosion, and improve environmental conditions in the surrounding area [2-6]. It is concluded that the recovery area only with native species present better development of vertical structure, with greater canopy closure [5].

The climate of the Stone Steppe is continental with relatively cold winters and hot, often dry summers. Atlantic air masses have the main influence on the formation of climatic conditions. The winter period lasts 137 days (on average). The steady snow cover lasts 103 days. The maximum amount of moisture in the snow accumulates in March. Wind direction is inconstant; south-east winds have the advantage in winter [7].

Hard precipitations usually fall in a more uniform layer than rain, due to their uniform nature. However, due to the specific gravity, snow easily starts moving at wind speeds of 2–4 m/s. It deposits in degradations and in various kinds of obstacles [8, 9].

The wind-measuring action of the forest belts introduces fundamental changes in the formation of snow cover. They prevent bottom snowstorms and drifting snow, reduce snow sublimation and the density of snow cover. The forest belts are also characterized by snow-retaining and snow-distributing properties, which are the result of low snow transport during snowing and snowstorms. They occur outside of their snow-protection influence.

Our observations for the accumulation and distribution of snow cover in the fields of various areas (in the system of forest belts) were carried out in the Stone Steppe for 5 years from 2015 to 2019. The areas of the fields were chosen in three sizes: 25-30 hectares, 45-50 hectares and 90-95 hectares. The fields with the smallest area (25-30 ha) are located in the system of forest belts of the expeditionary period (1899-1900). The main windbreaks are located from the north to the south. They are successfully combined with the peculiarities of dry and snowstorm southeast winds. Transverse or auxiliary forest belts were planted in the latitudinal direction and perpendicular to the main lanes. They divide the entire steppe into the rectangles and squares of fields surrounded by forest plantations. The main wind-shelter belts are planted with a greater width than the transverse ones. Their width is 45-65 m. The belts reach 110 m, sometimes more at the higher upland sections (closer to the watershed). The transverse forest belts were created with a width of 20-30 m [1]. These belts are mostly of windproof construction.

The fields with an area of 45-50 hectares and 90-95 hectares are located in the system of forest belts created in the middle of the last century (50s - 60s). These forest belts differ from plantations created by the expedition. They were planted in a narrow manner and have a width of 22-34 m. These belts have diverse species composition.

The relevance of this work is the need to clarify the size of the optimal area of the field in the design of ecological landscape farming systems.

2. Experimental part
The studies have been carried out according to the VNIALMI method [10] on the same objects in 5 years. Snow melting was carried out through the fields which were perpendicular to the forest plantations before snow melting to study the patterns of snow deposition under the protection of forest belts. It resulted in the data on the occurrence of snow cover in the field, in the windward and leeward trails, and also in the forest belt. The measurements were carried out using a portable snow gauge M-104 with an accuracy of up to 1 cm in triplicate. The route was: download (field - windward trail - forest belt - leeward trail - field). Measurements in the field were carried out every 10 m, and in the trails and forest belt - every 2 m.

The density of snow, for calculating the moisture reserve, was determined with VS-43 device. The measurements were carried out in triplicate in the trails and in the forest belt every 3 m, and in the field - every 100 m.

The absolute soil moisture was determined in the same sections of the route. Soil specimens were collected by a soil tube from a depth of 0-10, 11-20, 21-30, ..., 91-100 cm in triplicate, placed in the soil cups. Then they were dried in an oven at 105-150 °C to the constant weight. The calculation of the absolute moisture content was made according to the formula:
the smallest area in each 10 cm of the soil layer using the formula:

\[ W = \frac{a-b}{b-c}, \]

where
a - mass of the cup with wet soil, g;
b - mass of the cup with dry soil, g;
c - mass of the cup, g.

Using the data on the density and moisture content of the soil, we calculated the moisture reserves in each 10 cm of the soil layer using the formula:

\[ W_{inc} = 10 \cdot W_{ph}, \text{ mm}, \]

where
\( W_{inc} \) - moisture content, %;
\( p \) - soil density in the layer, g/cm³;
h - soil layer, mm

**Table 1.** The main indicators of snow cover on the fields of various areas in the system of forest belts for 2014-2019.

| Year of observation | Field area 25-30, ha (M+m) | Field area 45-50, ha (M+m) | Field area 90-95, ha (M+m) |
|---------------------|-----------------------------|-----------------------------|-----------------------------|
|                     | Snow cover height, cm        | Moisture reserve in snow, mm| Snow cover height, cm        | Moisture reserve in snow, mm| Snow cover height, cm        | Moisture reserve in snow, mm|
| 2014-2015           | 26.5±0.9                    | 79.8±2.8                    | 21.2±1.1                    | 67.8±2.9                    | 19.4±0.7                    | 67.9±3.0                    |
| 2015-2016           | 12.4±1.1                    | 27.3±3.0                    | 10.2±1.0                    | 25.5±3.1                    | 9.2±0.7                     | 23.9±2.8                    |
| 2016-2017           | 28.3±0.8                    | 58.6±3.1                    | 26.4±0.9                    | 63.7±2.9                    | 23.6±0.8                    | 59.0±3.0                    |
| 2017-2018           | 41.4±0.8                    | 95.6±2.8                    | 38.4±1.0                    | 95.6±3.0                    | 35.1±0.8                    | 94.8±2.8                    |
| 2018-2019           | 44.2±1.0                    | 103.1±3.0                   | 42.5±0.8                    | 112.5±3.1                   | 40.3±0.9                    | 126.7±2.8                   |
| **Average**         | **30.6±0.9**                | **72.8±2.9**                | **27.7±1.0**                | **73.0±3.0**                | **25.5±0.8**                | **74.5±2.9**                |

**Table 2.** Density of snow on various elements of the agrolandscape in 2014-2019 (g/cm²).

| Year of observation | Field (25-30 ha) | Field (45-50 ha) | Field (90-95 ha) |
|---------------------|------------------|------------------|------------------|
|                     | Field windward   | Trail leeward    | Forest belt      | Field windward   | Trail leeward    | Forest belt      | Field windward   | Trail leeward    | Forest belt      |
| 2014-2015           | 0.30             | 0.26             | 0.26             | 0.32             | 0.28             | 0.28             | 0.35             | 0.32             | 0.30             | 0.29             |
| 2015-2016           | 0.22             | 0.19             | 0.18             | 0.25             | 0.20             | 0.19             | 0.26             | 0.25             | 0.23             | 0.23             |
| 2016-2017           | 0.21             | 0.20             | 0.19             | 0.24             | 0.21             | 0.19             | 0.25             | 0.24             | 0.22             | 0.20             |
| 2017-2018           | 0.23             | 0.22             | 0.21             | 0.25             | 0.23             | 0.23             | 0.27             | 0.24             | 0.25             | 0.22             |
| 2018-2019           | 0.23             | 0.20             | 0.20             | 0.27             | 0.24             | 0.23             | 0.31             | 0.25             | 0.23             | 0.22             |

The actual distribution of snow on the forested fields of various areas can be judged from the materials of table 1 and figure1. The average height of snow (30.6 cm) is observed in the fields with the smallest area during 5 years. As it has been mentioned above, such fields are surrounded by forest
lanes of the expedition period. That is, the belts are relatively wide with an average height of 25 - 27 m. With an increase in the area of the field, the height of the snow cover decreases by 9.5% in fields of 45-50 hectares, and by 16.7% - in fields of 90 -95 hectares. The forest belts around such fields are 24–34 m wide, with a different composition of tree species. These include oak, green ash, Norway maple, poplar, elm, and other species with an average height of 18–22 m. Moisture reserve in the snow on the fields of various sizes has no particular differences and differs only by 0.3 - 2.7%.

This is due to the fact that the density of snow (table 2) increases with increasing field area. Therefore, moisture reserve in snow is almost the same at different heights of the snow cover.

In the forest belts, surrounding the fields, the greatest average height of the snow cover (over the 5-year period) is observed in the plantations of the expeditionary period. The height is 28.3 cm. These forest belts border the fields of the smallest area (table 3).

**Table 3.** The average height of snow cover and moisture reserves in the snow in the forest belts and trails surrounding the fields of various areas for the period of 2014-2019.

| Field area, ha | Windward trail | Forest belt | Leeward trail |
|----------------|----------------|-------------|---------------|
|                | Height, cm (M±m) | Reserve, mm (M±m) | Height, cm (M±m) | Reserve, mm (M±m) | Height, cm (M±m) | Reserve, mm (M±m) |
| 25-30          | 38.1±1.1                | 76.8±2.4               | 28.3±1.0                | 56.6±2.5               | 36.3±1.0                | 74.5±2.5               |
| 45-50          | 39.5±1.2                | 93.6±2.7               | 25.1±1.0                | 50.5±3.0               | 33.1±1.3                | 73.6±2.8               |
| 90-95          | 34.2±1.2                | 88.2±3.1               | 23.7±1.3                | 55.2±2.9               | 33.4±1.4                | 77.1±2.0               |

In the fields protected by the forest belts, soil moisture improves in spring due to the absorption of moisture from snow deposits. In spring, the highest moisture content and deeper soil wetting are observed in the forest belts and in the adjacent areas on both sides where snow trails were located. The length of the zone with increased reserves of soil moisture in spring, as a rule, coincides with the length of the trails.

The conducted research on the distribution of snow cover on the forested fields of different areas enables to identify the areas with increased snow accumulation. The average snow depth reached 36.3 cm with a snow moisture reserve of 74.5 mm on the leeward side, and 38.1 cm and 76.8 mm - from the windward one, which is 3% more than snow moisture reserve in the leeward trail. It occurs in the fields with a size of 25–30 ha with a distance of 27 m from the forest belt. On fields with an area of 45-50 hectares and 90-95 hectares, the same trend is observed, but with a greater difference: by 28% and 14%, respectively. From the foregoing, it can be noted that the snow moisture reserve is higher in the windward trail than in the leeward one. An interesting fact is that, during the years of observations, the density of snow was lower in the densely forested forest areas than in the field. This affects the moisture reserve in the snow.

**Table 4.** The average moisture reserve (mm) in the meter-high soil layer after snow melting in the forest belts and trails surrounding the fields of different areas, and on the arable land for the period of 2015-2019.

| Year of observation | Field area 25-30, ha | Field area 45-50, ha | Field area 90-95, ha |
|---------------------|----------------------|----------------------|----------------------|
|                     | Windward trail | Forest belt | Leeward trail | Arab le land | Windward trail | Forest belt | Leeward trail | Arab le land | Windward trail | Forest belt | Leeward trail | Arab le land |
| 2015                | 421               | 372               | 410               | 380               | 425               | 388               | 417               | 386               | 440               | 389               | 415               | 402               |
| 2016                | 348               | 325               | 330               | 312               | 372               | 360               | 366               | 358               | 389               | 356               | 363               | 342               |
| 2017                | 412               | 396               | 401               | 392               | 421               | 395               | 415               | 404               | 441               | 400               | 424               | 405               |
| 2018                | 404               | 384               | 396               | 387               | 451               | 400               | 420               | 392               | 417               | 376               | 392               | 371               |
| 2019                | 401               | 376               | 380               | 370               | 415               | 390               | 409               | 370               | 426               | 395               | 415               | 390               |
| Average             | 397               | 371               | 383               | 368               | 417               | 387               | 405               | 382               | 423               | 383               | 402               | 382               |
The moisture reserves in the soil (table 4) on the windward side after snow melting was also higher compared to the leeward side in all the cases: it was 397 mm on fields with an area of 25–30 ha; 417 mm - with an area of 45-50 ha, and 423 mm - with an area of 90-95. There are no particular differences in the amount of moisture in snow, just as there is no difference in the moisture reserve moisture in the soil after snow melting. The difference in soil moisture reserves relative to the fields of the smallest area is 3.7%.

![Figure 1](image.png)

**Figure 1.** The distribution pattern of the average snow heights and moisture reserves in snow depending on the area of the field.

3. Conclusion
Thus, moisture reserve in the snow is almost the same and averages 73.4 mm in fields with different areas (from 25 to 95 hectares) in the conditions of the Stone Steppe. Therefore, from our observations, field areas of 90-95 hectares, surrounded by a system of shelter belts are the most efficient ones. Such a system has less arable land afforestation and high snow-spreading capacity of plantations. It is beneficial for agricultural producers.

References
[1] Vavin V S, Rymar V T, Akhtyamov A G, and Sviridov L T 2007 *Creating long-lasting protective plantings of the South-Eastern Central Chernozem region* (Voronezh: Voronezh State Academy of Forestry Engineering)
[2] Timeryanov A Sh 2014 *Forest Land Reclamation* (St. Petersburg: Lan)

[3] Kay S, Crous-Duran J, Ferreiro-Dominguez N. et al. 2018 *Agroforest Syst* **92**(4) 1075-1089

[4] Kalinichenko N P 1986 *Anti-erosion reclamation* (M: Agropromizdat)

[5] Navas R and Silva R J 2016 Ecological restoration indicators in agroforestry systems in the Atlantic forest *Ciência e Natura* **38**(2) 656-664

[6] Kort J, Bank G, Pomeroy J and Fang X 2011 Effects of shelterbelts on snow distribution and sublimation *Agroforestri Systems* **86**(3) 78

[7] Stone steppe - 100 years later 1992 (Voronezh. Editorial and publishing department)

[8] Albensky A I 1971 *Agriculture and protective afforestation* (M: Kolos)

[9] Vasilyev M E 1979 To the theory of snow dynamics in the system: forest belt - protective field. Proceedings of VASNHL. *Ways of increasing the effectiveness of full-protective afforestation* (M.: Kolos) 34 - 49

[10] Methodical instructions for laying experiments and conducting research on thinning, reconstruction, reforestation in the forest shelter belts of the steppe and semi-desert zones of the USSR 1977 (Volgograd)