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Effectiveness Assessment of Methods for Moisture Accumulation During Winter Precipitation in the Arid Steppe of Northern Kazakhstan

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Abstract: The main limiting factor for increasing yields in the conditions of the arid steppe of Northern Kazakhstan is moisture. The accumulation of moisture during Winter precipitation for plants in arid conditions in the initial stage of the growing season was a serious production problem. For 3 years of field experiments, we assessed various methods of accumulating moisture during Winter precipitation. Research methods included analysis, technical and economic calculations, experimental studies. Analysis of various methods of snow accumulation made it possible to establish that seeding coulisses on fallow, establishing herbicidal fallow, snow ridging requires a significant funds for implementation. Among analyzed methods, continuous combing or formation of stubble coulisses are more preferable. Studies of snow accumulation on stubble coulisses, continuous combingand ordinary stubble showed that the density of snow between the coulissesis 9-29% higher than the density in the coulisses and the density of snow between the coulissesis 25-63% higher than the density in the stubble or continuous combing. The explanation of this phenomenon was the hypothesis that the dispersal of snow blizzards occurred between the coulisses due to this, snow blocked this space with high density. Field experiments indicated an intensive decrease in the depth of snow with increasing distance between the coulisses. Experimental studies have established that the following parameters were rational for the stubble coulisses: distance between the coulisses 6-18 m, the width of coulisses 1.5-2 m. Field experiments showed that the water reserves in snow of the stubble coulisses with rational parameters of 25.8-32.2 mm are higher thanin the continuous combing and for 68.0-99.3 mm higher than the stubble. The results obtained were explained by the established regularities of changes in snow density and depth in the stubble coulisses and in other methods.

Key words: Stubble, combing, stubble coulisses formation, density, depth, water reserves in snow, changes

INTRODUCTION

Relevance: The main limiting factor for increasing yields in conditions of the arid steppe of Northern Kazakhstan is moisture. During the year in this region an average precipitation is 190-360 mm about 60% of it in the growing season. However, every 3 years out of ten, drought is usually occurs. Seeding is usually performed in the second half of May. And in June, there is an intensive development of vegetative and generative organs of cultivated plants. However, in the conditions of the region, May-June is the most droughty Summer months. They are accompanied by strong dry winds, drying up the soil. Due to a lack of moisture in the soil during this period with intensive solar radiation, farmers often receive irregular and thinned shoots. Lack of moisture accelerates the development of crops with the formation of low stems and yields. Analysis of weather and climate conditions shows that, the main source of moisture in the soil in early Summer is the moisture from Winter precipitation. Therefore, the accumulation of moisture during Winter precipitation for guaranteed provision of plants in arid conditions at the initial stage of the growing season is a serious production problem. Due to snow, it is possible to provide up to 40% of annual soil moisture reserves. These reserves are sufficient for obtaining good seedlings and ensuring the need for plants in moisture in the first half of the Summer before the precipitation in July. Thus with the help of Winter precipitation, the foundation of the future crop is laid. Therefore, the justification for an effective method of accumulating moisture during Winter precipitation in the arid steppe of Northern Kazakhstan is an urgent scientific problem, the solution of which is of great practical importance.

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Analysis of known methods of snow accumulation: Currently, the following methods of Winter precipitation moisture accumulation are used in the North Kazakhstan region:

- Leaving plants remains (stubble) of 12-15 cm high after harvesting crops (Barayev, 2008)
- Leaving plants remains (stubble) of 20-25 cm high after harvesting crops (Dvurechensky, 2004)
- Seeding two rows of mustard coulisses with 8 m distance between the coulissesand two or three rows of sunflower with 12-16 m distance between the coulisses (Dvurechensky *et al*., 2008)
- Herbicidal (chemical) fallow (Kaskarbaev, 2007)
- Seeding of coulisses on herbicide (chemical) fallow (Kaskarbaev, 2007)
- Snow plowing across the prevailing winds with 5-6 m distance between snow ridges (Baraev *et al*., 2008a-c)
- Harvesting of crops with continuous combing (Kaskarbaev, 2007)
- Formation of stubble coulisses with 30-50 cm height and 3.5-4.0 m width (Kaskarbaev, 2007)

Barayev (2008a-c) claims that the leaving stubble on the field provides an increase in snow accumulation compared to the dump tilling from 19.2-34.3 cm. According to the Kustanai Research Institute of Agriculture, the average snow depth for an empty fallow is 8-18 cm for stubble, treated with a subsurface cultivator 3-20 cm for untreated stubble 32-33 cm (Dvurechensky *et al*., 1979). In the studies by Barayev and Dvurechensky, it is stated that seeding the coulisses on empty fallowin the conditions of Northern Kazakhstan increases the snow accumulation in comparison with the dump tillingup to 2.5 times. Researches by Dvurechensky *et al*. (1979) that in the same region herbicide (chemical) fallow provides an increase in snow accumulation by about 1.8 times compared with the stubble and better preservation of moisture in the soil compared to empty fallow. Studies of Barayev, Kaskarbayev notes that snow ridgingin North Kazakhstan provides an increase in the depth of the snow cover compared with the dump tilling from 20-25 to 40-50 cm, the depth of soil wetting at the same time increases from 30-40 to 70-80 cm. Kaskarbaev points out that snow ridging, continuous combing and stubble coulisses are approximately equivalent in snow and water accumulation and provide an increase in yields of up to 4 c/ha compared to the stubble. Similar studies of Winter precipitation accumulation were conducted in Canada and the USA. Staple *et al*. (1960) found that 37% of Winter precipitation in Swift current accumulates on the stubble and only 9% on fallow. Caprio *et al*. (1986) found that in Montana's conditions for stubble, the depth of the snow cover is for 30-80% more than on fallow. Sharratt (2002) notes that leaving an even stubble is the easiest way to hold snow on the surface of the soil in windy areas. In studies by Fowler and Moats (1995), it is noted that the measure of stubble efficiency in snow retention is characterized by Stubble Trapping Potential (STP), determined by the Eq.:

$$STP = \frac{\text{Stubble height (cm)} \text{number of stams m}^2}{100}$$

The recommended values of STP for different crops range from 20-80. Kirkland and Keys (1981) in Saskatchewan studied the following methods of accumulating Winter precipitation: snow ridgingon fallow and stubble; coulisses of sunflower with a width of 7.5 and 15 m; coulisses of corn with a distance of 3.6 m on fallow field; wheat stubble. The results of the research indicate that wheat stubble in the long rotation was most effective and accumulated 50-60 mm of annual moisture more than empty fallow. During the snow ridging in 11 out of 16 years of experiments, snow was either blown from the rolls by strong winds or the moisture of the melted snow drained off the field in the early spring without wetting the frozen soil. The sunflower coulisses slightly increased the moisture reserves in comparison with the empty fallow. The accumulation of moisture with corn coulisses was comparable to the accumulation of moisture with wheat stubble. Pomeroy and Gray (1995) investigated several other methods of accumulating moisture during Winter precipitation such as: even stubble; stubble of different heights; formation of ungathered coulisses; formation of combed coulisses; snow ridging. According to these studies, freshly fallen snow in even stubblehas an average of about 10% of moisture. However, when the snow blows, the amount of moisture can increase to 35%. The stubble height 30-60 cm provides 31 mm of moisture in the soil compared to low stubble height of 15-30 cm. Grain losses from narrow ungathered coulisses with width of 30 cm can be compensated by favorable conditions of additional accumulated moisture. Combed coulisses should be form with a width of at least 40-60 cm. However, combed coulisses are more effective with the following parameters: the width of the coulisses 1.5 m and the distance between coulisses 10 m. These parameters provide an increase of

moisture during Winter precipitation in favorable years to 48 mm. Snow ridging gives an effect if the rolls of snow strengthen after their formation. Otherwise, they can be "blown out" by the wind. Similar esults were obtained in the Canadian steppes by Steppuhn.

Goal and objectives of study: The results of methods assessment of snow accumulation in the conducted studies are very contradictory. In some studies there are equivalence of snow ridging, continuous combing and stubble coulisses (Kaskarbaev, 2007). And in other studies there are greater efficiency of wheat stubble and corn coulisses (Kirkland and Keys, 1981) and the preference for combed coulisses. The goal of the study is to justify an effective method of accumulating moisture during Winter precipitation while cultivating grain crops in the arid steppe of Northern Kazakhstan. To achieve this goal, the following objectives were studied:

- Analysis of possible methods of accumulating the moisture during Winter precipitation in the conditions of the region and identify their advantages, disadvantages and prospects
- Explore the snow and moisture accumulation of the used methods
- Justify the parameters of promising methods

Object of study: Methods of moisture accumulation during Winter precipitation while cultivating grain crops in Northern Kazakhstan.

MATERIALS AND METHODS

The following study methods were used:

- Analysis of the snow accumulation methods used in the Northern region of Kazakhstan
- Technical and economical calculations of the costs for implementing these methods
- Experimental studies of snow and moisture accumulation on stubble, stubble coulisses and continuous combing

Technical and economical calculations of the costs for implementing various methods of snow accumulation were carried out according to a standard procedure (GOST Inc, 2010). The direct operating costs for the implementation of a particular method of snow accumulation included the costs for labor, depreciation, repair and maintenance, fuel and lubricants. When justifying the parameters of the stubble coulisses, experiments were carried out to study the snow and water accumulation instubble coulisses with various parameters. The width of the coulisses was set to 1, 1.5, 2, 3, 4 m. The distance between the coulisses was set to 6; 7, 9, 11, 14, 18, 26 m. The depth of the snow cover and the density of snow were determined using portable snow measuring rod and snow gage WS-43. Then, calculations of water reserves in snow were carried out. The obtained results were processed by the methods of mathematical statistics (Dospekhov, 1965; Guter and Ovchinsky, 1970). The justification of parameters for the formation of promising methods was carried out based on the maximum water reserves in the snow, determined by the results of field experiments. Experimental studies on the accumulation of snow on various crops and with various parameters of the stubble coulisses were carried out on the fields of "Zhanakhai" farm in Kostanay Oblast. "Zhanakhai" farmis located in a moderately arid steppe zone of the Northern region of Kazakhstan with an average annual precipitation of about 360 mm (Dvurechensky *et al*., 1979).

RESULTS AND DISCUSSION

Analysis of the methods used to accumulate moisture of Winter precipitation in the conditions of the region: The carried out analysis of researches and the executed technical and economical calculations have allowed us to formulate advantages and disadvantages of various methods of snow accumulation in the conditions of Northern Kazakhstan (Table 1).

The methods 3-5 require additional time and money. For example, seeding the on empty fallow requires up to 30 USD/ha for the preparation of fallow and about 2 USD/ha for seeding the coulisses; establishing herbicidal fallow requires up to 30 USD/ha; snow ridging requires about 7 USD/ha (Astafyev and Temirov, 2016). Method 6 does not require additional time and money because the productivity and prime cost of the combing is comparable to the productivity and prime cost of direct combining. The increase of yields by the comparative methods of snow accumulation is not constant: from 0% in the wet year to 100% in the dry year. Among considered methods, continuous combing and the formation of stubble coulisses are more preferable. These methods provide sufficient snow accumulation and do not require additional costs for implementation. Therefore, we will study these methods in more detail.

Study of snow and water accumulation parameters in perspective methods: The results of studies on snow

Table 1.Advantages and disadvantages of various methods of snow accumulation

Method of snow accumulation	Advantages	Disadvantages
Stubble 12-15 cm (check)	Does not require additional time and money	Insufficient accumulation of moisture (no more than 30-50 mm)
Stubble with height of 25 cm	Does not require additional time and money Provides an increase in snow accumulation in 1.5-1.6 times in comparison with the check Ensures good moisture retention before and after seeding with an anchor or a disk	It is impossible to apply on low stems in drought Does not ensure the yield increase in the wet year
Coulisses on empty fallow in 7-9 m	Provides an increase in snow accumulation up to 2.5 times compared to the check	Requires additional time and money: about 30 USD/ha for the preparation of fallow and 2 USD/ha for seeding the coulisses Up to 50% of moisture evaporates before seeding in spring Does not ensure the yield increase in the wet year
Herbicidal fallow	Provides an increase in snow accumulation by 1.8 times in comparison with the check Ensures good moisture retention before and after seeding with an anchor or a disc	Requires a lot of time and money (up to 30 USD/ha) Applicable only for no-till Does not ensure the yield increase in the wet year
Snow ridging in 4-6 m	Provides an increase in snow accumulation up to 2 times compared with the check	Requires a lot of time and money about 7 USD/ha Does not ensure the yield increase in the wet year
Continuous combing or stubble coulisses	Provides an increase in snow accumulation up to 2 times compared with the check Does not require additional time and money Ensures good moisture retention before and after seeding with an anchor or a disc	Duckfoot tineclogs during seeding on continuous combing Does not ensure the yield increase in the wet year

Table 2: Dependence of water reserves accumulation in snow from parameters of the stubble coulisses (2015)

Ground/variants	Parametersof stubble coulisses, height (cm/width, m)	Average depth of snow (cm)	Average density of snow (g/cm^3)	Reserve of water in snow (mm)
Stubble coulisses in 6 (m)				
1	1/46	46	0.24	110.4
2	2/46	47	0.23	108.1
Stubble coulisses in 9 (m)				
3	1/46	37	0.24	88.1
4	2/46	45	0.24	108.0
5	3/46	45	0.23	104.0
Continuous combing				
6	46/continuous	46	0.17	78.2
Stubble (check)				
7	20/continuous	20	0.18	36.0

accumulation and water reserves in snow on continuous combing and stubble coulisses in 2015 are presented in Table 2.

Snow accumulation and water reserves in snow depend on the ground. The smallest depth of snow and water reserves in 2015 are accumulated on stubble with an average snow depth of 20 cm, water reserves are 36.0 mm. Reserves of water in snow with a continuous combing are 78.2 mm. On stubble coulisses the water reserves in the snow are 2.9-3.1 times larger (Variants 2, 4, 5) than on stubble. Calculations show that the difference in the accumulation of water according to the grounds is significant. The decrease in water reserves in snow on continuous combing is explained by a decrease in snow density by 35-41% compared to the snow density on stubble coulisses at the same stubble height. Also in 2015, we have a lower density of snow by 28-33% on stubble than on stubble coulisses. Analyzing these facts, hypothesis was suggested that a decrease in the density of snow on stubble or continuous combingwas due to the absence of a zone to disperse snow blizzards. On stubble coulisses the acceleration of blizzards occurs between the coulisses due to this the snow clogs this space with high density. In connection with this in the studies of 2016 and 2017 we set the goalto estimate the density of snow in the coulisses and between the coulisses.

It is also found that the depth of the snow cover and the accumulation of water in the snow depend on the parameters of the stubble coulisses. With an average height of 46 cm and a distance of 9 m between the coulisses with a reduction in the width of the coulisses from 3-1 m, the depth of the snow cover decreases from 45-37 cm and the water reserves in snow fall from 108.0-104.0 mm (Variants 4, 5) to 88.1 mm (Variant 3). Calculations show that this difference is significant. The smallest significant difference with a confidence probability of 0.95 for these variants is 11.2 mm in fact, 15.9-19.9 mm. The decrease in the depth of the snow cover according to the variant 3 was due to the collapse of the coulisses by the wind and snow storms with a width of <1 m. In this variant, the depth of the snow cover was significantly uneven, although the snow between the coulisses had an increased density. Reserves of water in snow under variant 3 are at the level of variant 6. In

Table 3: Dependence of water reserves accumulation in snow from parameters of the stubble coulisses (2016)

Ground/Variants	Parametersof stubble coulisses, height (cm/width, m)	Average depth of snow (cm)	Average density of snow (g/cm^3)	Reserve of water in snow (mm)
Stubble coulissesin 7 m (1)	50/1.5		In coulisse	Average 135.0
		48	0.24; 115.2	
			Between coulisse	
		48	0.29; 139.2	
Stubble coulissesin 18 m (2)	50/3.9		In coulisse	Average141.1
		50	0.24; 120.0	
			Between coulisse	
		47	0.31; 145.7	
Stubble (check) (3)	15/continuous	33	0.19; 63.4	63.4

Table 4: Dependence of water reserves accumulation in snow from parameters of the stubble coulisses (2017)

Ground/Variants	Parametersof stubble coulisses, height (cm/width, m)	Average depth of snow (cm)	Average density of snow (g/cm^3)	Reserve of water in snow (mm)
Stubble coulissesin 11 (m) (1)	55/1,6		In coulisse	Average 153.3
		50	0.27;135.0	
			Between coulisse	
		52	0.30; 156.0	
Stubble coulissesin 26 (m) (2)	55/3,9		In coulisse	Average 98.8
		54	0.23; 124.2	
			Between coulisse	
		38	0.25; 95.0	
Stubble (check) (3)	17/continuous	27	0.20; 54.0	54.0

variants 2, 4 and 5, the water reserves in the snow are at the same level. Variants 1 and 3 are not studied because of coulisses collapse possibility with wind and snowstorms and a width of <1 m.

Thus, under the conditions of 2015, the stubble coulisses allow increasing the water reserves in snow as compared to the stubble by 2.9-3.1 times and by 1.4 times compared to the continuouscombing.

The results of the studyon the depth of the snow cover and water reserves in snow on various grounds under conditions of 2016 are presented in Table 3.

In 2016, the density of snow between the coulisses was higher than in the coulisses by 21-29%. The difference in water reserves of the Variants “in the coulisses” and “between the coulisses” is significant at a confidence coefficient of 0.90. It should be noted that the density of snow between the coulisses during 2016 was higher by 53-63% than on the stubble.

On 15 cm height stubble, the average depth of the snow cover was 33 cm, the water reserves in snow was 63.4 mm. On stubble coulisses, the water reserves in the snow were 2.0-2.2 times larger. This difference is significant at a confidence coefficientof 0.95. It should be noted that in the northern region of Kazakhstan in January-March 2016, there was precipitation, exceeding the average annual rate by 2.2 times. However, even with increased snow accumulation on stubble, the stubble coulisses showed their effectiveness.

The results of studies on the depth of the snow cover and water reserves in snow on various grounds in 2017 are presented in Table 4.

With a distance between the coulisses in 11 m, water reserves in snow on 54.5 mm were higher than at a distance of 26 m between the coulisses. This difference is significant at a confidence coefficientof 0.95. The water reserves on the stubble were 2.9 times lower than on the stubble coulisses in 11 m. The density of snow on the stubble was 25-55% lower than the density of snow between the coulisses. The density of snow between the coulisses was only 9-11% higher than the density of snow in the coulisses.

Dependence of the snow depth on the distance between the coulisses: With a distance of 26 m between the coulisses, water reserves in the snow between the coulisses were 24% less than the water reserves in the snow of the coulisses. With a distance between the coulisses of 11 m, the situation was reversed: the water reserves in the snow between the coulisses were 16% higher than the water reserves in the snow of the coulisses. Decrease in reserves is explained by an intensive decrease in the depth of snow with increasing distance between the coulisses. The maximum decrease is observed in the middle of the distance between the coulisses. Figure 1 shows the dependence of the snow depth on the distance between the coulisses, reduced to the same height of the coulisses. The dependencies are approximated by the second order polynomials.

The analysis of the obtained results makes it possible to define the following recommendations on the choice of the stubble coulisses parameters. The width of the coulisses should be at least 1.5 m to exclude the collapse of the wind and snowstorms and not more than 2 m excluding rolling away by propellers (Fig. 2).

The distance between the coulisses should be no more than 18 m. Since, with a small difference in the

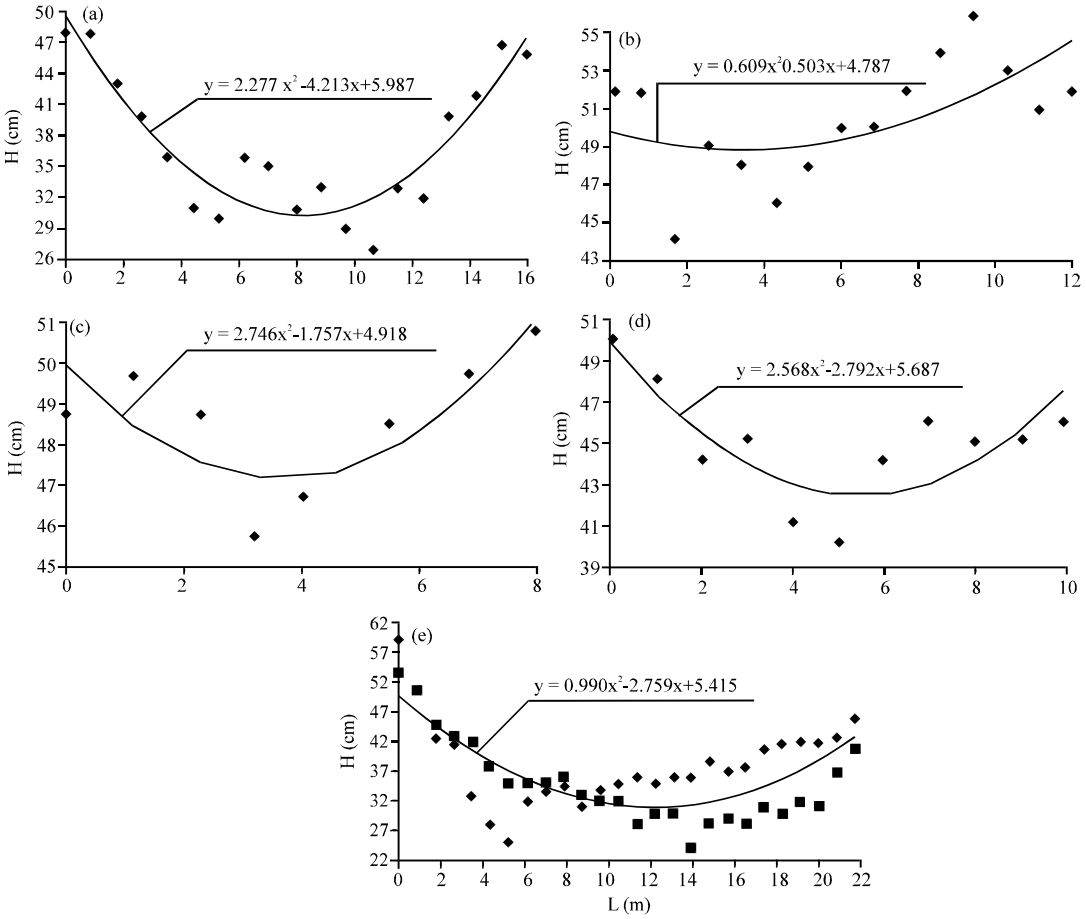

Fig. 1: Dependence of the snow depth on the distance between the coulisses; a) L = 7 m, approximation error 1.9%; b) L = 11 m, approximation error 2.7%; c) L = 14 m, approximation error 4.2%; d) L = 18 m, approximation error 5.1%; e) L = 26 m, approximation error 4.8%

Fig. 2: Rolling of the coulisses by the combine harvester

density of snow in the coulisses and between the coulisses and with a wide width of the coulisses, it is possible to obtain a decrease in water reserves in the snow due to a decrease in the snow cover depth. Thus, field experiments indicate that the following parameters are rational for the stubble coulisses: the distance between the coulisses is 6-18 m, the width of the coulisses is 1.5-2 m.

The obtained results on different density of snow in the coulisses and between the coulisses in the stubble coulisses and on the continuous combing in the stubble coulisses and on the stubble are new. A hypothesis explaining the cause of these phenomena is also new. The obtained dependences of the snow cover depth on the distance between the coulisses are also new. The new results show the preference of the stubble coulisses before snow ridging, continuous combing and stubble. These results are the opposite to the statements by Kaskarbaev (2007) that the stubble coulisses are equivalent in the accumulation of water in the snow with snow ridgingand continuous combing. This also contradicts the statements by Kirkland and Keys (1981) that the maximum of accumulated moisture is observed in standing stubble in a long crop rotation. The obtained

results develop existing knowledge about the methods of snow accumulation and are consistent with the statements by Pomeroy and Gray (1995) on the advantages of the stubble coulisses.

CONCLUSION

Today, among many researchers, there is no consensus on the preference for any method of snow accumulation. The analysis of opinions is contradictory. In this connection, the purpose of the research was to justify an effective method of accumulating moisture during Winter precipitation for the cultivation of grain crops in the arid steppe of Northern Kazakhstan. Research methods included analysis of studies, technical and economical calculations and experimental studies.

Analysis of the advantages and disadvantages of various methods of snow accumulation showed that many of them require significant costs. For example, seeding coulisses on empty fallow requires up to 30 USD/ha for fallow preparation and about 2 USD/ha for seeding the coulisses; herbicide fallow is up to 30 USD/ha; snow ridgingis about 7 USD/ha. Among the analyzed methods, continuous combing and formation of stubble coulisses are preferred, since they provide a sufficiently high snow accumulation and do not require additional costs for the implementation.

Studies on snow accumulation of the stubble coulisses, continuous combing and stubble showed that the density of snow between the coulisses is higher by 9-29% than the density in the coulisses; and by 25-63% higher than on a stubble or continuous combing.

This fact is explained by the hypothesis that the decrease in the density of snow on the stubble, continuous combing or coulisse soccurs due to the absence of dispersal zone of snow blizzards. On the stubble coulisses, dispersal of snow blizzards occurs between the coulisses, due to this, snow clogs this space with high density.

Field experiments showed the dependence of the snow depth on the distance between the coulisses, approximated by second order polynomials with an error of 1.9-5.1%. These studies show an intensive decrease in the depth of snow with increasing distance between the coulisses. For example, an intensive decrease in the snow depth affects a significant decrease in water reserves on 54.5 mm with an increase in the distance between the coulisses from 11-26 m.

Experimental studies have shown that the following parameters are rational for the stubble coulisses: the distance between the coulisses 6-18 m, the width of the coulisses 1.5-2 m. Experimental studies showed that the water reserves in the snow of the stubble coulisses with rational parameters are 25.8-32.2 mm higher than on the continuous combing and 68.0-99.3 mm higher than on the stubble. The established patterns of variation in snow density and snow depth in the stubble coulisses and other methods explained by the results.

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