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Assessment of methods of the autumn-winter moisture accumulation in poor draining soil in the arid region of Northern Kazakhstan

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Abstract

In the initial stage of the growing season, the accumulation of autumn and winter precipitation moisture in poorly draining soil in arid conditions in the Northern region of Kazakhstan was a serious production problem. Research methods included measurements of autumn and winter moisture reserves in poorly draining soil and snow on the backgrounds of ordinary stubble, stubble coulisses and tall stubble left after stripper header (continuous combing) with and without autumn chiselling. The study revealed that the use of the continuous combing and stubble coulisses on poor draining soil: (a) supports reserves of moisture in autumn soil; (b) the lack of chiselling leads to increased water runoff and the formation of limans in the fields. The use of stubble coulisses during snowy winters allowed moisture reserves in the snow to be increased in comparison with the stubble background. The use of chiselling on the background of stubble coulisses allowed: (a) to reduce runoff moisture loss in poorly draining soil by 35–50% after snowy winters, by 25–35% after little snowy winters, and prevent the formation of limans in the fields; (b) in comparison with the stubble background to increase the total reserves of autumn-winter moisture in poorly draining soil by 61–105 mm in favourable years, and by 57 mm in years with the low autumn-winter precipitation. The use of chiselling on a stubble background did not significantly affect the total reserves of autumn-winter moisture in poorly draining soil.

Key words: *arid region, coulisses, chiselling, moisture accumulation, over crusting soil*

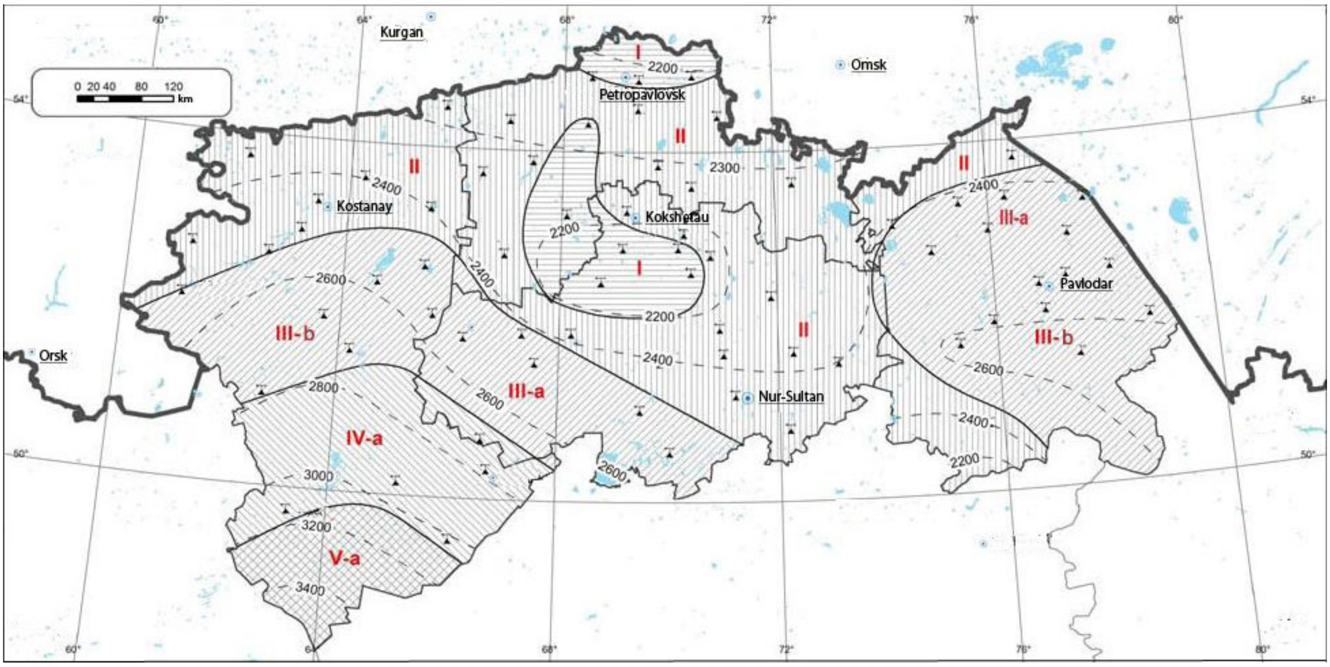
INTRODUCTION

RELEVANCE

The region of Northern Kazakhstan has four distinct features: an arid climate, the presence of overcrusting, poorly draining soils with a low humus content of 3%, and the instability of precipitation over the years (Fig. 1). The average precipitation in the region is 320 mm per year, with variations over the years from 100 to 560 mm. Every three years out of ten are usually marked with a severe drought, three years encounter average humidity, and four years of average dryness.

Sowing is carried out in the second half of May. The maximum summer precipitation in the region (on average 50–60 mm) is only in July, whereas in May–June, the precipitation is only 25–35 mm. However, these months of vegetation are accompanied by strong dry winds that dry up the soil. The analysis of climatic conditions shows that in the first half of the crop plants growing season the main source of moisture in the soil is autumn and winter precipitation. In winter, there is an average 90 mm precipitation in the form of snow, which rapidly melts down in the first half of April. However, the presence of over crusting and poorly draining soil properties complicate moisture absorption into the soil. Thus, limans are often formed in the fields. The drying of limans is often delayed by 1.5 months. Therefore, the sowing in such areas is carried out only in June. The June sowing causes late maturation of crops and losses during the harvest period due to early frosts and autumn precipitation.

Thus, the accumulation of moisture from autumn and winter precipitation in poorly draining soil is necessary to support plants in arid conditions in the initial stage of the



I – moderately moist moderately warm   II – weakly moist moderately warm   III-a – weakly dry moderately warm
III-b – weakly dry warm   IV-a – moderately dry warm   V-a – very dry moderately hot

Fig. 1. Agroclimatic zones of the Northern Kazakhstan; source: BAISHOLANOV *et al.* [2018]

growing season. In the Northern region of Kazakhstan, it has been a serious production problem.

JUSTIFICATION OF THE RESEARCH DIRECTION

In the region of Northern Kazakhstan, the following methods of moisture accumulation from winter precipitation are known and have been used at various times:

– leaving plant residues (stubble) after harvesting of agricultural crops [BARAYEV 2008; LOVCHIKOV *et al.* 2017; ŁABĘDZKI, BĄK 2017],
– snowploughing across the prevailing winds with a distance of 5–6 m between snow ridges [ROSSATO *et al.* 2017],
– harvesting of agricultural crops with continuous combing [KASKARBAEV 2007; PATRO, ZUBALA 2020; SULEYMENOV 2008], and
– formation of stubble coulisses [ASTAFYEV *et al.* 2017].

POMEROY and GRAY [1995] investigated the following methods of accumulating moisture from winter precipitation: even stubble, stubble of various heights, formation of ungathered coulisses, formation of combed coulisses, snow ridging [POMEROY, GRAY 1995]. Of all the methods, combed coulisses are more effective with the following parameters: the width of the coulisses of 1.5 m and distance between the coulisses of 10 m. In favourable years, these parameters increase the accumulation of moisture from winter precipitation to 48 mm. Snow ridging is effective, provided the rolls of snow strengthen after their formation. Otherwise, they can be "blown out" by the wind. Similar results have been obtained in the Canadian steppes by STEPPUHN *et al.* [2009].

Our research revealed that in the region of Northern Kazakhstan, the most effective method of snow accumulation is the formation of stubble coulisses. The following parameters are rational for stubble coulisses: in snowy winters, the distance between coulisses is 5–14 m and in little snowy winters 5–7 m, with the width of the coulisses of 1.0–1.5 m [ASTAFYEV *et al.* 2019]. However, previous studies have not examined the accumulation of moisture from autumn and winter precipitation in over crusting of poorly draining soil.

PURPOSE AND OBJECTIVES OF THE RESEARCH

Purpose of the research: to assess the process of moisture accumulation from autumn and winter precipitation on various backgrounds in poorly draining soils of the arid region of Northern Kazakhstan.

To achieve this purpose, the following tasks were performed:

– assessment of moisture accumulation from autumn precipitation on the backgrounds of short stubble, stubble coulisses and continuous combing in poorly draining soil at various degrees of pre-winter moisture;
– evaluation of moisture accumulation from winter precipitation on the backgrounds of short stubble, stubble coulisses and continuous combing in snowy and little snowy winters;
– estimation of the total autumn-winter accumulation of moisture on the backgrounds of short stubble, stubble coulisses and continuous combing high shear in poorly draining soil at various degrees of autumn-winter moisture.

The objective of research is to investigate the process of moisture accumulation on various backgrounds in poorly draining soil in arid conditions of the Northern region of Kazakhstan. At the beginning of the research, a hypothesis was proposed that it was possible to accumulate autumn-winter moisture in over crusting, poorly draining soils in different years by combining a method that increases snow accumulation with another method that improves the absorption of moisture into the soil.

MATERIALS AND METHODS

Research methods included:

– experimental studies of autumn moisture reserves on the backgrounds of short stubble, continuous combing, deep tillage on a short stubble background, stubble coulisses and deep tillage on the background of stubble coulisses in over crusting, poorly draining soil;
– experimental studies of snow moisture reserves on the backgrounds of short stubble, continuous combing, deep tillage on a short stubble background, stubble coulisses and deep tillage on the background of stubble coulisses;
– experimental studies of the total reserves of autumn--winter moisture on the backgrounds of short stubble, continuous combing, deep tillage on a short stubble background, stubble coulisses and deep tillage on the background of stubble coulisses in over crusting, poorly draining soils.

Stubble coulisses were formed of 1.5–3.0 m in width, with a distance between coulisses of 5–9 m [ASTAFYEV *et al.* 2019].

To increase the absorption of moisture into poor draining soil, a chiselling of the soil to a depth of 35 cm was used, with preserving the stubble of 90% on the field surface. Research by REDDY [1995] showed that it was necessary to apply deep soil-free treatment to saturate the upper and lower horizons of low-humus poorly structured soils with winter moisture [REDDY 1995]. Chiselling was performed with a chisel of 8.8 m in working width and the distance between tillage tools of 0.8 m. The chisel plow was aggregated with a Case STX 535 tractor. It should be noted that on the background of continuous combing, the chiselling was not used due to the accumulation of stubble and plant residues on the tillage tools of the chisel plow.

Experiments to determine the reserves of autumn and winter moisture on the indicated backgrounds were conducted in the conditions of a lack of autumn precipitation and little snowy winters in 2018–2019, an average level of autumn and high level of winter precipitations in 2016–2017, and a high level of autumn and the average level of winter precipitations in 2020.

The soil moisture level was determined by a well--known method. Essentially, the method determined moisture loss while drying the soil. Moisture reserves in the *i*-th horizon were determined by the equation:

$$B_i = 0.1 W_i d_i h_i \tag{1}$$

Where: B_i = moisture reserves in the *i*-th soil horizon (mm); d_i = volume mass of soil in the *i*-th soil horizon (g·cm^{-3}); h_i = thickness of the analysed soil horizon (cm); W_i = moisture in the *i*-th soil horizon (%); 0.1 = coefficient of conversion of the height of the water layer from cm to mm.

Moisture reserves in the meter layer of soil were determined by summing the moisture reserves in individual soil horizons:

$$B = 0.1 \sum W_i d_i h_i \tag{2}$$

Where B = moisture reserves in the meter layer of soil (mm).

The depth of snow cover and snow density were determined by known methods using a portable snow gauge and a snow weight meter VS-43. Then, the water reserves in the snow were calculated.

Water reserves in the snow were calculated using the equation:

$$z = 10 h\rho \tag{3}$$

Where: z = water reserves in snow, mm; ρ = snow density (g·cm^{-3}); h = the snow depth (cm); 10 = conversion coefficient t·ha^{-1} in mm.

Measurement results were processed by mathematical statistics methods [DOSPEKHOV 1965; DVURECHENSKY 1979; GUTER, OVCHINSKIY 1970]. Experimental studies on the assessment of moisture accumulation on various backgrounds in over crusting of poor draining soils were conducted in the fields of the "Zhanakhay" agricultural farm in the Kostanay Region. The "Zhanakhay" farm is located in a moderately arid forest-steppe zone of the northern region of Kazakhstan with an average annual precipitation of about 360 mm [DVURECHENSKY 1979]. The land-use area is 9,200 ha, including 8,300 ha of arable land. The third part of arable land was located on pronounced slopes with an inclination up to 8°. Cultivated crops: wheat, barley, oats, flax, rapeseed, mustard, sunflower, soy, vetch, field pea, and false winter flax. The farm used a moisture-saving technology of cultivation based on the crop rotation. The soil type in the farm is ordinary chernozem with a significant (up to 40%) inclusion of solonetz. Mechanical components of the soil are heavy and medium loam (65%) as well as a sandy loam (35%). Experimental studies were carried out in fields with a heavy mechanical soil composition.

RESULTS

Table 1 presents the results of water accumulation studies based on autumn and winter precipitation on overcrusting of poorly draining soils in 2015–2016.

In autumn of 2015, pre-winter moisture reserves on the background of stubble coulisses were higher than the average level of 72–76 mm. On the background of stubble, they were 58–62 mm, which is an average level, whereas on the background of a continuous combing 78 mm.

During chiselling of the stubble and stubble coulisses, the loss of autumn moisture in the soil by evaporation increased slightly by 4 mm compared to the untreated background.

In winter of 2016, the snow precipitation was 184 mm. It was twice the annual rate of winter precipitation. Therefore, even on the background of stubble without tillage, 63 mm of moisture accumulated from winter precipitation.

Table 1. Autumn and winter moisture reserves in the soil in 2015–2020

Background	Autumn soil moisture reserves	Snow height	Water reserves in snow	Total soil moisture reserves after melting of snow
	mm	cm	mm	mm
2015–2016				
Stubble (control)	62	33	63	109
Chiseling on stubble	58	33	65	117
Chiseling on the background of stubble coulisses	72	48	138	210
Stubble coulisses	76	47	135	144[1)]
Continuous combing	78	50	120	138[1)]
2016–2017				
Stubble (control)	60	27	51	98
Chiseling on stubble	57	26	52	104
Chiseling on the background of stubble coulisses	70	50	143	203
Stubble coulisses	74	52	153	151*
Continuous combing	76	54	124	138*
2017–2018				
Stubble (control)	47	16	21	63
Chiseling on stubble	45	17	22	65
Chiseling on the background of stubble coulisses	52	42	72	120
Stubble coulisses	54	43	73	108
Continuous combing	55	49	55	96
2018–2019				
Stubble (control)	58	13	31	81
Chiseling on stubble	56	13	31	84
Chiseling on the background of stubble coulisses	62	35	100	155
Stubble coulisses	63	34	98	127
Continuous combing	64	25	61	111
2020				
Stubble (control)	97	21	48	133
Chiseling on stubble	93	21	48	136
Chiseling on the background of stubble coulisses	108	39	93	194
Stubble coulisses	112	39	95	174
Continuous combing	114	38	76	163

[1)] Limans were formed on the field.
Source: own study.

In winter, on the background of stubble coulisses, 69–75 mm more snow accumulated (2.1 times) than on the background of stubble. It should be noted that on overcrusting, poorly draining soils and the chiselling provided full absorption of moisture from winter precipitation into the soil. This significantly reduced runoff, freezing and evaporation of winter moisture. Chiselling on the stubble background provided a slight increase in the total autumn--winter moisture compared to the untreated stubble background by 8 mm. During chiselling on the background of stubble coulisses, all winter moisture was absorbed into the soil. On the background of stubble coulisses, as well as the background of continuous combing, about 50% of winter precipitation was lost due to the runoff and formation of limans in the fields. It should be noted that, in snowy winter of 2016, the use of deep tillage on the background of stubble coulisses allowed the total reserves of autumn-winter moisture on poorly draining soils to be significantly increased by 93% compared to the stubble background.

In autumn of 2016, pre-winter moisture reserves were at an average level (Tab. 1). The largest autumn moisture reserves in the soil were observed on the backgrounds of continuous combing and stubble coulisses, 76 mm and 70–74 mm respectively. Autumn moisture reserves in the soil on the stubble background were 57–60 mm. During chiseling of the stubble and stubble coulisses, the loss of autumn moisture in the soil by evaporation increased slightly by 5 mm compared to the untreated background.

In winter of 2017, the precipitation in the form of snow was 120 mm (Tab. 1). It was higher by 33% than the annual winter precipitation rate. Therefore, even on the background of stubble without tillage, 51 mm of winter precipitation moisture was accumulated. In the winter period, more snow moisture was accumulated on the backgrounds of stubble coulisses by 91–102 mm (2.7–3.0 times) than on the background of stubble. It should be noted that on overcrusting, poorly draining soils, and the chiselling supperted full absorption of moisture from winter precipitation in 2017 into the soil. This reduced the runoff, freezing and evaporation of winter moisture. Chiselling on the stubble background provided a slight increase in the total autumn–winter moisture in comparison with the undisturbed stubble background by 6 mm. However, this is not due to the low efficiency of chiselling, but first of all, it is explained by a poor accumulation of snow moisture on the stubble background. Continuous combing and stubble coulisses on the untreated backgrounds, about 50% of moisture from winter precipitation was lost due to the water runoff and the formation of limans in the fields. On the backgrounds of stubble coulisses tilled by the chisel, all the moisture accumulated from winter was absorbed into the soil. In snowy winter of 2017, the use of chiselling on the background of stubble coulisses allowed the total reserves of autumn–winter moisture on poorly draining soils to be increased by 2.1 times in comparison with the stubble background.

In autumn of 2017, pre-winter moisture reserves in the stubble field were at a low level, whereas on the backgrounds of continuous combing and stubble coulisses at an average level. During chiselling, the moisture loss in the soil by evaporation increased slightly by 2 mm compared to the untreated background (Tab. 1).

In winter of 2018, there was 58 mm of precipitation in the form of snow (Tab. 1). It is 35% lower than the annual winter precipitation rate. On the stubble background without tillage, the moisture from winter precipitation of 21 mm was accumulated. In little snowy winter of 2018, 72–73 mm of snow accumulated on the backgrounds of stubble coulisses. It is approximately two times less than in 2016–2017. During chiselling of the background of stubble coulisses, all the accumulated winter moisture (73 mm) was absorbed into the soil. On the untreated backgrounds of continuous combing and stubble coulisses, a part of the moisture from winter precipitation was lost due to the runoff from overcrusting of poorly draining soil. In little snowy winter of 2018, the use of deep tillage on the background of stubble coulisses allowed the total reserves of autumn–winter moisture to increase on poorly draining soils by 1.9 times compared to the stubble background.

In autumn of 2018, pre-winter moisture reserves were at an average level (Tab. 1). Thus, the autumn reserves of moisture in the soil on backgrounds of continuous combing and stubble coulisses were 64 mm and 62–63 mm respectively, on the stubble background they were 56–58 mm. During chiselling, the moisture loss in the soil by evaporation increased by 1–2 mm compared to the untreated background.

In winter of 2019, there was 90 mm of precipitation in the form of snow (Tab. 1). This corresponds to the annual rate of winter precipitation. On the background of stubble coulisses without tillage, 31 mm of moisture accumulated from winter precipitation, whereas on the backgrounds of stubble coulisses in winter period, 98–100 mm of snow moisture was accumulated. During chiselling on the background of stubble coulisses, all the accumulated winter moisture was absorbed into the soil. In the untreated backgrounds of continuous combing and stubble coulisses, some of the moisture from winter precipitation was lost due to the water runoff from the fields. In normal snowy winter of 2019, the use of chiselling on the background of stubble coulisses allowed the total reserves of autumn-winter moisture on poorly draining soils to be increased by 1.9 times compared to the stubble background.

In autumn of 2019, pre-winter moisture reserves for the studied backgrounds were at a high level (Tab. 1). On the background of continuous combing, these were 114 mm, stubble coulisses 108–112 mm, and on the background of stubble 93–97 mm. During chiselling, the moisture loss in the soil by evaporation increased by 4 mm compared to the untreated background.

In winter of 2020, there was 119 mm of precipitation in the form of snow. It exceeded the annual winter precipitation rate by 32%. On the background of stubble without tillage, 48 mm of moisture from winter precipitation was accumulated, whereas 93–95 mm of snow moisture was accumulated on the backgrounds of the stubble coulisses (Tab. 1). During chiseling of the background of stubble coulisses, all the accumulated winter moisture was absorbed into the soil. In the untreated backgrounds of continuous combing and stubble coulisses, some of the moisture from winter precipitation was lost due to the runoff from the fields. In snowy winter of 2020, the use of chiselling on the background of stubble coulisses allowed the total reserves of autumn-winter moisture in poorly draining soil to be increased by 46% compared to the stubble background.

DISCUSSION

Thus, the results obtained indicate that:

- the use of continuous combing and stubble coulisses on poor draining soil can increase the autumn soil moisture reserves at different degrees of pre-winter moisture by 10–26% and 9–24% respectively by reducing the wind speed in coulisses and reducing evaporation losses compared to the untreated stubble background;
- in snowy winters, the use of stubble coulisses can increase the snow moisture reserves in comparison with the stubble background by 45–92 mm (1.9–2.8 times), whereas in normal and little snowy winters by 51–69 mm (3.2–3.3 times);
- the impact of continuous combing on the accumulation of snow moisture is about 1.5 times less than stubble coulisses; the use of continuous combing in snowy winters can increase the snow moisture reserves in comparison with the stubble background by 28–73 mm (1.6–2.4 times), whereas in normal and little snowy winters by 30–34 mm (2.0–2.6 times);
- the use of stubble coulisses or continuous combing without chiselling on poorly draining soils leads to increased runoff and winter moisture loss from the fields in little snowy and normal winters, and in snowy winters it leads even to the formation of limans in the fields;
- the application of chiselling in the autumn period leads to additional insignificant losses of autumn moisture reserves in poorly draining soil due to evaporation by 2–6% both on the background of stubble and stubble coulisses;
- the use of chiselling on the background of stubble coulisses reduces the loss of water runoff on poor draining soil by 35–50% after snowy winters, and by 25–35% after little snowy winters and prevents the formation of limans in the fields;
- the use of chiselling on the background of stubble coulisses in comparison with the stubble background allows autumn-winter moisture reserves in poorly draining soil to increase by 61–105 mm (1.5–2.1 times) in years of high moisture, and by 57 mm (1.9 times) in years of insufficient autumn–winter precipitation;
- the use of chiselling on a short stubble background does not significantly affect the total reserves of autumn–winter moisture in poorly draining soil.

The first statement regarding the stubble coulisses is new and significantly expands the boundaries of their application efficacy. Previous research showed that high stubble after continuous combing increases snow accumulation, reduces wind speed and moisture loss due to evaporation after snow melting [YORGEY *et al*. 2017]. Our results indicate that the moisture loss by evaporation can also be reduced by the background of stubble coulisses while conserving the autumn precipitation.

The second statement allows us to assess the efficacy of the use of stubble coulisses in snowy and little snowy winters. A more significant effect of stubble coulisses occurs in little snowy winters when it is almost impossible to accumulate enough winter precipitation on the stubble background. Stubble coulisses in little snowy winters delay snow during snowstorms, which even during insufficient autumn precipitation provide the necessary moisture for the first half of the plants vegetation period. In snowy winters, stubble coulisses produce a significant effect during the lack of autumn moisture. This occurred in 2016 and 2017 when due to a good snow accumulation in snowy winters, excellent moisture accumulation in the soil was provided after snow melting despite insufficient autumn moisture reserves. The results refute the opinions of many farmers in Northern Kazakhstan that it is not necessary to accumulate snow in a snowy winter. In the snowy winter, 50–60 mm of precipitation is accumulated on the short stubble. With an average level of autumn, spring and summer precipitation, there is a guarantee to get an average yield of 1.0–1.2 t·ha^{-1}. However, our research in 2016 and 2017 (Tab. 1) shows that if snow accumulates in stubble coulisses, 100 mm more moisture is accumulated. In this case, the yield is 0.5–0.7 t·ha^{-1} higher. At the same time, the second statement completes the results of our previous research on the advantage of stubble coulisses in snowy and little snowy winters [ASTAFYEV *et al*. 2017]. Results presented in this paper agree with the statements on the advantage of stubble coulisses compared to the stubble background [POMEROY, GRAY 1995; STEPPUHN *et al*. 2009].

The third statement shows boundaries of snow accumulation in a continuous combing in snowy and little snowy winters. This statement contradicts conclusions that the maximum accumulated moisture is observed in standing stubble and not in stubble coulisses [KIRKLAND, KEYS 1981].

The fourth statement agrees with the results of research that deep tillage leads to additional losses of autumn moisture reserves in the soil [BAKIROV, PETROVA 2014]. In our opinion, the moisture loss is explained by the formation of cracks and the rise of the soil by 2–3 cm during tilling. However, it should be noted that in autumn of 2015–2019, the moisture loss due to evaporation was insignificant and amounted to 2–6%.

The fifth and sixth statements reveal the main effect of chiselling in poorly draining soil on the background of stubble coulisses which accumulate snow moisture. If there is a large amount of accumulated moisture, the effect results from chiselling. Results obtained agree with researches on the need for deep subsurface tillage or chiselling in arid conditions to provide the absorption of moisture from winter precipitation in the lower horizons of heavy, poor structured soils [CHEBOCHAKOV 2020; KUZINA 2016; SAMUILOV, MUKHITOV 2012].

In Northern Kazakhstan, winter moisture accumulates in insufficient amount on the short stubble. Regative results of chiselling or deep subsurface tillage on heavy, poorly draining soil based on the results from a number of studies and production experience are explained by the insufficient accumulation of winter moisture on short stubble backgrounds [BAKIROV, PETROVA 2014; MAKSYUTOV 2004]. This explains the seventh statement based on research results.

CONCLUSIONS

1. The studies revealed that for the accumulation of moisture in poor draining soil of the arid region of Northern Kazakhstan, it is necessary to carry out a set of measures to reduce the loss of autumn moisture, decompact the soil to ensure the absorption of snow moisture and snow accumulation.

2. The best way to decompact the poor draining soil for the absorption of snow moisture is chiselling. This treatment includes loosening of the soil, cutting of slots to completely absorb the accumulated winter moisture and ensure maximum stubble preservation on the soil surface.

3. The best way to accumulate snow is the formation of stubble coulisses. Firstly, this method provides the largest reserves of water in the snow. Secondly, on the stubble coulisses, chiselling can be performed to decompact the soil and cut slots to promote absorption. Thirdly, this method can significantly reduce losses from evaporation of autumn moisture.

4. Other measures (chiselling on stubble, stubble coulisses without deep cultivation or continuous combing) are significantly inferior to the set of measures specified in 1–3. This is caused either by a significant decrease in snow accumulation, or by a significant increase in winter moisture loss by runoff from the fields in poor draining soil.

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