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Yield, oil content and biochemical composition of seeds of milk thistle, depending on the methods of soil cultivation in the Volga region steppe zone

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Abstract

In our researches, special attention was given to the influence of soil treatment methods on the accumulation of moisture and its role in the appearance of even shoots, their preservation that ultimately affected the growth and development of plants. A direct relationship had been established between the field germination and the moisture content of the soil seed layer. The different depth of presowing treatment affected the soil moisture. The maximum indicators of field germination of milk thistle in our experiments were observed in plowing to a depth of 25-27 cm in combination with presowing harrowing and one cultivation to 5–7 cm representing 84,0%, which was 8–12% higher compared to shallow plowing to 18–20 cm in combination with presowing harrowing and cultivation. It was revealed that the seeds of milk thistle had high laboratory germination, which was kept at a high level at storage of seeds up to 1–3 years. A close correlation had been established between the depth of basic soil treatment and photosynthetic activity of milk thistle plants. Soil treatment had an impact on soil moisture reserves, total water consumption and the consumption factor. However, weather conditions had a more significant impact on these indicators as compared to soil treatment. On average, during the years of research, the maximum yield of seeds (0.96 t/ha) was achieved by plowing at a depth of 25-27 cm in combination with presowing harrowing and cultivation, which was 19.4–43.2% lower compared to other basic treatment methods. With the increase in the treatment depth from 18–20 cm (ordinary plowing) to 25–27 cm (deep plowing) the content of biologically active and biochemical substances also increased. The presowing treatment methods did not influence the chemical composition of the seeds.

Keywords: milk thistle, chernozem soils, basic and presowing soil treatment, total water consumption, structure and density of soil, postharvest root remains, weed infestation of crops, seed productivity, oil content, biochemical Indicators.

Introduction

Milk thistle is a valuable medicinal culture on the basis of which drugs have been developed to treat hepatitis, cirrhosis, biliary tract diseases. The flavolignans of milk thistle promote for active withdrawal of toxins from the liver, as well as salts and slags [1-4, 5]. It is possible to fully provide the population with medicinal products on the basis of this culture by expanding the area of its crops and increasing the yield.

It should be noted that milk thistle along with its valuable medicinal properties is a productive fodder culture. This is due to the high content of biologically active substances, full protein (up to 18%), polyunsaturated oils (up to 23%) and balanced full-fledged vitamin-mineral complex in its biomass and seeds. Therefore, the use of silage, grass meal and cake in rations of farm animals increases their productivity by 13-15% [6, 7, 8].

Increasing the yield of milk thistle should follow the path of improving the technology of its cultivation and creation of highly productive varieties. In the technology of cultivation of milk thistle, the basic and presowing treatment of soil are the most intensive techniques. It is this problem that should be given special attention to. The analysis of scientific literature showed the absence of data on the use of basic and presowing soil treatment in the dry zone of the Volga region [9, 10, 11]. Only short-term experiments on the study of basic soil treatment in isolation from presowing treatment were conducted. It has not allowed establishing the efficiency of a combination of the basic and presowing soil treatment that is important for the determination of optimum terms of sowing and creation of the most favourable conditions of crop formation [8, 11].

On the basis of literature and production data, the specific scheme of field experiment was created, directed on the development of adaptive basic and presowing preparation of soil on Chernozems of the Volga region steppe zone.

The aim of the research was to study the optimal combination of basic and presowing soil preparation in cultivation of milk thistle, aimed at obtaining the maximum yield of seeds with optimal parameters of oil content and biochemical indicators; to establish the influence of soil treatment methods on its fertility and water-physical properties, weed infestation of crops and on formation of the above-ground biomass and root system.

Methods

Field experiments were conducted in 2013-2016 on the experimental field of the Saratov State Agrarian University. The scheme of a long-term two-factor experiment included the study of methods of basic and presowing soil treatment.

Methods of basic soil treatment (factor A):

1) Ordinary plowing to a depth of 18-20 cm; 2) deep

plowing to a depth of 25-27 cm; 3) subsurface cultivating treatment to a depth of 25-27 cm; and 4) treatment to a depth of 25-27 cm with the use of the SibIME racks.

Methods of presowing treatment (factor B):

1) harrowing; 2) harrowing + cultivation; and 3) harrowing + 2 cultivations.

The released high-yielding variety of Amulet milk thistle developed by us (Patent No. 6446, No. 8954188; appl. 30.11.20110, publ. 17.02.2012, Bull. No. 22) had been sown.

The climate of the region is sharply continental. By the amount of precipitation, the HTI was 1.21-1.40 in wet years; in the well-covered years - 0.71-0.92, and in arid years – 0.57-0.63. The average annual precipitation was 350-460 mm.

The soil of the experimental field is the southern low-humus medium-heavy heavy loam chernozem. The humus content (according to Tyurin) is 3.2-4.3%, the mobile phosphorus is 18.2-22.6 mg/kg, the exchangeable potassium (according to Machigin) is 28.0-34.6 mg/100 g of soil. The water-physical properties of the soil layer 0-70 cm are: density is 1.25-1.36 g/cm^3, the minimum water capacity (WC) is 28.1%, and the permanent wilting coefficient is 13.8% to the dry mass of the soil.

Field experiments were carried out in four replications, by a randomized method. The area of the registration plot was 120-150 m^2, and that of the sowing plot was 210-250 m^2. The technology of cultivation of milk thistle in experiments was generally accepted for the region in the use of the common method of sowing and the norm of sowing of 500 thous. germinating seeds per 1 hectare.

The organization and conduct of field experiments and studies were carried out according to generally accepted methods [12-14]. Soil samples were selected in accordance with GOST 174.3.01-83, GOST 28168-89, GOST 174.4.02-84. The granulometric composition and density of the soil were determined according to GOST 12536-79, humidity - by the thermostatically-weighted method under GOST 20915-89. Structural and quality indicators of seeds were determined as follows: moisture - by drying method under GOST 12041-76, chemical composition - under GOST 10842-76.

Statistical processing of the experimental data was performed by the method of dispersion and correlation analysis [15].

Results

It has been identified that the highest biomass formation rates were established by deep plowing to 25-27 cm as the basic treatment and harrowing with a single cultivation as presowing treatment – 28.57 t/ha, which was 18% higher than the ordinary plowing to 18-20 cm and the same presowing treatment.

For all methods of basic soil treatment, the maximum biomass formation rates were observed on the options with presowing harrowing and a single cultivation. The harrowing only or harrowing with subsequent two cultivations reduced this figure by 12-18%, which was caused by the increased weed infestation of crops with a single harrowing as a presowing treatment. Two cultivations before sowing resulted in delay of sowing for 10-12 days and loss of moisture from the surface soil layer.

Deep plowing to 25–27 cm together with presowing harrowing and a single cultivation provided the maximum values of the leaves area (49.1 thous.), the photosynthetic potential (2,260 thousand m^2/ha·day), PAR efficiency – 1.62, and bound energy (10.0 mln. kcal/ha). For other methods of presowing treatment, these indices were lower by 10-15%. The indices of photosynthetic activity of milk thistle plants for subsurface cultivating treatment and treatment using SibIME racks were lower by 8-12% as compared to deep treatment. These differences were observed for all presowing treatment methods.

A direct correlation was established between the amount absorbed by photosynthetically active radiation and the total cost of photosynthetic potential ($r = 0.86$), which was confirmed by the studies conducted at the Institute of Plant Physiology [13].

Total water consumption. In arid conditions of the Volga region moisture is the main limiting factor for the formation of high yield [14, 16, 17]. The results of our studies show that the accumulation of moisture in the soil and the total water consumption of milk thistle are noticeably changed by years, and to a lesser extent – by soil treatment methods.

The total water consumption was the highest in the wet 2015 and 2016 - from 200.4 to 237.0 mm/ha, and in the dry 2013 and 2014 it was from 98.0 to 156.1 mm/ha. On average, during the years of the research, the maximum total water consumption was noted for deep plowing to 25-27 cm depending on the presowing soil treatment methods (172.5–181.8 mm/ha), and the minimum - for ordinary plowing to a depth of 18–20 cm (152.1–159.3 mm/ha). The soil treatment methods had the same effect on the water consumption ratio, which was minimal for deep plowing to 25-27 cm – 185.2–246.6 mm per 1 ton of seeds, and maximum for ordinary plowing to 18–20 cm – 223.8–262.9 mm per 1 ton of seeds.

Such an effect of ordinary soil treatment on water consumption was manifested in all presowing treatment methods.

The increase in water-physical properties and soil fertility. Roots and stubble-root remains are crucial for creating a fine-grained soil structure and the formation of humus [18-20]. Our research has shown that the milk thistle plants contributed to a noticeable increase in the number of hydro-resistant aggregates in all options of the experiment. A significant increase in the number of waterproof aggregates was observed in options with deep soil treatment. On average for 2013–2016, in the layer of 0–15 cm for deep plowing it was 30.4%, and for ordinary plowing – 29.2%. This was due to the best development of the root system and the mass of stubble remains.

The soil density is closely related to the macroaggregate composition. This indicator is adjusted by mechanical treatment [19, 20]. While the treatment depth increased, the bulk density reduced (11–13%) throughout the depth of the plowing layer. The more friable bulk density of soil in a layer of 20–40 cm was observed on the option with a deep treatment (to 25-27 cm).

Accumulation of the stubble-root remains in the milk thistle crops. Domestic and foreign studies found that the bulk of the roots (55-80%) were usually found in the 0-40 cm layer, where the greatest amount of moisture and nutrients was observed [20-22]. We have found that by the time of seed ripening, the milk thistle accumulated a lot of roots, from 4.00 to 4.70 t/ha (Table 1), depending on the soil treatment methods.

Table 1 - Accumulation of the root mass of milk thistle, depending on the soil treatment method, the average for 2013-2016

Method and depth of basic soil treatment	Weight of dry roots by soil layers, t/ha				
	0–25 cm	25–50 cm	50–75 cm	75–100 cm	0–100 cm
Plowing to 18-20 cm	2.77	0.83	0.35	0.05	4.00
Plowing to 25-27 cm	3.05	1.05	0.50	0.10	4.70
Subsurface cultivating treatment to 25-27 cm	3.2	0.8	0.45	0.07	4.62
Treatment with SibIME racks to 25-27 cm	3.14	1.06	0.45	0.05	4.70

Table 2 - Accumulation of roots and stubble remains on milk thistle crops, t/ha

Method and depth of basic soil treatment	Root weight by years in the 0-50 cm layer				Stubble remains' weight by years				Total, the average for 2014-2016
	2014	2015	2016	average	2014	2015	2016	average	
Plowing to 18-20 cm	3.8	3.4	3.6	3.6	1.8	1.6	2.3	1.9	5.5
Plowing to 25-27 cm	4.1	3.9	4.3	4.1	2.0	2.0	2.3	2.1	6.2
Subsurface cultivating treatment to 25-27 cm	4.3	3.7	4.0	4.0	2.6	1.9	2.4	2.3	6.3
SibIME racks treatment	4.1	3.9	4.6	4.2	1.9	2.2	2.3	2.1	6.3

Table 3 - The effect of soil treatment methods on the size and structure of the milk thistle yield

Method and depth of basic soil treatment (Factor A)	Method of presowing soil treatment (Factor B)	Yield of seeds by years, t/ha					Crop structure (average for 2013-2016)			
							number of heads per one plant		seed weight from 1 plant, g	Mass of 1000 seeds, g
		2013	2014	2015	2016	average for 2013-2016	total, pcs.	riped, %		
Plowing to 18-20 cm	Harrowing	0.36	0.45	0.82	0.81	0.61	3.8	83	2.3	27.1
	Harrowing+ cultivation	0.47	0.49	0.86	0.86	0.67	4.0	87	2.5	28.3
	Harrowing+ 2 cultivations	0.43	0.38	0.80	0.79	0.60	4.9	88	2.4	27.0
Plowing to 25-27 cm	Harrowing	0.55	0.52	0.98	0.92	0.74	4.5	83	3.0	28.1
	Harrowing+ cultivation	0.64	0.69	1.28	1.24	0.96	4.7	87	3.1	29.1
	Harrowing+ 2 cultivations	0.63	0.42	1.10	1.05	0.80	4.6	88	3.0	27.2
Subsurface cultivating treatment to 25-27 cm	Harrowing	0.51	0.46	0.91	0.92	0.70	3.8	87	2.8	26.4
	Harrowing+ cultivation	0.49	0.58	1.20	0.95	0.80	4.0	82	2.6	27.2
	Harrowing+ 2 cultivations	0.55	0.56	1.05	0.89	0.76	4.0	82	2.6	26.1
Treatment with SibIME racks to 25-27 cm	Harrowing	0.49	0.53	0.84	0.84	0.67	4.0	85	2.8	27.1
	Harrowing+ cultivation	0.59	0.55	1.24	1.04	0.85	4.2	83	2.8	28.1
	Harrowing+ 2 cultivations	0.55	0.47	1.25	0.80	0.76	4.1	83	2.7	27.3
F_{fact}		171.4	44.39	513.6	447.8	106.51				
LSD_{05} by factor A		0.014	0.021	0.016	0.014	0.02				
F_{fact}		34.17	58.97	364.8	155.22	63.922				
LSD_{05} by factor B		0.014	0.021	0.016	0.014	0.02				
F_{fact}		10.84	9.748	22.21	38.75	4.521				
LSD_{05} by AB factors' interaction		0.028	0.043	0.032	0.027	0.04				

From the studied methods of soil treatment, the greatest effect was observed for deep plowing, which ensured the accumulation in the meter layer of 4.70 t/ha of root mass, which was 0.4-0.7 t/ha (12-16%) higher than in ordinary plowing to 18-20 cm.

The study of the accumulation of the stubble-root remains in the soil layer of 0-50 cm made it possible to establish that most of them were observed in deep ordinary treatments (Table 2).

Significant differences in the accumulation of stubble-root remains between deep soil treatments to 25-27 cm and ordinary plowing to 18-20 cm could not but affect the dynamics of humus in the plowing layer. In experiments, we used the mineralization and humification of stubble-root remains ratios proposed by M.M. Kononova [23]. When growing milk thistle only on options with deep plowing (25-27 cm), subsurface cultivating treatment and treatment using SibIME racks, a positive balance of humus was obtained.

The effect of soil treatment on the weed infestation of the milk thistle crops and its productivity. The methods of primary and presowing treatment, depending on their combination, had a noticeable effect on the weed infestation of soil. The minimum weed infestation of the thistle crops in the rosette phase was observed in deep plowing with presowing harrowing and a single cultivation - 14.6 pcs/m^2 with their vegetative mass of 361.8 g/m^2, which was 40% lower than the weed infestation on subsurface cultivating treatment and treatment using SibIME racks to the same depth.

The size of the yield of milk thistle seeds largely depends on the technology of cultivation and the amount of precipitation. In wet 2015 and 2016, the most favourable conditions for the growth and development of milk thistle developed, so the yield of seeds was the maximum for the options of the experiment - from 0.81 to 1.24 t/ha, and in dry 2013 and 2014 it was 0.44-0.80 t/ha, which was 28–48% lower (Table 3).

Both in wet and dry years, a positive effect of deep basic soil treatment on the yield of milk thistle seeds was observed in comparison with usual plowing. This pattern was observed for all methods of presowing soil treatment. With interaction of the basic and presowing soil treatment, the maximum yield of seeds of 0.96 t/ha was obtained on plowing to 25-27 cm in combination with presowing harrowing and cultivation, and on conventional plowing to the depth of 18–20 cm and the same presowing treatment it was lower by 30% and amounted to 0.67 t/ha.

The deep plowing to 25-27 cm had provided for the increase in the yield of milk thistle to 8-12 t/ha in comparison with the subsurface cultivating treatment and treatment using SibIME racks to the same depth.

The reached value of the seed production depending on soil treatment methods was confirmed also by its structure (see Table 4). Thus, for deep plowing the maximum was the number of heads per plant - from 4.5 to 4.8 pcs., and the weight of seeds from one plant from 3.0 to 3.3g. For ordinary plowing, these figures were 15 to 24% lower. The number of shoots per plant and the height of plants by the time of harvesting were higher on options with deep basic treatment as compared to conventional plowing. A close correlation relationship was established between these indicators and the yield of seeds (Figure 1, 2).

The studied methods of ordinary soil cultivation had an effect on the chemical composition of the seeds. On average in 4 years an increase in depth of treatment from 18–20 to 25-27 cm contributed to an increase in protein content in the seeds of milk thistle from 21.3 to 23.8–23.5%, and that of oil - from 28.8 to 31.1–31.5% (Table 4). In wet 2015 and 2016, the oil content in the seeds of milk thistle was 1.3-2.9% higher compared to the dry 2013 and 2014.

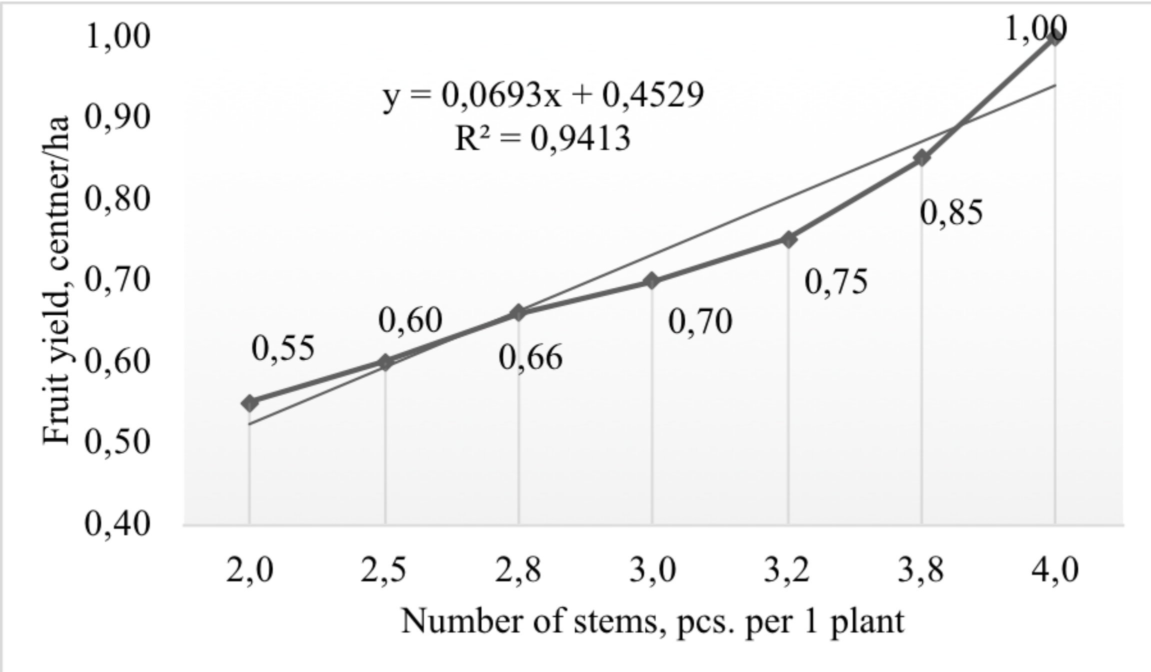

Figure 1. The effect of the number of productive stems on the yield of milk thistle, the average for 2013-2016

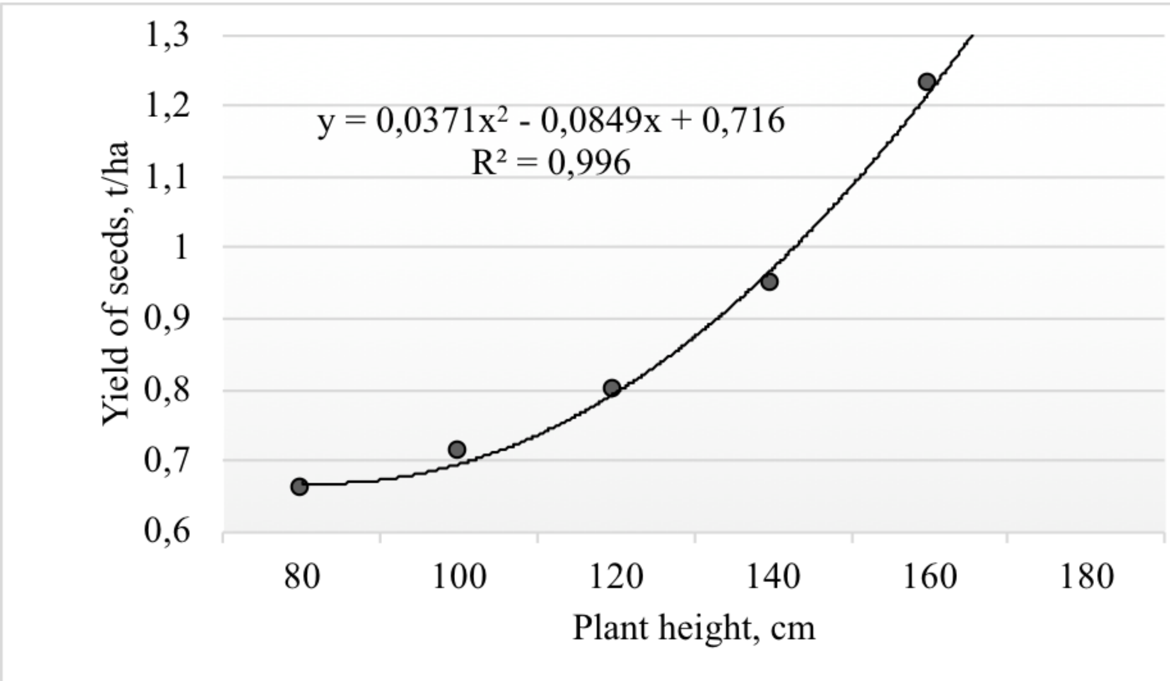

Figure 2. The effect of plant height on the yield of seeds of milk thistle on plowing to a depth of 25-27 cm, the average for 2013-2016

Table 4 – The content of oil and protein in the seeds of milk thistle, depending on the methods of basic soil treatment, % of absolutely dry matter

Method and depth of basic soil treatment	Oil					Protein				
	2013	2014	2015	2016	Average for 4 years	2013	2014	2015	2016	Average for 4 years
Plowing to 18-20 cm	27.8	26.8	30.8	29.8	28.8	23.2	23.4	19.4	19.0	21.3
Plowing to 25-27 cm	29.4	30.4	33.6	32.2	31.4	21.9	21.7	25.7	25.9	23.8
Subsurface cultivating treatment to 25-27 cm	30.0	30.9	31.9	33.0	31.5	22.1	21.0	24.2	25.2	23.1
SibIME racks' treatment	30.2	30.0	33.0	31.0	31.0	21.4	21.4	25.5	25.6	23.5
LSD $_{05}$ by factor A	0.9	0.8	1.0	1.0	0.9	0.5	0.5	0.7	0.6	0.7
LSD $_{05}$ by factor B	1.0	1.0	1.2	1.1	1.0	0.6	0.6	0.8	0.7	0.8
LSD $_{05}$ by factor AB	1.0	1.1	1.3	1.2	1.2	0.7	0.7	0.9	0.8	1.0

CONCLUSION

The appearance of even sprouts depends on the presence of moisture in the 0–10 cm layer. Deep plowing in combination with presowing harrowing provided the optimal accumulation of moisture and high germination of plants – 84.8%, and viability – 93.5%, and the reduction of the basic processing depth and carrying out presowing harrowing only or two cultivations reduced these indices by 7.1 and 9.0%, respectively.

The methods of soil treatment influenced the photosynthetic activity of milk thistle plants. Thus, the maximal flowering parameters of the leaf surface and above-ground biomass (49.3 thousand m^2 and 28.6 tons/ha, respectively) were 25-27 cm on plowing in combination with harrowing and cultivation, which was 15% higher compared to ordinary plowing to 18-20 cm.

The total water consumption was maximum on plowing to 25-27 cm. Depending on the presowing treatment methods, it varied from 172.5 to 185 mm/ha, while the minimum for ordinary plowing to 18-20 cm was 152.1-159.3 mm/ha, or 13% lower.

Milk thistle plants have contributed to the increase in the quantity of the waterproof units on all methods of soil treatment. Plowing to a depth of 25-27 cm ensured an increase in the content of waterproof aggregates in the soil layer of 0-20 cm by 12-14% as compared to ordinary plowing, and the density of soil, by contrast, on plowing to 25-27 cm was 11-13% lower compared with the usual plowing to 18-20 cm.

Deep treatment to 25-27 cm in combination with presowing harrowing and cultivation ensured the minimal weed infestation of crops by the rosette phase - 141 pieces/m^2 with their vegetative mass of 240 g/m^2, which was 35-40 pcs lower as compared to the subsurface cultivating treatment and treatment using SiBIME racks.

As compared to the soil treatment, weather conditions had a greater impact on the yield of milk thistle seeds. In dry years (2013 and 2014) as compared to the wetter ones (2015 and 2016), the yields of seeds were 25–55% lower – 0.28–0.35 and 0.44–0.80 t/ha, respectively. On average, during the years of research the maximum yield of seeds (0.96 t/ha) was achieved by plowing at a depth of 25-27 cm in combination with presowing harrowing and cultivation. The minimum yield (0.67 t/ha) was obtained for ordinary plowing to 18-20 cm, which was 19.4-43.2% lower as compared to other basic treatment methods. This pattern was observed for all methods of presowing treatment.

With the increase in the treatment depth from 18-20 cm (ordinary plowing) to 25-27 cm (deep plowing), the content of biologically active and biochemical substances increased: flavolignans - from 3.1 to 3.5%, nitrogen - from 3.01 to 3.24%, phosphorus - from 1.11 to 1.22%, potassium - from 0.58 to 0.78%, and the amount of fibre, on the contrary, slightly decreased from 25.6 to 23.0%.

When assessing the oil content of seeds, depending on the methods of soil treatment, it was established that the usual plowing to 18-20 cm reduced the oil content to 26.0%, while deep plowing to 25-27 cm, subsurface cultivating treatment and treatment using SibIME racks increased this index to 26.8; 26.5 and 26.7%, respectively.

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