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EFFECT OF HARVESTING AND DESICCATION METHODS ON QUALITY OF OIL FLAX PRODUCTS AND ECONOMIC EFFICIENCY OF THE CROP IN CASE OF ITS USE BOTH FOR SEED AND FIBRE

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Abstract

The five-year research devoted to the study of harvesting methods and desiccation effects on the yields and quality of oil seed flax of dual use was conducted in the field conditions on the dark-chestnut soil in the South of Ukraine during 2013-2017. The study defined the highest effectiveness of pre-harvesting desiccation of the crop by glufosinate ammonium in the dose 2 L ha^{-1} followed by direct harvesting that can increase the yield of flax seeds by 0.15 t ha^{-1} or by 11.9%, and the yield of flax straw – by 0.22 t ha^{-1} or by 12.7%. At the same time, the increase in the yield is accompanied by the improvement of qualitative parameters of the straw through better orientation of the stems in a roll, the share of fibres, which are longer than 200 mm, in comparison with the separate harvesting increases by 8%, and the contamination of the straw decreases 3 times in comparison to the variant without desiccation. Desiccation conducted by using glyphosate preparation in the dose 3 L ha^{-1} allowed increasing of the net profit by 15.67 euro ha^{-1}.

Key words: *direct harvesting, net profit, oil flax of dual use, quality of straw, seed yield, separate harvesting*

INTRODUCTION

Cultivation of flax (*Linum usitatissimum*) in the South of Ukraine is mainly directed on the production of oilseed. However, the straw of flax is suitable for use as a bast raw material but this opportunity is ignored [2].
However, scientific researches and experience of some countries testifies about industrial, economic and ecological feasibility of the use of oil flax straw for the production of fibrous materials and cellulose-containing products [4, 8].
This situation results in many problems and causes insufficient profitability of oil flax production not contributing to further development of flax growing in the area. The use of the stems of oil flax are not widely used in the industry because of low quality indicators, to the improvement of which very little attention is paid both by plant breeders and agricultural engineers. For example, there are no varieties of flax for dual use in Ukraine until now.
The yield and quality both of seeds and straw depends on the ways and conditions of harvesting. The main problem in harvesting of flax is in the difficulties connected to the achievement of balance between two processes – the formation of high yields of qualitative seeds and fibre, especially in unpredictable weather conditions [13, 16, 17].

For long-fibred flax, which is collected in the stage of early yellow maturity, these issues are insufficiently explained in scientific literature [10]. For oil flax, the issues of harvesting are studied and explained much less. According to some reports, the highest yields of seed and fibre were provided by harvesting in the stage of yellow maturity [16, 17]. The 10–day delay with harvesting gradually decreased the yield of bast. The same tendency was mentioned by Rovna [19].

Conventional harvesters used for harvesting of cereal crops obtained the most spreading in flax harvesting. The harvesting could be performed by two methods: separate harvesting in the stage of biological maturity, and direct harvesting in the stage of full maturity [20]. Dudariev proposed four technological schemes of harvesting flax: conventional combined harvesting, conventional separate technology for getting qualitative seeds, combined and separate technologies aimed to obtain both seeds and bast [6].

The above-mentioned recommendations are actual mainly for the zone of long-fibred flax cultivation [11]. Shuvar & Voitovych recommend separate method of harvesting in the zone of Polissya if there is a lot of precipitation in the pre-harvesting period. They propose mowing of flax by the means of the machine Z–169 with further harvesting by the means of grain harvester. However, the least losses of seed yield (by 32.2%) were reached by the direct harvesting [21].

Recommendations to harvest flax in a separate way are connected both with the direct losses of the yield and the need of the primary refinement of seeds, because in direct harvesting there is an incomplete threshing and larger danger of warming of wet seeds, especially if rainfall during the ripening and harvesting of the crop takes place.

However, the drying of the plant mass of flax can be performed by chemical means, which is especially important for the rainy conditions [9]. As Zaluzhnyi et al. claims, the application of diquat and glyphosate even in comparatively low doses provides significant drying of the crop vegetative mass, improves working conditions of harvesters, provides an opportunity for direct harvesting and obtaining the highest yield of seeds (0.85–0.89 t ha-1) [24]. Application of diquat in the dose of 3 L ha-1 resulted in the highest seed yields of 1.28 t ha-1 under the direct harvesting in the study by Makhova et al. [14, 15].

In the Steppe zone there is a lack of the specialized flax harvesting machinery, and therefore the technology is based entirely on the use of the existing grain harvesting machines, and should take into account the need for the crop desiccation. Under such conditions, the question of the yield and quality of the side products is not only unsolved, it even did not arise a scientific problem for the researchers. Therefore, the issue of the quality of oil flax straw was insufficiently studied both in Ukraine and abroad [3]. But the side products of oil flax cultivation could be used as a bast and cellulose raw material and increase the crop profitability by 30%.

Our study is directed to the investigation of the possibility of use of oil flax for dual (seed and fibre) purposes in the conditions of the Steppe zone through the improvement of its harvesting method and application of desiccants to obtain the greatest net profits from the crop production.

MATERIALS AND METHODS

Field experiments on the effectiveness of the terms and methods of harvesting were carried out at the scientific research farm Askaniyska (46°33``N 33°49``E) of the Institute of Irrigated Agriculture of NAAS of Ukraine during the period of 2013–2017. The scheme of the experiment included 2 methods of harvesting flax: direct harvesting and separate (double-phase) harvesting. Direct harvesting was carried out without desiccation and with desiccation by using diquat in the dose 3 L ha^{-1}, glyphosate in the dose 3 L ha^{-1} and glufosinate ammonium in the dose 2 L ha^{-1}.

The desiccation was carried out by the syringe OHN–200/10 with the spraying rate of the working solution at the level of 200 L ha^{-1}. At the two–phase harvesting mowing was performed by a self–propelled mower E–303 equipped with grain reaper E-309, the cut height was set at the level of 12–15 cm. For the collection of rollers and direct harvesting we used John Deere S–660 self–propelled harvester with the switched off shredder. Straw packing was carried out by the means of Pottinger 3120 GA–CR12.

The technology of cultivation of oil flax was based on the recommended one for the zone of the study conduction. The basic tillage involved disking on 8-10 cm and mouldboard ploughing on 20–22 cm after the application of mineral fertilizers $N_{45}P_{30}K_{30}$. Before sowing, harrowing and combined tillage with the aggregate unit APB–6 on 3–4 cm was performed. The sowing was conducted by a seed drill Klen–6 with the sowing rate of 6 million seeds ha^{-1}. At the stage of stem extension a mixture of herbicides was applied (MCPA in the dose 1.0 L ha^{-1} mixed with metsulfuron-methyl in the dose 0.008 kg ha^{-1}).

The field experiment was conducted in four replications using the method of incomplete randomization in the variants placement. The area of the accounting plot was for the seeds – 300 m^2, for the straw – 50 m^2. Laboratory tests were conducted through sampling 10 plants in two nonadjacent replications on each variant to create representative samples of the studied plants. The complex of additional researches was aimed mainly to revealing the influence of elements of harvesting technology on the yield and quality of the both products. Contamination of the straw was determined by organoleptic method in accordance with GOST 28285–89 using the laboratory apparatus LM–3.

The strength of the bast in the previously obtained samples was measured according to DSTU 5015:2008 using a dynamometer DKV–60. Segments of the tape were twisted by the device KV–3. The measurements were performed with a ten-time repetition with 0.1 daN accuracy.

Conventional losses of the bast were determined by the calculation and balance method. The share of fibres was determined by hand-parsing of the samples into individual fibres with the least damage according to GOST R 53483–2009. The groups by the length were formed with the step of 20 mm.

The orientation of the stems in the rolls was carried out in five replications manually. The stems of the plants more than 100 mm long were divided into 5 groups according to their location with further weighing. All studies were accompanied by mathematical data processing to determine the significance of the defined differences. The analysis of variances was performed at $P < 0.05$ using the Agrostat New program [23], standard deviation was calculated in Microsoft Excel 2010. The differences significance was evaluated by using the least significant difference (LSD_{05}).

RESULTS AND DISCUSSIONS

Yields of flax seed and fibre

The results of the five-year study showed that the method of harvesting and application of pre-harvesting desiccation created conditions for the obtaining of different yields both of main and side products of oil flax (Table 1).

Table 1. Oil flax yield depending on assembly technology, t ha^{-1}

Desiccation	Year					Average
	2013	2014	2015	2016	2017	
Direct harvesting						
without desiccation	1.24[1]	1.06[1]	1.30[1]	1.21[1]	1.49[1]	1.26[1]
	1.98[2]	1.40[2]	1.86[2]	1.53[2]	1.87[2]	1.73[2]
glufosinate ammonium, 2 L ha^{-1}	1.35[1]	1.29[1]	1.43[1]	1.36[1]	1.61[1]	1.41[1]
	2.15[2]	1.73[2]	2.06[2]	1.79[2]	2.02[2]	1.95[2]
glyphosate, 3 L ha^{-1}	1.31[1]	1.26[1]	1.40[1]	1.33[1]	1.58[1]	1.38[1]
	2.05[2]	1.68[2]	1.99[2]	1.72[2]	1.97[2]	1.88[2]
diquat, 3 L ha^{-1}	1.34[1]	1.23[1]	1.43[1]	1.36[1]	1.63[1]	1.40[1]
	2.10[2]	1.65[2]	2.03[2]	1.75[2]	2.02[2]	1.91[2]
Separate harvesting						
without desiccation	1.11[1]	1.18[1]	1.19[1]	1.14[1]	1.41[1]	1.21[1]
	1.58[2]	1.38[2]	1.53[2]	1.29[2]	1.58[2]	1.47[2]
LSD_{05}, t ha^{-1}	0.08[1]	0.06[1]	0.08[1]	0.06[1]	0.07[1]	
	0.17[2]	0.07[2]	0.08[2]	0.09[2]	0.09[2]	

Source: Own study; [1] Seed yields, [2] Straw yields.

Both in terms of seed productivity and the straw yield there was an advantage for the crops, where flax was harvested by the direct harvesting method. Average for five years seed yield in this variant was 1.40 t ha^{-1} against 1.26 t ha^{-1} in the variants without desiccation. The type of desiccant had no significant effect on the yield, but there is a tendency to the advantageous use of glufosinate ammonium, which in some years created the advantage and contributed to the best yield of flax straw (1.95 t ha^{-1}).

If we compare the methods of harvesting without the use of desiccants, the advantage of direct harvesting is quite evident. The yield of seeds was by 0.05 and the straw yield was by 0.26 t ha^{-1} higher than in the case of separate harvesting. This could be explained by the fact that due to the two-phase way of harvesting there is an increasing loss of the yield due to mowing and subsequent collection of the rolls for further threshing.

These features predetermined various output and objective loss of the bast. The highest nominal yield of the bast was ensured by the use of desiccation – 334–344 kg ha^{-1}, comparing to the harvesting of untreated crops – 302 kg ha^{-1}, and two-phase harvesting – 272 kg ha^{-1}. In comparison with direct harvesting, separate harvesting resulted on one hand to the decrease in the conditional yield of the bast (by 10.2%), and on the other hand – to the increase of losses (by 61%).

Quality of the obtained products

One of the key differences between the stem mass of long-fibred flax and oil flax is that in the latter it is a highly disoriented totality of the intact and damaged stems of different length. The break of the stems in technological lines during primary processing requires perpendicular placement of stems to the flutes of the working bodies [22]. This requires consideration of the orientation level of stem mass (Table 2). The studies show that in the process of cutting the stems are placed in the roll chaotically, which affects their orientation in the roll. By the deviation angle, the stems were divided into four groups: 0–10; 10–30; 30–50 and more than 50 degrees from perpendicular to the central axis of the roll to one side or another.

Table 2. Angle orientation of oil flax stems in the roll

Harvesting technology (A)	Segment relative degree to the longitudinal roll line (B)				Contamination,%
	0–10	10–30	30–50	> 50	
Location of the stems in the roll,%					
direct harvesting: without desiccation	17.3	27.3	29.8	25.5	0.91
desiccation with glufosinate ammonium in the dose 2 L ha^{-1}	16.2	27.2	29.3	27.3	0.3
desiccation with glyphosate in the dose 3 L ha^{-1}	15.8	26.7	30	27.5	0.35
desiccation with diquat in the dose 3 L ha^{-1}	16	27.5	29.7	26.8	0.32
two-phase harvesting	11.2	28.8	30.5	29.5	0.44
LSD_{05}: A – 1.2; B – 1.0; interaction of the AB – 2.3					
The average angle of the stems location in the segment ± standard deviation					Average
direct harvesting: without desiccation	5.1 ± 2.7	20.6 ± 5.8	40.6 ± 5.5	64.4 ± 9.0	32.6
desiccation with glufosinate ammonium in the dose 2 L ha^{-1}	5.3 ± 2.8	20.5 ± 5.8	40.3 ± 5.6	63.5 ± 9.0	32.4
desiccation with glyphosate in the dose 3 L ha^{-1}	5.4 ± 2.8	19.8 ± 5.7	40.8 ± 5.6	64.3 ± 9.3	32.6
desiccation with diquat in the dose 3 L ha^{-1}	5.5 ± 3.0	20.4 ± 5.7	40.6 ± 5.7	63.9 ± 9.8	32.6
two-phase harvesting	5.7 ± 3.2	21.5 ± 5.8	41.4 ± 5.4	66.0 ± 9.7	33.7

Source: Own study.

The number of stems with minimal deviation increased from 11.2% – at two-phase harvesting, up to 17.3% – on the crops that matured in natural way. In the application of desiccation, the proportion of such stems, compared with the control, was less by 1.1–1.5 points.

At the two-phase harvesting, the share of the stems in the groups with a deviation of more than 10 degrees was the highest in comparison to other variants.

At the direct harvesting of the crops, which matured in natural way, the proportion of stems, which deviated more than 50 degrees, was significantly lower than in the variants of desiccation. In other cases, and between the technologies, which provided chemical drying of the plants, the differences were within the error of the experiment. This testifies that under the double effect of mowing and threshing on the plant mass, the disorientation of the stems has got the highest values.

In all the groups of location and on average, the largest average angle of the stems was at the two-phase harvesting of the crops. The differences between the rests of the variants were insignificant and were observed only within individual segments of the angle of location. The presented data show that the additional technological mowing operation with the roll formation and its collecting has increased the chaotic location of the stems, the reduction of the share of those that are located along the work of the roll pick, which is undesirable for the following technological operations of the straw processing.

An important indicator of the quality of flax straw is the presence of impurities, which are the plants of weeds. The norm of contamination of oil flax is not provided by the normative documents, however, it is limited for long-fibred flax to 5%. Depending on the technology of harvesting, the contamination changed from 0.3 to 0.91%, and was significantly lower than the basic level. Previous desiccation resulted in the reduction of weed fraction in 2.6-3.0 times, to the smallest values in the study – 0.30–0.35%. At the two-phase harvesting, the mass of weeds was higher – 0.44%. This is partly due to the grinding of dried weed plants that do not have powerful mechanical tissues during the threshing process.

Peculiarities of distribution of technical fibres of oil flax by the length are represented in Table 3.

Table 3. Distribution of the share of fibres by the length depending on oil flax harvesting technology, %

Indicators	Harvesting technology				
	direct harvesting				two-phase harvesting
	without desiccation	glufosinate ammonium, 2 L ha^{-1}	glyphosate, 3 L ha^{-1}	diquat, 3 L ha^{-1}	
average length, mm	150	152	151	153	139
fibre share: 0-100 mm	32	31	32	32	37
100-200 mm	38	37	38	36	39
200-300 mm	23	26	23	23	22
> 300 mm	7	6	7	9	2
standard deviation	92.4	90.5	89.9	93.8	80.7
Fibre share: < 200 mm	70	68	70	68	76
> 200 mm	30	32	30	32	24

Source: Own study.

The oil flax fibre is much shorter, and in most cases does not exceed 300 mm in length. Regardless on harvesting technology, the largest share is of fibres with the length up to 200 mm, with some dominance of the fibres of the fraction 100-200 mm. For two-phase harvesting, the proportion of 0–100 mm fibres increased by 5–6%, relatively both to direct harvesting and desiccation. The difference between the fibres groups of 100–200 and 200–300 mm in length was less pronounced and did not exceed 4%. As a result, the average length of the fibres varied from 139 mm in the variant of two-phase harvesting, to 150–153 mm at the direct harvesting with the use and without the use of desiccation.

The economic efficiency of flax cultivation

Flax harvesting schemes require different number and content of technological operations that affect economic results. Therefore, the difference in production costs between the variants of the experiment was substantial and reached 16.7%. During cultivation of oilseeds at the direct harvesting without desiccation, the costs amounted to 298 euro ha^{-1}. In case of two-phase harvesting, the total production costs increased by 2 euro ha^{-1}. The most expensive is the cultivation of oil flax using preliminary desiccation.

The results of our researches are connected with the works of other scientists. For example, Onyukh claimed that direct harvesting by the means of harvester cannot be considered universal for the zone of Western Polissya [18]. Its application is reasonable in favourable years in the stage of early yellow maturity after processing of desiccation of the crops.

Dumych concludes that in the climatic conditions of oil flax cultivation in western region of Ukraine, it is advisable to use direct harvesting at the condition of desiccation [7]. The least loss of seeds of 1.6% was obtained at the use of a harvester Palesse GS12. At the same time, the author came to the conclusion that the separate harvesting can be considered as one of the ways of yield collection, which provides the dual use of oil flax – for fibre and seeds. Cut height, which was 8.9 cm, provided less loss of stems, compared with single-phase harvesting with grain harvester Challenger 647 and Palesse GS12 where the cut-off height was 12–15 cm.

The results of Makhova et al. agree with the results obtained in our study that the best way of harvesting oil flax is direct harvesting [14, 15]. Besides, there is information that desiccation effect on the flax yields and quality does not depend on the desiccant used [12]. The obtained results have a confirmation in other scientific researches and show that in the conditions of the corresponding technology of harvesting the straw of oil flax can be positioned as industrial bast material [1, 5].

Unfortunately, due to the lack of standards and regulations, we have not considered changes in the cost of straw depending on qualitative indicators. However, we can predict that prices will be higher for high-quality products. This fact will make the direct harvesting using desiccation more attractive and profitable.

CONCLUSIONS

According to the corresponding cultivation technology and harvesting of oil flax, its straw can be used for the production of fibrous and cellulose-containing materials. Two-phase harvesting and desiccators positively influences the quality of the straw and the oil flax fibres compared to the direct harvesting. Desiccation of flax crops reduces the conventional losses of seeds and straw during harvesting, decreases contamination of straw with weeds and positively influences on its physical and mechanical parameters. Two-phase harvesting increases the disorientation of the stems when they are rolled. Harvesting of flax for dual use should be anticipated with desiccation of the crops in the yellow maturity and mowing stage at the minimum possible cut-off height, with stacking the straw in the rolls.

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