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RESEARCH OF TECHNICAL MEANS FOR DRILLING FALSE FLAX AND BARLEY SEED COMBINATIONS IN ECOLOGICAL AGRICULTURE

Summary

The analysis shows that comparative indicators of grain quality in ecological or intensive technologies of wheat, rye and barley growing, i.e. structural elements of yield and grain quality are lower in ecological farms. To a large extent it is determined by the weediness of ecological crops. According to the literature analysis, it was established that the existing biologically active and environmentally friendly plant protection preparations have little effect on cereal crops. The relationship between the parameters of false flax seed distribution within a drilling strip and the coulter was established; an experimental coulter for strip drilling was designed; its technological and energetic evaluation was made, and an analytical method to evaluate seed distribution within a drilling strip was proposed; experimental research of false flax drilling together with barley was carried out and the technological elements of barley and false flax mixture were investigated.

1. Introduction

With an increase of allergic, cancerous and other diseases, spreading of deformities and cases of pesticide intoxication, people start avoiding products treated with chemicals [1]. There is no any other area of agricultural specialization in the European Union (EU), which would have such rapid development as ecological agriculture [2]. Each year ecological food is getting more popularity, both in Europe and all over the world. Therefore, its demand is increasing fast. In 2001 the Committee on Rural Affairs of the Lithuanian Seimas decided that ecological farms should be certified. In 2010 such farms should make totally up to 15 % of all agricultural land in the country. Lithuania had approved a Programme of Ecological Agriculture Development for 2003 – 2006. Measures of the Programme include the development of ecological agricultural production and market, improvement of certification system, education of farmers, etc.

Crop yield is about two times lower in ecological farms, compared with the traditional practice. One of the main problems of ecological agriculture is high weediness of crops. The literature analysis [3-5] shows that under the efficient weed control, catch crops have good perspective – they are plants grown before sowing of the main crop, together with the main crop or after they are harvested the same year. Catch crops are drilled between the rows of the main crop; they shade weeds in the competition for nutrients. In addition, catch crops are used for feed or technical purposes, after their yield has been harvested. One of such catch crops could be false flax (*Camelina sativa*) [6-7]. It is an oil plant [8-11], distinguished for its high resistance to negative external impacts. It grows well in light soils; when drilling false flax together with cereals, this plant shades weeds and due to low demand for nutrients, it does not compete with the main crop.

False flax oil is valuable raw material, used in food industry, cosmetics, in biodiesel production, etc. Growing area of false flax is increasing in EU countries and in the USA – namely as a catch crop for cereals and peas. Cropping of false flax in the ecological farms of Lithuania has not been investigated yet. There is no data about its drilling methods, influence on crop weediness and achieved yield. Therefore, the research for solving these tasks is relevant in terms of science and production.

During recent years catch crops grown in the interrows of the main crop are more widely used for weed control. Under Lithuanian conditions it is expedient to grow false flax as a catch crop in ecological cereal crops. An assumption can be made that in order to ensure the efficient control of weeds it is advisable to drill false flax into thinned out cereal crops by applying strip drilling method. In applying such a technology and trying to achieve greater efficiency of weed control, false flax seeds should be distributed evenly within the width of a drilling strip. It is necessary to investigate the factors determining the integrity of seed distribution within a drilling strip, choose design elements of a seed coulter, establish the forces affecting the coulter during drilling and test the efficiency of the proposed method of weed control under field conditions. The presented work analyses the drilling technology of crop and false flax combinations and working parts.

Research objective is to elaborate a method of weed control in ecological cereal (barley) crops, by applying catch crops (false flax), to substantiate theoretically and to test experimentally the design, technological and power parameters of seed coulters, adapted for strip drilling of small seeds.

Research tasks:

- Theoretical analysis of the process of false flax seed distribution within a drilled strip;
- Investigation of biological, physical and mechanical characteristics of false flax grain;
- Testing of evenness of distribution of false flax seeds under laboratory conditions;
- Carrying out laboratory research of draught resistance forces affecting the experimental coulter;
- Testing of weed control efficiency during false flax growing in the interrows of barley under production conditions.

2. Theory

Investigation of seed movement in a drilling hose. At the initial time moment sheave drilling apparatus gives speed to a seed v_a. After that the seed falls along a vertical drilling hose at the average constant speed v_n. The condition of seed movement along an inclined drilling hose is described by equation (1).

$$m\frac{dv}{dt} = mg\sin\alpha - F_{tr} - R\,, \tag{1}$$

when: m – seed mass, g; v - seed speed, m/s; α - angle between horizontal direction and direction of seed movement, deg.; g - acceleration of free falling seed, m/s^2; F_{tx} – friction force, N; $F_{tx} = f \cdot N$; f - frictional coefficient; R – resistance force of external environment, N; $R = kv^2$ (v > 0,2 m/s); k – proportionality coefficient, determined experimentally; $k = k_o \cdot m$; k_o – coefficient of flittering, 1/s.

$$N = mg\cos\alpha\,, \tag{2}$$

when N - normal reaction force, N.

After insertion equation (2) and F_{tr} into equation (1) and some rearrangements, we achieve:

$$\frac{dv}{dt} + k_o v^2 = g(\sin\alpha - f\cos\alpha)\,, \tag{3}$$

We suppose that the initial speed of seed is known, i.e. when t = 0, thus v = v_o. Having evaluated this assumption and integrated equation (3), we compose the expression of seed movement:

$$v = \frac{(A+v_o)e^{2Ak_o t} - (A-v_o)}{(A+v_o)e^{2Ak_o t} + (A-v_o)}\,, \tag{4}$$

when

$$A = \sqrt{\frac{g}{k_o}(\sin\alpha - f\cos\alpha).} \tag{5}$$

Having applied the feature: $e^{\ln x} = x$ and rearranged proportion $\dfrac{A+v_o}{A-v_o} = e^{2Arcth\frac{v_o}{A}}$:

$$v = A\frac{e^{2(Ak_o t+B)} - 1}{e^{2(Ak_o t+B)} + 1}\,, \tag{6}$$

when

$$B = Arcth\frac{v_o}{A} = \frac{1}{2}\ln\frac{1+\dfrac{v_o}{A}}{1-\dfrac{v_o}{A}} \tag{7}$$

After a succession of mathematical rearrangements, we work out seed speed at the end of the drilling hose.

$$v = \frac{(A+v_o)\exp(2(-B+\ln(D+\sqrt{D^2+1}))) - (A-v_o)}{(A+v_o)\exp(2(-B-\ln(D+\sqrt{D^2+1}))) + (A-v_o)}\,. \tag{8}$$

The established kinematic dependences of the movement of a small seed of irregular shape in the drilling hose, enable determination of its speed, depending on drilling hose inclination angle α, initial seed speed v_o and length of path s. Seed speed v in the inclined drilling hose mainly depends on its angle α_o.

Investigation of seed movement on a spherical surface of the coulter spreader. For further even distribution of seeds in soil we take a spherical surface, the curviness angle of which is $\rho = r$ and we have tested different sizes of the sphere. We will find the variation of seed's movement speed v_r, depending on radius r. The forces influencing the seed moving along the coulter spreader are shown in Fig. 1.

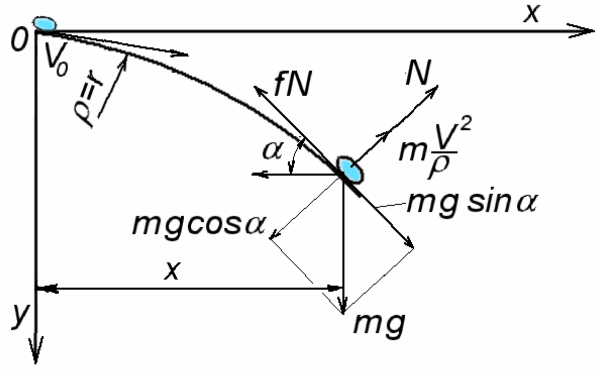

Fig. 1. Seed movement along spherical surface of a coulter spreader (resistance force is neglected)

Having evaluated active forces, differential equation of the seed movement is as follows:

$$m\frac{dv}{dt} = mg\sin\alpha - fN\;. \tag{9}$$

The seed movement along the spreader surface is influenced by centrifugal force mv^2/ρ. Thus normal reaction force will be:

$$N = mg\cos\alpha - m\frac{v^2}{\rho}\,, \tag{10}$$

when ρ –radius of curviness, in our case $\rho = r$.

Having performed mathematical operations, we work out:

$$\frac{dv}{dt} = g\left(\frac{dy}{ds} - f\frac{dx}{ds}\right) + f\frac{v^2}{ds}\frac{y_x^{//}d_x}{1+y_x^{/2}}\,. \tag{11}$$

Having rearranged equation (11), we can put it this way:

$$v\frac{dv}{dx} - fv^2\frac{y_x^{//}}{1+y_x^{/2}} = g(y_x^{/} - f)\,. \tag{12}$$

Marked $p(x) = f\dfrac{y_x^{//}}{1+y_x^{/2}}$ and $q(x) = g(y_x^{/} - f)$ produce the following:

$$v\frac{dv}{dx} - p(x)v^2 = q(x)\,. \tag{13}$$

We get Jacob Bernoulli equation, work it out and find speed of seed movement, when it moves along spherical surface.

$$v_r=\sqrt{\frac{2gf}{1+4f^2}\left((2rf-2)\cos\frac{z}{2f}-(r+4f)\sin\frac{z}{2f}\right)+\left(v_o^2-\frac{4gf(rf-1)}{1+4f^2}\right)e^{z}} \qquad (14)$$

According to formula (14) and a special programme, we calculate the dependence of seed's movement along the spherical surface on radius *r*, distance *x* and coefficient of friction *f* = 0,2 (Fig. 2).

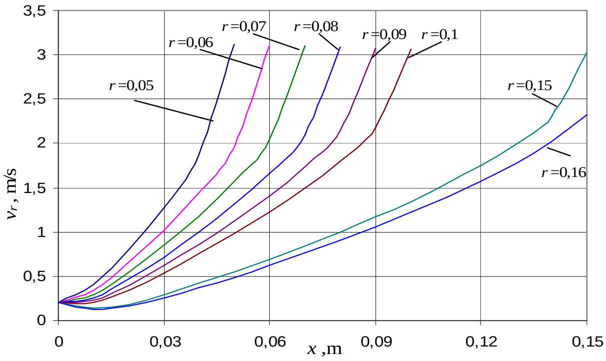

Fig. 2. Dependence of speed of seed movement on spherical radius *r* and distance *x*, when (*f* =0,2)

Speed of seed movement v_r along a spherical surface depends on radius r, distance x and coefficient of friction *f*. At spherical radius equal to r=0,15-0,17, when a false flax seed lands on spherical surface at speed of 0,2 m/s, the speed decreases down to 0,1 m/s at the first moment. After the seed has moved 0,02-0,03 m distance, its speed increases. When the seed travels along 0,05 m distance from the centre of a sphere, its speed reaches 0,5 m/s. By varying spherical radius r, distance x and variety of a seed, it is possible to establish seed movement's speed. The optimum speed, at which the seeds would fall off the surface and distribute evenly on soil, is 0,1-0,4 m/s and that depends on seeds' aerodynamic characteristics.

3. Results and discussion

Biological, physical and mechanical characteristics of false flax grain. It was established that false flax grain has oblong oval shape. Oval length is 2,2 ± 0,18 mm and width 1,1 ± 0,11 mm. Grain thickness – 0,6 ± 0,09 mm. Mass of 1000 grains at 15 % humidity compounds 1,5 ± 0,23 g and density of their layer is 0,75 ± 0,013 $g{\cdot}cm^{-3}$. Coefficient of friction of false flax grain, moving along the surface of rolled steel, is 0,32 ± 0,085 and 0,31 ± 0,058 along a plastic surface respectively.

Experimental trials established that the average steady speed of false flax grain was 6,6 ± 0,47 $m{\cdot}s^{-1}$. The average flittering coefficient of grain was 0,22 ± 0,016 m^{-1}.

Seed movement kinematics. The speed of seed movement at the end of the drilling hose, depending on the angle of inclination α of the drilling hose is presented in Fig. 3.

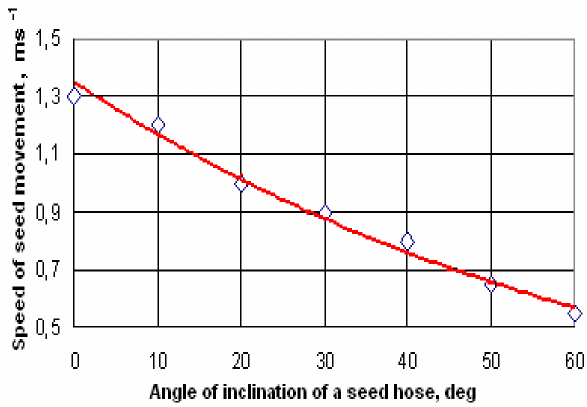

Fig. 3. Dependence of seed movement speed on a drilling hose's inclination angle from vertical direction

At variation of drilling hose's inclination angle from 0 (vertical position) to 60^0, seed movement speed at the point of leaving the drilling hose decreased from 1,30 ± 0,09 $m{\cdot}s^{-1}$ to 0,55 ± 0,04 $m{\cdot}s^{-1}$. Having compared the experimental data with the theoretical data calculated according to expression (8), the average error does not exceed ± 3,8 % at reliability level of 0,95. Speed of seed movement after its impact on spreader surface is characterized by speed retention coefficient μ in the best way, i.e. the ratio between seed movement speed before and after the impact on spreader surface is presented (Fig. 4):

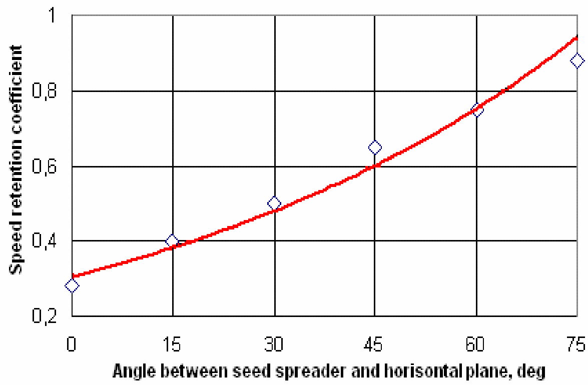

Fig. 4. Dependence of retention coefficient of seed movement's speed on angle between horizontal projection of seed spreader and horizontal plane

We can see from the achieved results that the greater angle of spreader position with regard to the horizontal surface, the higher value of the retention coefficient of seed movement's speed.

Research of draught force of a seed coulter. The resistance forces of the investigated coulters in loosened soil when drilling at a depth of 2-3 cm are relatively small. Horizontal resistance's force of the experimental coulter (EC) in sandy loam soil is 44,5 – 92,3 N and in loam it is 60,3 – 109,7 N. The same indicators of commercially sold coulter (CC) are 19,0 - 51,3 kPa and 52,0 - 98,2 N respectively. Vertical resistance force, when drilling at the mentioned depth, for EC is 14,4 - 29,8 N in sandy loam and 19,8 - 45,0 N in loam; the same indicators for CC are 14,6 - 19,5 N and 20,1 - 30,3 N respectively.

Seed distribution in drilling a strip. We have adjusted seed distribution within a drilling strip by changing the inclination angles of the coulter spreader's upper edge and drilling hose with regard to horizontal plane and the distance between the drilling hose end and the spreader. Investigating at a chosen interval, we can achieve seed distribution within a drilling strip both even and denser in the middle and outside of a strip (Fig. 5 and 6).

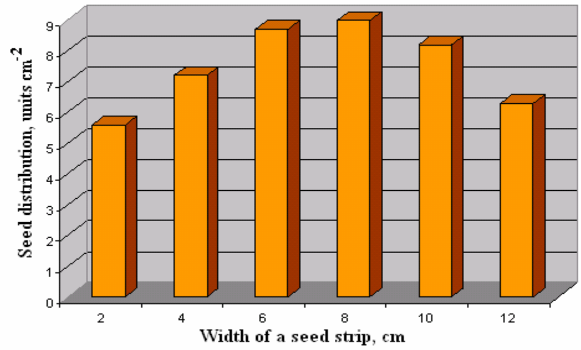

Fig. 5. Seed distribution within drilling strip with increased density in middle of the strip; EC is used for drilling (R_{05}= 0,87 u.·cm^{-2}; h= 5mm; α = 45^o; β = 20^o)

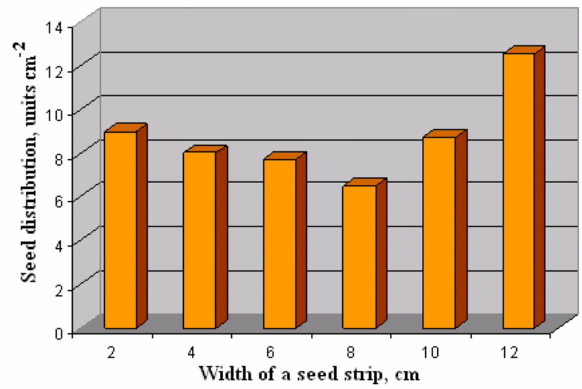

Fig. 6. Seed distribution within drilling strip with increased density at sides of a strip; using EC for drilling (R_{05}= 0,82 u.·cm^{-2}; h= 20 mm; α = 65^o;β = 0^o)

When CC coulter is used for drilling; seed distribution is not adjusted and a denser pattern is achieved at sides of the drilling strip (Fig. 7).

Fig. 7. Seed distribution within drilling strip with increased density at sides of the strip, using CC coulter for drilling (R_{05}= 0,96 u.·cm^{-2})

The experiments carried out show that the greatest influence on seed distribution within the drilling strip is made by the angle between upper edge of the spreader α and horizontal plane. By varying this angle from 0^o to 20^o (h = 5 mm, α = 45^o) we can reduce amount of seeds within 2 cm side strips from 106,1% to 74,0% of the average seed amount within the entire strip, while in the middle part of the strip the amount of seeds increases from 90,8% to 12,8% (Fig. 8).

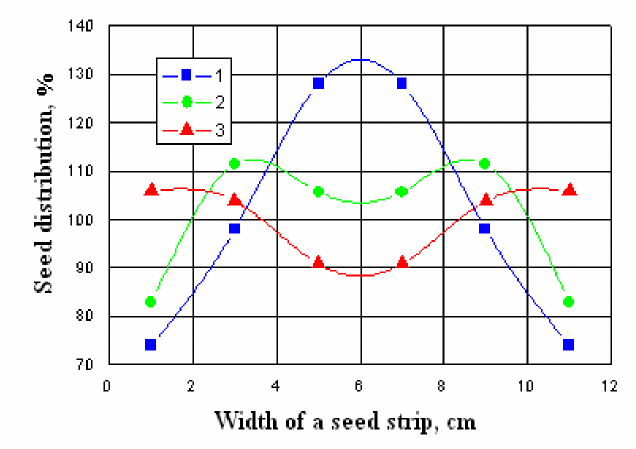

Fig. 8. Comparative seed distribution within the width of the drilling strip, when EC is used, depending on spreader inclination angle β (angle α = 45^o; distance h = 5mm). 100% of seed amount is taken, when their distribution is even within the entire width of the strip: 1) β_1 = 20^o; 2) β_2 = 10^o; 3) β_3 = 0^o

With an increase of spreader inclination's angle, the seed amount in the middle section of the drilling strip consistently increases. At 10^o inclination angle the seed amount in the middle section of the strip comprises 105,7 % of the average seed amount in the entire strip, and in the side sections of the strip it comprises only 82,9 %. Therefore, by changing this angle we can adjust seed distribution within the width of the drilling strip effectively. Variation of drilling hose inclination α has somewhat less influence on seed distribution. The increase of angle α from 45^o to 65^o, when β = 20^o, h = 5 mm results in moderation of seed amount in the middle section of the strip from 128,0 % to 94,1 %, and it increases from 74,0 % to 92,8 % in the side sections of the strip. Modification of distance between the spreader and the drilling hose's end h is less efficient. The increase of distance h from 5 mm to 20 mm increases the amount of seed in the side sections of the strip from 76,0 % to 81,6 %, and decreases it in the middle section from 123,0 % to 117,0 %. The variations in intermediate sections of the strip sections changed only from 98,0 % to 101,5 %, however, these variations were within the error range (R_{05} = 7,8 %).

Results of field-laboratory research of growing false flax and barley. The research of the influence of drilling depth on germination of false flax seed shows that the best germination is achieved, using shallow drilling as is the case with small seed plants. After drilling the majority of seeds germinated at a minimal drilling depth of 1 cm – 76,3%. Germination decreases with an increase of drilling depth, and at 4 cm depth it makes 62,7%. A further increase of drilling depth reduces viability dramatically (Fig. 9).

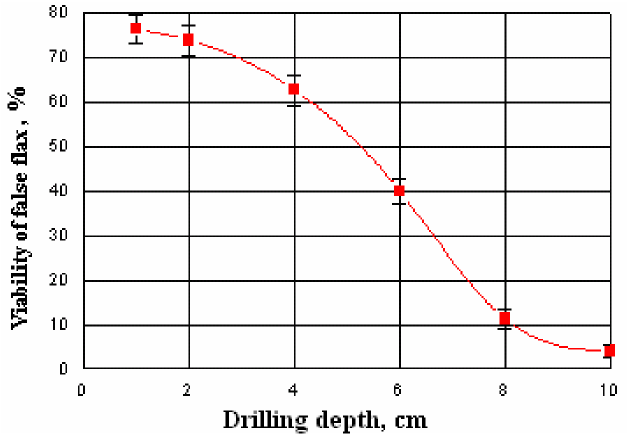

Fig. 9. Dependence of viability of false flax seeds on drilling depth

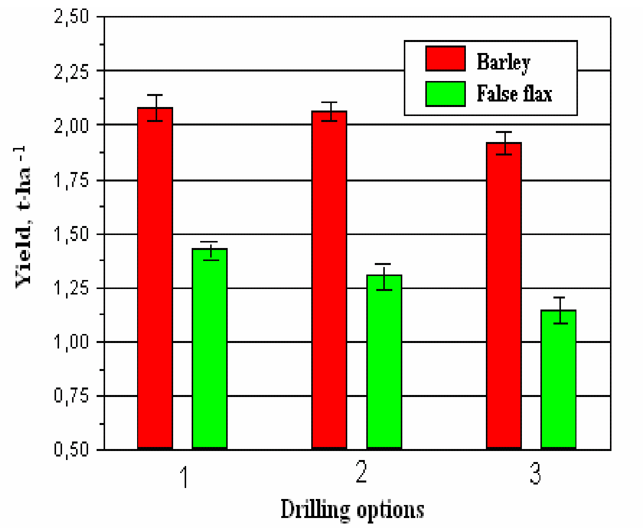

Fig. 10. Dependence of barley and false flax yield on drilling options at 24 cm interrows (false flax yield $LSD_{(05)}$ = 0,10 t·ha^{-1}, barley yield $LSD_{(05)}$ = 0,12 t·ha^{-1}): 1 – barley with wedge-type coulters, false flax with EC coulters; 2 – barley with wedge-type coulters, false flax using CC coulters; 3 – barley and false flax, using wedge-type coulters

False flax drilled in between barley rows shaded weeds efficiently. Compared with pure barley crops, the false flax drilled in interrows reduced the quantity of weeds by 1,79 times at the end of bushing, and at the end of vegetation their mass was even 1,95 times lower (Table 1). False flax was drilled using CC coulter for comparison. It resulted in higher average amount of weeds; however, it was within error limits.

The highest compounded yield of false flax and barley was obtained, after the mixture had been drilled on 16 of April. The drilling on 11 May resulted in a reduced false flax yield by 0,11 t·ha^{-1}. That somewhat exceeded the limit of reliable difference for false flax yield ($LSD_{(05)}$ = 0,09 t·ha^{-1}). Barley yield, after it had been drilled on 11 May, decreased by 0,31 t·ha^{-1} ($LSD_{(05)}$ = 0,13 t·ha^{-1}) and after drilling of 14 June, it decreased by even 0,31 t·ha^{-1} or 28,6%. Therefore, it is not expedient to delay barley drilling. In addition, the crop reaches maturity later; therefore, it might be a problem to harvest it.

Table 1. Weed amount in barley and false flax crops

Research options	Weed amount		
	End of bushing, u.·m^{-2}	Before harvest	
		u.·m^{-2}	g·m^{-2}
1. Barley, 200 kg·ha^{-1} (2003)	360	160	34
2. Barley, 200 kg·ha^{-1} (2005)	420	215	43
3. Row drilling, 160 kg of barley + 5 kg of false flax (2004)	284	128	29
4. Row drilling, 120 kg of barley + 10 kg of false flax (2004	272	125	28
5. False flax drilled in strips between barley using EC coulters, 160 kg·ha^{-1} of barley + 8 kg·ha^{-1} of false flax (2005)	235	96	22
6. False flax drilled in strips between barley using CC coulters, 160 kg·ha^{-1} of barley + 8 kg·ha^{-1} of false flax (2005)	242	121	24

Table 2. Data of experimental seed coulter usage

Indices	Data
Additional yield of false flax seeds, kg·ha^{-1}	120
Energetical value of additional yield of false flax seeds, MJ·ha^{-1}	3240
Oil amount obtained, kg·ha^{-1}	49,2
Oil energetical value, MJ·ha^{-1}	1771,2
Increase of energy costs, due to increased pulling resistance, MJ·ha^{-1}	1,21
Total efficiency rate of a tractor	0,149
Increased diesel consumption, MJ·ha^{-1}	8,12
Increased use of diesel, kg·ha^{-1}	0,19
Energetical coefficient of experimental coulter, used for drilling of false flax	399

The increase of interrow width from 12 cm to 24 cm resulted in the reduction of barley yield by 0,03 t·ha^{-1}, which was within error limits. The increase of false flax yield was considerable, actually 14,7% or 0,18 t·ha^{-1} ($LSD_{(05)}$ = 0,09 t·ha^{-1}). Thus, the compounded yield of false flax and barley increased.

Investigations of drilling, using EC coulters at 24 cm intervals for false flax drilling, evaluated the advantage of these coulters over wedge-type and CC coulters for strip drilling. The research proves that the drilling of false flax using EC coulters gives an additional 9,2% of yield, compared with drilling with CC coulters (Fig. 10). However the change in barley yield was not identified (change was within error limits).

Energy evaluation of false flax drilling with experimental coulters. According to the data of experimental research, horizontal force, resisting pulling the experimental coulter used for drilling of false flax, is greater compared with that of a traditional coulter used for strip drilling.

The achieved energy saving due to an increased false flax yield was established on the base of the experimental research data. The achieved yield of false flax was 1430 kg·ha^{-1}, additional yield resulting from using experimental seed coulters was 9,2%. The energy value of false flax seeds was 27000 kJ·kg^{-1}. The rate of oil amount in seeds was k_s = 0,41, its energy value - E_a = 36·10^3 kJ·kg^{-1}. Energy value of diesel fuel is E_d =42700 kJ·kg^{-1}. According to this data we can establish the total energy amount in false flax seeds and their oil; increase of energy consumption for false flax drilling and the coefficient of energy efficiency of using the experimental seed coulters (Table 2).

The data achieved shows that drilling false flax with experimental coulters results in the increase of energy costs, which is not significant compared to the additional energy yield. The total energetical value of false flax yield is 3240 $MJ \cdot ha^{-1}$, however, the most valuable product is the oil of the seeds. Its energetic value is 1771,2 $MJ \cdot ha^{-1}$. Having evaluated the energy costs of oil pressing, the energy rate will be lower than the achieved one; however, these costs are not relatively high.

4. Conclusions

1. Growing mixture of false flax and barley in ecological agriculture is promising and useful in terms of ecology and economy: producing food and technical plants is balanced, weed spreading is impeded and a higher compounded relative yield is obtained, to compare with growing the plants separately.
2 Mathematical dependencies of seed movement in a drilling hose and along the surface of the coulter spreader were proposed, the usage of which allows substantiating of spreader parameters, ensuring even distribution of seeds in the soil, during drilling of false flax in strips between rows of barley.
3. It was established by the experimental research that mass of 1000 grains of false flax comprises 1,5 ± 0,23 g and density of their layer is 0,75 ± 0,013 $g \cdot cm^{-3}$. The grains' shape is oblong oval: length of oval is 2,2 ± 0,18 mm and width - 1,1 ± 0,11 mm. Thickness of grain – 0,6 ± 0,09 mm. The coefficient of friction of grain at its movement along the surface of rolled steel is 0,32 ± 0,085 and 0,31 ± 0,058 along polymeric surface respectively. Seed steady speed is 7,3 ± 0,25 $m \cdot s^{-1}$, and coefficient of flittering – 0,22 ± 0,016 m^{-1}.
4. It was established by theoretical and experimental investigations that drilling of false flax with an experimental coulter resulted in even distribution of seeds within the drilling strip, when the drilling hose inclination angle in relation to horizontal plane was 55^0 and that of the spreader - 10^0.
5. The horizontal resistance force of the designed experimental coulter while drilling at a depth of 2-3 cm in sandy loam soil is 44-92N and in loam – 60-110N. The vertical resistance force does not exceed 45N.
6. After drilling false flax in strips between barley rows, the amount of weed decreased by 1,79 times and their mass - 1,95 times respectively.
7. At drilling mixture of barley and false flax it is expedient to drill barley in rows at 24 cm raw spacing and false flax – in the interrows in strips at the end of April or at the beginning of May.
8. The experimental research of barley and false flax mixture drilling with 24 cm interrows shows that an additional false flax yield of 14,7% is obtained, and with experimental coulters, false flax yield increases by additional 9,2%, compared with the drilling of both crop mixture in rows.

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