Developing photodegradable crop protection: optimizing cotton seeder parameters for environmental sustainability

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Abstract. To mechanize the spreading of photodegradable polyethylene films on cotton crops, a device has been developed for spreading narrow (300 mm wide) film strips on cotton crops, consisting of a reel with film, a film-spreading drum with a film-pressing roller and spherical disks for sealing the edges of the film. In order to maintain the operational performance of the seeding unit, the rational diameter of the film reel is D_1n=0.4 m, at which the reel is changed simultaneously with the filling of seeds and fertilizers.The paper presents the results of the study of the optimal arrangement of the working bodies of the device covering the photodegradable film on the planted rows and the research of the operating modes. For this, a multifactorial experiment was carried out using the method of mathematical planning. The following optimal rounded values of the factors were determined: the angle of attack of the disk is 13º, the depth of its course is 0.04 m, the distance between the edges of the disk and the film - 0.02 - 0.03 m and unit speed - 1.25 - 1.39 m / s.

1 Introduction

Currently, polyethylene film is the most common mulching material due to its lightness, strength, elasticity and relatively low cost.

However, the film cannot be reused, since it becomes heavily contaminated and damaged upon contact with the soil. Used polyethylene film does not participate in biochemical cycles and accumulates as waste that pollutes the environment.

Since 1970, work has been carried out in a number of countries to create decomposable plastics. Three types of polymeric materials have been created: photodegradable, biodegradable and water-soluble.

Photodegradable film, having all the properties of conventional polyethylene film, specified by service life, color and thickness, is a promising mulching material and allows eliminating the operation of collecting and removing used film. To increase the effectiveness of photodegradable film, in a number of countries it is impregnated with herbicides against weed growth. The use of such films 300 mm wide allows to improve the hydrothermal regime of the root layer of the soil during the most important period - emergence and the beginning

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of vegetation - and to eliminate the need for labor and money for removing and cleaning the film at the end of vegetation [1,2].

Materials and methods. Analysis of trends in the development of technical means for sowing seeds under seed protection film, as well as the results of patent research indicate that the development and creation of technical means for sowing cotton seeds under photodegradable film can be carried out in one of the following directions:

- Development of machines for laying film on a pre-seeded field;
- Development of devices for existing cotton seeders for laying film simultaneously with sowing;
- Development of a seeder design that ensures the laying of film and its perforation with simultaneous sowing of seeds in the formed holes.

In accordance with these first two directions, three schemes of technical means for laying narrow film strips on cotton crops were developed, manufactured and tested for operability in the sowing mechanization laboratory. One of them is an independent unit that lays film over each sown row after the seeder passes (Fig. 1).

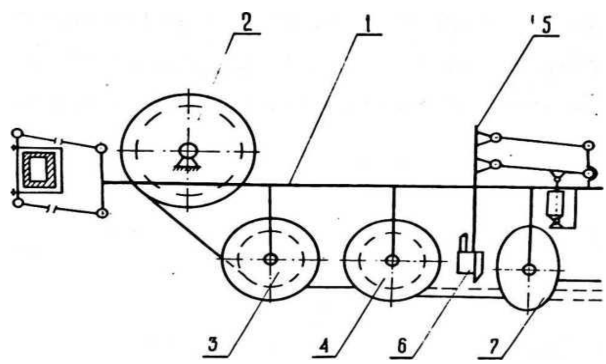

Fig. 1. Schematic diagram of the device for spreading film over the field above the seeds: 1-frame; 2-spool with film; 3-film-spreading drum; 4-pressing wheel; 5-suspension; 6-cutting mechanism; 7-spherical disks.

The device is manufactured in a four-row version [3]. A four-link cultivator with a frame 1 is installed on a common beam with support wheels and a three-point hitch system on a tractor for each row covered with film with a given row spacing, on which a spool 2 with film, a film-spreading drum 3, a press wheel 4, a cutting mechanism 6 with a lever suspension 5 driven by a hydraulic cylinder and working bodies 7 for sealing the edges of the film with soil are fixed in supports.

At the beginning of the spreading, the end of the film from the spool is manually tucked under the drum and pressed to the soil surface. As the unit moves, it unwinds along the entire length of the run and is covered with soil rollers on both edges. At the end of the run, the film is cut off by a knife driven by a hydraulic cylinder connected to the tractor's hydraulic system. The second technical device (Fig. 2) is designed as an attachment to a cotton seeder for laying film simultaneously with sowing.

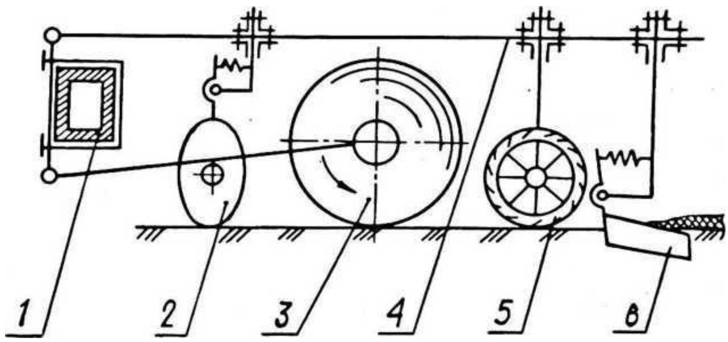

Fig. 2. The seeder attachment, made according to the second scheme, for laying film: 1-rear beam of the seeder frame; 2-furrow-cutting disk; 3-roll of film; 4-frame of the attachment; 5-pressing wheel; 6-coverers.

It is hung on the rear beam 1 of the seeder instead of the roller section. The working bodies are arranged in a layered manner on the frame: furrow-cutting disks 2, pressing wheels 5 and coverers 6. Roll of film 3 is attached to the rear beam of the seeder and freely rolls out over the field. According to this scheme, film laying is performed in the following sequence: furrows are cut on both sides of the film in the direction of movement using disks; laying out the film with free rolling of the roll, pressing the edges of the film into the furrows with pressing wheels and covering the edges of the film with soil with coverers.

1. The device (Fig. 3.) according to the third scheme is a mechanism hung on the rear beam of the frame of a cotton seeder [4].

In order to limit the filling of the surface of the spread film with soil, safety shields are introduced into the design of the device.

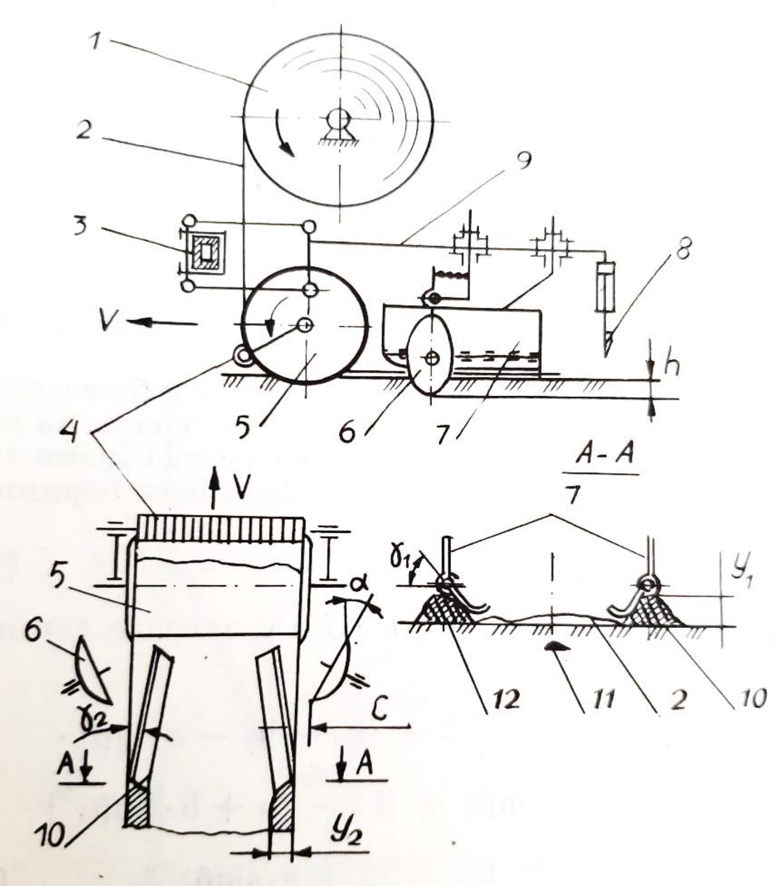

Fig. 3. Seeder attachment for film laying, made according to the third scheme: 1-film reel; 2-film; 3-rear beam of seeder frame; 4-pressing roller; 5-film-laying drum; 6-spherical disks; 7-plate shield; 8-knife; 9-frame; 10-shield wings; 11-sown seed; 12-soil roller; α – disk attack angle; h- disk stroke depth; C - distance between edges of film and disk; V - direction of unit movement; У1 - height and У2 - width of soil ridges

The attachment to the cotton seeder (Fig. 3) consists of sections for each row, including a reel 1 with film 2, a film-spreading drum 5 with a pressure roller 4, spherical disks 6, a plate shield 7 and a knife 8, mounted on a frame 9.

Each section is hung on the rear beam 3 of the cotton seeder frame instead of the rolling section and works as follows. Before the first pass of the seeding unit, the film is unwound from the reel with the frame raised and tucked between the pressure roller and the drum. During the movement of the seeding unit, the film passes between the roller and the drum and is placed on the row with seeds 11.

The following working bodies (spherical disks) pour a loose layer of soil 12 from each edge of the film. Plate shields prevent soil from getting on the surface of the film when the spherical disks are working. In the lower part, the shields have hinged wings 10, installed at an angle of 30-40 ° and directed inside the row. The longitudinal plane of each shield is located at an angle of 10-15 °. At the edge of the run, the tractor driver cuts the film using a knife controlled by a hydraulic cylinder.

In order to select the technical means, comparative tests were carried out on a normal sowing background. The criterion for assessing the performance of technical means was to ensure the technological process of laying without tearing the film with sealing its edges with soil rollers of the required height, leaving the maximum possible surface of the film open, in order to more fully expose it to solar radiation. If the layout of wide rolls of film and filling its edges with a thick layer of soil does not require precise calculations, then the layout of narrow strips of very thin film with the filling of minimal-sized rollers of soil along the edges in order to save expensive material requires theoretical development to reduce experimental work. In accordance with the above, the task of theoretical research included substantiation of the main parameters of the reel with film, the film-laying drum and determination of the operating mode of the device. To determine the optimal relative position of the working elements and the operating modes of the device, a multifactorial experiment was conducted using the method of mathematical planning. The search for extreme conditions that ensure the filling of a soil ridge 0.030-0.035 m high with minimal filling of the film edges along the width was carried out using a well-known method in order to obtain a mathematical model of a second-order polynomial.

A soil channel was prepared in advance, the conditions of which meet the requirements of a normal sowing background.

The experiment was carried out according to plan B4 in a randomized order, and its results were processed and the polynomial coefficients were calculated (Table 1).

Table 1. Levels of factors and intervals of their variation.

Factors	Levels of variation			Variation interval
	Upper (+1)	Base (0)	Lower	
Angle of attack of the disk, X1, deg	25	15	5	10
Depth of the disk stroke X2, m	0,06	0,04	0,02	0,02
Distance between the edges of the disk film, X3, m	0,08	0,05	0,02	0,03
Speed of the unit, X4, m/s	2,71	1,94	1,11	0,83

2 Results

Comparative tests of technical means for laying film were carried out on the second gear (1.25 m/s) of the tractor. Table 2 shows the performance indicators of technical means for laying film:

Table 2. Assessment of designs and performance indicators of technical means for laying film.

№	Evaluation of structures and performance indicators	Unit	First scheme	Second scheme	Third scheme
1	Laying of film		second pass after sowing	simultaneously with sowing	
2	Mass of one section	kg	145	30	40
3	Number of film breaks at a distance of 10 m	times	I…2	нет	нет
4	Parameters of soil roller - height	m	up to 0.02	0,02- 0,03	0,03- .0,04
5	Parameters of soil roller - width	m	0,08-0,10	0,02- 0,03	0,03-0,05

The performance of the cotton seeder film spreader attachment depends on the parameters of the film reel and the film spreading drum, which affect the integrity of the film, its high-quality spreading across the field in an unsteady mode of movement and the pressure of the drum on the soil. Theoretical analysis of the main design elements of this film spreader attachment and some parameters that affect its integrity and spreading across the field in an unsteady mode of movement allowed us to derive an expression that determines the permissible linear acceleration of the unit [5].

$$a \leq \frac{2R_{1n} \cdot \delta\,[\sigma_{\text{p}}]}{\pi\rho(R^4{}_{1n} - R^4{}_b)} \tag{1}$$

where a is the acceleration of the seeding unit;

R_1n is the radius of the reel with n layers of film;

δ is the film thickness;

⌊σ_p ⌋ is the permissible tensile stress of the film in the longitudinal direction;

ρ is the density of the film;

R_b is the outer radius of the sleeve.

Analysis of the obtained dependence (1) shows that the greater the film density ρ, the bobbin radius R_(1n), the less the permissible translational acceleration of the unit will be. For a visual representation, we will construct a graph (Fig. 4) of the influence of the bobbin radius at other constant values: (δ=30* 〖10〗 ^(-6)m, ⌊σ_p ⌋=16MPa, ρ = 90 kg/m^3, R_b=0.05 m) - on the acceleration of the seeding unit.

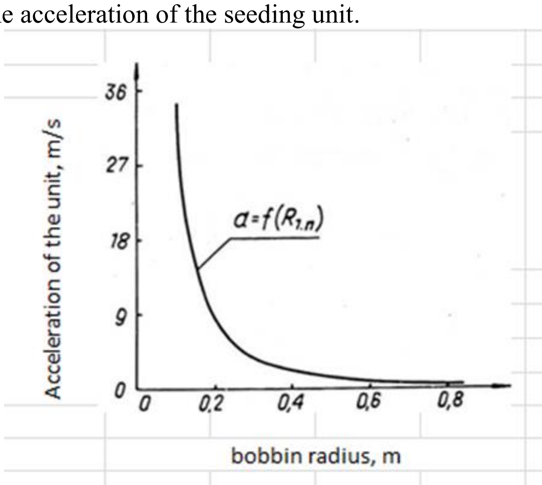

Fig. 4. Graph of change in acceleration of the seeding unit depending on the radius of the reel.

During a multifactorial experiment using the method of mathematical planning to determine the optimal relative position of the working bodies and operating modes of the device, it was found that the optimization parameter (U - the height and width of the soil rollers) of the technological process of laying the film is mainly influenced by such factors as the depth of the spherical disk h, its angle of attack α, the distance between the edges of the film and the disk C and the forward speed of the device V (Table 3).

Table 3. Results of experiments on optimization of the parameters (height and width) of the soil roller poured onto the edges of the film.

No. of experiments	Height, m			Width, m		
	y_1^{I}	y_1^{II}	y_1^{III}	y_2^{I}	y_2^{II}	y_2^{III}
1.	0,0044	0,0032	0,0098	0,0167	0,0262	0,0201
2.	0,0085	0,0069	0,0137	0,0316	0,0364	0,0436
3.	0,0185	0,0165	0,0143	0,0383	0,0303	0,0403
4.	0,0458	0,0490	0,04950	0,0640	0,0511	0,0665
5.	0,0035	0,0057	0,0076	0,0101	0,0111	0,175
6.	0,0073	0,0048	0,0085	0,0383	0,0351	0,0316
7.	0,0190	0,0162	0,0145	0,0301	0,0286	0,0350

Continuation of Table 3.

8.	0,0401	0,0390	0,0430	0,0550	0,0479	0,0501
9.	0,0080	0,0071	0,0110	0,0323	0,0386	0,0254
10.	0,0091	0,0112	0,0139	0,0424	0,0586	0,0361
11.	0,0198	0,0202	0,0151	0,0440	0,0398	0,0480
12.	0,0490	0,0520	0,0515	0,0570	0,0715	0,0741
13.	0,0048	0,0071	0,0086	0,0255	0,0281	0,0314
14.	0,0121	0,0093	0,0038	0,0475	0,0331	0,0355
15.	0,0251	0,0251	0,0212	0,0349	0,0410	0,0369
16.	0,0410	0,0453	0,0475	0,0660	0,0687	0,0488
17.	0,0215	0,0214	0,0174	0,0312	0,0419	0,0362
18.	0,0365	0,0324	0,0373	0,0492	0,0531	0,0612
19.	0,0124	0,0184	0,0203	0,0370	0,0361	0,0304
20.	0,0428	0,0390	. 0,0430	0,0467	0,0547	0,0570
21.	0,0395	0,0351	0,0346	0,0379	0,0463	0,0481
22/	0,0315	0,0354	0,0315	0,0388	0,0346	0,0334
23.	0,0255	0,0294	0,0315	0,0328	0,0435	0,0419
24.	0,0324	0,0367	0,0353	0,0550	0,0461	0,0514

After processing the experimental results, regression equations were obtained that adequately describe the parameters of the soil ridge:

- height

$$\text{У}_1 = 3{,}45 + 0{,}75\, X_1 + 1{,}23X_2 - 0{,}11X_3 + 0{,}16X_4 + 0{,}62X_1X_2 - 0{,}15X_1X_2 - 0{,}66X_1^2 - 0{,}51X_2^2 - 0{,}30X_4\,;$$

- width

$$\text{У}_2 = 4{,}48 + 0{,}96X_1 + 0{,}87X_2 - 0{,}33X_3 + 0{,}46X_4 + 0{,}18X_1X_2 - 0{,}47X_3^2$$

3 Discussion

The results of comparative tests of technical means show that the metal content of each section of the first technical means is 3...5 times greater than the others, and the sealing working elements sprinkle the surface of the film with soil at a depth of 0.08...0.10 m on each side, which is unacceptable when laying narrow strips of film. Due to the large mass of the first technical means, when the film-spreading drum runs over protruding lumps of soil, overstrain is formed in the film and it breaks at a distance of 10 m. I...2 times. With an echeloned arrangement of the working elements of the device (second scheme), the seeding unit becomes more cumbersome (the total length of the device is more than 2 meters), and as a result, the performance of the seeding unit deteriorates sharply (the center of gravity of the seeder goes beyond its frame). In order to reduce the reduced costs and compaction of the soil, and also on the basis of the presented preliminary tests, the third scheme of the technical means, which is an adaptation to a cotton seeder, was adopted as an object of research for further development of the parameters.

From Fig. 4 it is evident that the diameter of the bobbin (D_1n= 〖2R〗 _1n) of this device can reach 0.8 m, at which the permissible acceleration of the unit will be less than 1.3 m/s, since the tractor unit usually has such acceleration.

Increasing the diameter of the bobbin beyond this limit requires a very smooth start-up or the installation of an additional mechanism for unwinding the bobbin at the moment of start-up in order to avoid film breakage.

Analysis of the regression equations shows that the height and width of the soil rollers poured onto the edges of the film are greatly influenced by the angle of attack of the disk, the depth of its movement and the speed of movement.

The joint solution of the obtained equations under the condition Y1 = 0.030 – 0.035 m and Y2→min gave the following optimal rounded values of the factors: X1 = - 0.25, X2 = 0.01, X3 = - 1.00 and X4 = -0.82, or in natural terms, respectively, 13º, 0.04 m, 0.02 m and 1.28 m/s.

4 Conclusion

At present, special attention in cotton, growing is paid to the use of photodegradable polyethylene films on cotton crops. Photodegradable films laid on cotton rows during early sowing periods decompose after a certain time, depending on weather conditions, which does not interfere with field work on cotton care and eliminates the need to perforate the laid film and remove it from the field after use. The film is laid immediately or simultaneously with sowing in the middle of each row (above the line of sown seeds), in order to avoid moisture loss in the seed embedding layer. Of the existing directions of development and creation of technical means for sowing cotton seeds under a narrow strip of photo destructible film, the most promising should be considered the development and creation of devices for existing cotton seeders, consisting of a reel with film, a film-laying drum with a film-pressing roller and spherical disks for sealing the edges of the film. During the operation of the device, no film breaks were observed. The sealing working elements of the device sprinkle soil rollers 0.030 ... 0.035 m high along the edges of the film, leaving on the surface the maximum possible area of the film not sealed in the soil, in order to affect it with solar radiation. In order to maintain the performance of the seeding unit, the rational diameter of the reel is D_1n=0.4 m, at which the reel is changed simultaneously with the filling of seeds and fertilizers, but from the conditions of the integrity of the film at the time of starting off, D_1n=0.8 m is allowed, i.e. the reel can be replaced after one filling of seeds and fertilizers.

Based on the results of experimental studies, it was established that in order to ensure high-quality laying of narrow strips of photodegradable film, the parameters of the relative position of the working parts and the operating modes of the device should be as follows:

- angle of attack of the disk - 13°;
- depth of the disk stroke - 0.04 m;
- speed of movement of the device - 1.25...1.39 m/s;
- distance between the edges of the film and the disk - 0.02...0.03 m.

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