Evaluation of the Possibility of Single-Seed Sowing of Beech Seeds (*Fagus Sylvatica* l.) with the Use of Pneumatic Sowing Set

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Abstract

The aim of the present study was to adapt the pneumatic seeder designed for thick seeds to the sowing of beech seeds and to select appropriate parameters of its operation. In order to evaluate the possibility of sowing particular seeds by the single-seed seeder, one must examine the process of their gathering by the sowing set, stability of the outlet and the flight trajectory. All these parameters can be evaluated simultaneously by applying the accelerated motion film technology. This task was performed using the GoPro Black Edition film camera. The research was performed at a laboratory measurement site, for four rotational speeds of the spreading disc, four values of the vacuum and three dimensions of the spreading disc holes. As a result, the most appropriate parameters for sowing beech seeds were determined. The research found that, after modification, the disc pneumatic seeder of the Agricola Italiana PK can be applied as a machine for sowing the seeds of European beech. The best sowing parameters are obtained using the disk with holes having a diameter of 5 mm, under a vacuum of 800 mm H_2O*; and the frequency of unfilled openings in the spreading disc in the case of beech depends more on the value of the applied vacuum than on the rotational speed of the spreading disc. It was also found that the calculated theoretical trajectory of the seed flight is similar to the trajectory obtained from the analysis.*

Keywords: beech, single-seed sowing, film method, sowing parameters

1. Introduction

In Poland, between 50 and 60 thousand hectares of forest are regenerated annually, of which only about 1.5 thousand hectares is natural regeneration. For the remaining area, seedlings are needed. The area of forest nurseries in Poland amounts to 2282 ha; these nurseries produce over 800 million of seedlings per year (Forests in Poland 2011). It follows that such a high demand for the planting material requires continuous investment in forest nurseries and development of new technologies that will reduce workload, reduce the difficulty of the work, shorten the periods of sowing, improve the use of the sowing space and yield planting material of better quality (Wesoły and Hauke 2009). One way to improve the quality of sowing and reduce its workload is the use of single-seed sowing (Zhao-qian et al. 2005).

This kind of sowing is commonly used in agriculture and horticulture but in forest nurseries it is still uncommon; however, the practice of forest management clearly feels its absence. The specificity of sowing in forest nurseries, mainly under controlled conditions, requires a good use of the sowing surface. Under these conditions, the substrate usually consists of peat, which is imported not only in Poland but in many countries; controlled mycorrhization is also often used (Alexandrowicz-Trzcińska et al. 2013). In addition, expensive granular fertilizers with a prolonged period of decomposition are used, and the construction of troughs, greenhouses or plastic tents is also expensive. For these reasons, well performed sowing has special significance (Walczyk and Słowiński 2013).

So far, due to the lack of appropriate equipment, the sowing of beech under controlled conditions has been performed manually or with the use of less accurate row seeders. This way of sowing does not guarantee a uniform vertical and horizontal distribution of seeds and proper contact of the sown seeds with the soil. The result is worse germination and the seedlings are characterized by a great diversity of morphological parameters (Barzdajn 1981). These problems can be avoided by using the single-seed sowing method. However, there are technical problems that need to be dealt with. Thus in the case of beech seeds, due to their shape, it is difficult to gather the sowing sets. Sowing these seeds requires a seeder with a large seed chamber, since they tend to hang up in the container, which particularly concerns the sprouted seeds. Thus, for the purposes of this study and modification, the Agricola Italiana, PK model of the disc pneumatic seeder for sowing single large seeds was selected as potentially suitable for sowing beech seeds. In order to fully evaluate its usefulness in this application, the scope of the research included:

⇒ analysis of gathering the seeds by the spreading disc in terms of number of seeds sucked to the disc, determination of the point of outlet of the seeds from the spreading disc and the trajectory of the sown seeds;

⇒ selection of the vacuum on the spreading disc, the diameter of the disc holes and the rotational speed of the spreading disc necessary to obtain a single seed in a hole of the spreading disc.

2. Materials and methods

The study was performed at a measurement set-up (Fig.1) for:

⇒ four speed ranges of the spreading disc, which corresponds to four seeder driving speeds: 18, 35, 50, 70 rev min^{-1},

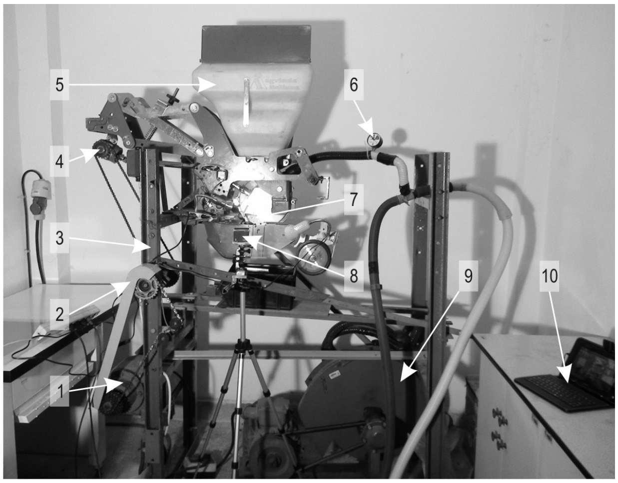
⇒ three diameters of the spreading disc holes: 3, 5 and 6 mm,

⇒ four vacuums: 600, 700, 800 and 900 mm H_20.

2.1 Description of the measurement setup

The basic elements of the measurement setup (Fig. 1) are a section of the tested Agricola Italiana PK seeder and a film camera. Other components of the equipment, such as the propulsion system with an electric motor with a reducer and a multi-chain transmission, a fan with a stepless expenditure regulation and a pressure gauge allow for changing the relevant parameters of the seeder operation, i.e. the vacuum value and the rotational speed of the spreading disc.

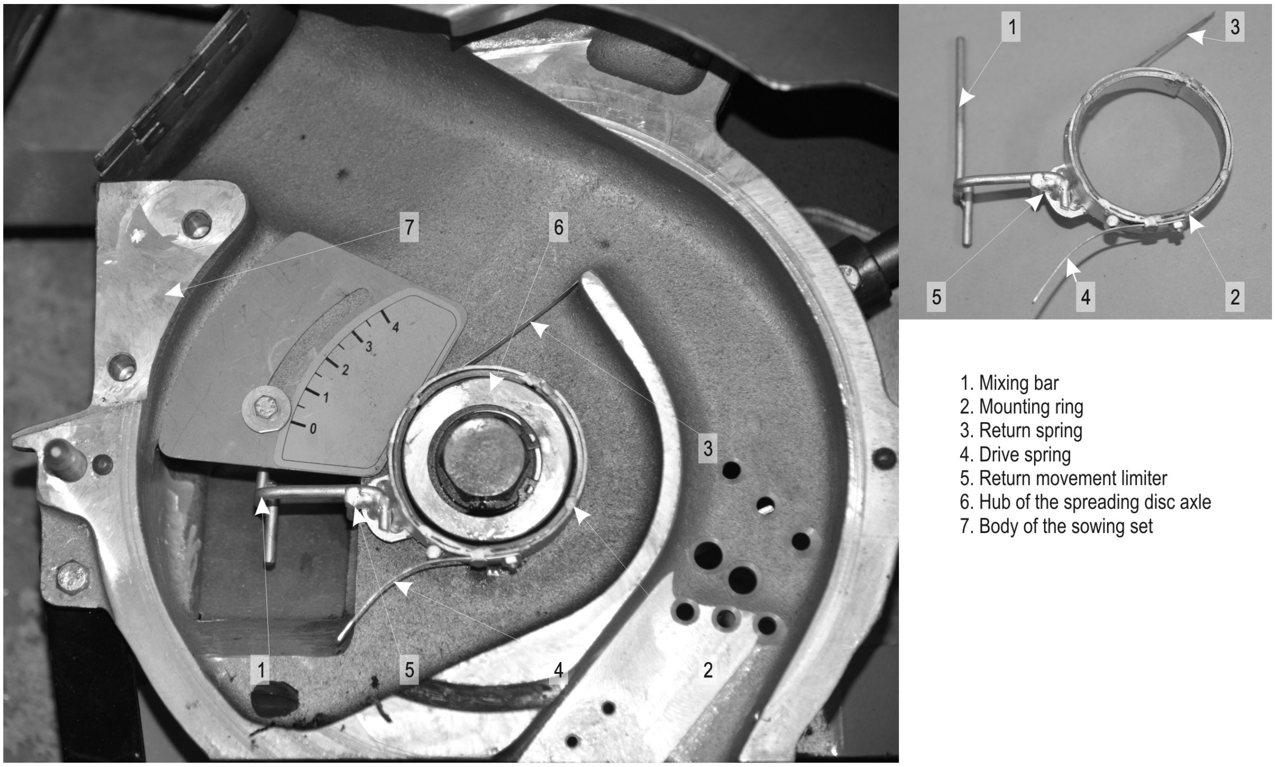
The Agricola Italiana PK seeder belongs to a group of vacuum single-seed seeders. It is designed for precise sowing of thick seeds, such as maize, faba beans, kidney beans, and it is constructed as a typical seeder. It has a sectional structure with the possible number of sections from 2 to 12, seed chambers with a capacity of 20 dm^3, a central vacuum fan, elastic air hoses, coulters, kneading wheels, wheels pressing the seeds in the furrow, sweeps, a system for regulating the sowing depth and the drive system. Adjustment of the seeder to the sowing of a given seed type is done by using the spreading disc with a different diameter and number of holes as well as by vacuum selection. Adjusting the distance of seeds in a row is done by changing the gear ratio of the drive system or the use of the spreading disc with a different number of holes.



1. Drive engine
2. Multi-stage chain transmission
3. Frame
4. Seeder chain transmission
5. Examined seeder section
6. Vacuum gauge
7. Filmed outlet of seeds from the spreading disc
8. GoPro film camera
9. Fan
10. Tablet controlling the camera

Fig. 1 A view of the measurement site

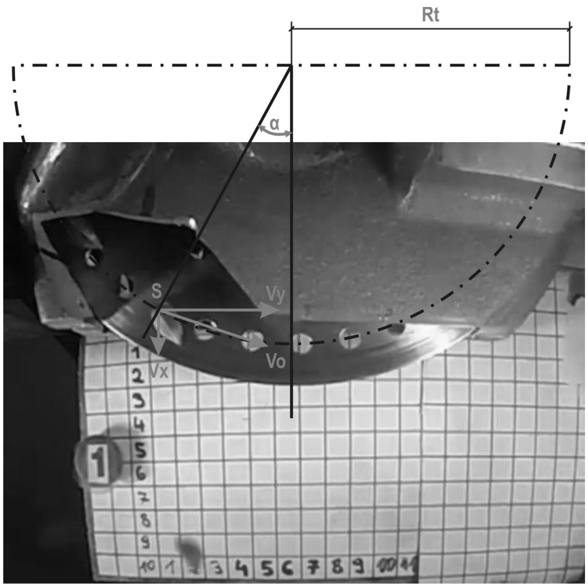
The sowing of beech seeds was done using the spreading discs with a single row of holes on their circumference. The first attempts to sow at the measurement setup showed a high non-uniformity of seeder operation. The reason for this was frequent suspension of the seeds in the seed chamber of the sowing set. To prevent this phenomenon, it was necessary to design a seed mixer. It was assumed that the mixer should be easily removable and should not interfere with the structure of the seeder design. The mixer constructed in this way (Fig. 2) meets these requirements and effectively prevents suspending the seeds in the container, thus allowing stable operation of the sowing unit (Walczyk and Tylek 2014). The mixer (Fig. 2) consists of a ring, to which the following items are attached: a stirring rod, drive spring, return spring and return movement limiter. It is mounted on the hub of the spreading disc axle in the seed chamber of the tested seeder and its operation does not require any other equipment or structural changes of the seeder. It is operated by the projections located on the spreading disc, which, by catching on



1. Mixing bar
2. Mounting ring
3. Return spring
4. Drive spring
5. Return movement limiter
6. Hub of the spreading disc axle
7. Body of the sowing set

Fig. 2 The seeder mixer constructed in the present study

the drive spring, cause the rotation of the ring on the hub, and thus also the movement of the seed mixer in the seed chamber.



Rt – radius of the spacing of the sowing holes
vo – circumferential speed of the disc
S – seed outlet point,
α – angle of seed outlet from the disc

Fig. 3 Diagram of the analysis of the seed flight trajectory

2.2. Recording seeder operation and determining the outlet point and seed flight trajectory

The seeds used for sowing were beech (*Fagus sylvatica* L.), with the weight of a thousand grains amounting to 306 g. Recording and analysing of the sowing process in the range indicated above is not possible without applying the accelerated motion film technology, as evidenced by the studies of other authors (Karaya et al. 2006). Therefore, the filming of the course of sowing was done with the use of the Black Edition GoPro camera, filming the course of sowing with a frequency of 240 frames s^{-1}. During the rendering in the Adobe Premier Pro CS6 editing software, the film was decelerated 10 times and subjected to qualitative and quantitative analysis (Walczyk 2005).

Under the research conditions at the measurement setup, the circumferential speed v_o, acting on a seed sown at the outlet point *S*, has a horizontal component v_x and a vertical component v_y (Fig. 3). In order to calculate a route *s* travelled by the seed in the horizontal direction in a given time, the horizontal speed component v_x (eq. 1) must be multiplied by the seed flight time (eq. 2):

$$V_x = V_o \quad cos\alpha \tag{1}$$

$$S = t \quad V_x \tag{2}$$

Table 1 The effect of the spreading disc hole-diameter on gathering of seeds by the spreading disc holes for the vacuum of 800 mm H_2O and 35 disc revolutions per minute

Spreading disc dimensions	Voids		Single seed gathering		Double seed gathering	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
45* x 3.0**	33.0	2.2	67.0	2.2	0.0	0.0
35* x 5.0**	2.7	1.3	95.2	1.9	2.1	1.4
35* x 6.0**	3.7	1.5	86	2.7	10.3	2.1

*number of holes, **disc hole diameter (mm)

The analysis of the film allowed for simultaneous determination of the number of seeds in individual holes of the spreading disc. The angle α of the outlet of seeds from the disc was determined for the x and y coordinates of the point of a seed at the moment of its falling from the hole of the disc. It was also the zero point for the analysis of the trajectory of a falling seed. The coordinates of the position of successive points of the falling seed trajectory were determined at every 6 frames of the film, i.e. at every 0.025 s. Measurement of the seed trajectory was performed over a period of 0.1 s, i.e. for 4 points of the trajectory. On the basis of the measurements, the path travelled by the seed in the direction of the x axis (horizontal) was determined for each circumferential speed of the spreading disc and it was compared with the theoretical path obtained by using eq. (1). In order to limit the number of repetitions performed during the study, which would disturb the transparency of the obtained results, first the effect of the spreading disc hole diameter on the gathering of the seeds was determined at the vacuum, recommended by the manufacturer, for the sowing of large seeds. Then, for the diameter of the holes, for which the best results were obtained, an analysis of the effect of the vacuum and the rotational speed of the disc on sowing quality was performed.

3. Results

3.1. Analysis of seed gathering

Results of research concerning the selection of hole diameters of the spreading disc, appropriate for seeds of beech of the given weight, showed that the best results were obtained for the disc with 35 holes having a diameter of 5.0 mm (Table 1). The operation of this

Table 2 The effect of vacuum and spreading disc rotation on gathering of seeds, for a disc hole-diameter of 5 mm

Disc rotations rev/min^{-1}		Vacuum on spreading disc holes, mm H_2O											
		600			700			800			900		
		Number of seeds gathered through disc holes 0–voids, 1–single seed gathering, 2–double gathering											
		0	1	2	0	1	2	0	1	2	0	1	2
18	Mean	10.7	89.3	0.0	9.2	83.0	7.7	4.1	87.5	8.5	10.8	76.2	13.0
	Std. dev.	2.1	2.8	0.0	2.3	2.7	2.2	1.9	2.7	2.3	2.7	3.1	3.2
35	Mean	12.4	87.6	0.0	11.2	86.9	2.0	3.7	91.6	4.7	5.0	88.5	6.4
	Std. dev.	2.3	2.7	0.0	2.4	3.1	1.8	1.8	2.1	1.6	1.7	3.5	2.1
50	Mean	14.5	85.5	0.0	12.4	87.6	0.0	4.8	95.2	0.0	2.9	94.1	3.0
	Std. dev.	3.1	2.8	0.0	2.5	2.4	1.8	1.6	1.9	0.0	1.3	1.9	1.2
70	Mean	18.1	81.9	0.0	12.9	87.1	0.0	5.6	94.4	0.0	2.4	97.6	0.0
	Std. dev.	3.5	3.7	0.0	2.7	2.2	0.0	2.1	1.8	0.0	1.2	1.7	0.0

Table 3 Results of the statistical analysis for the disc hole diameter of 5 mm

Disc rotations rev/min^{-1}	Single seed gathering %	Voids %	Double gathering %	Execution of the sowing standard,%
18	87.5	4.1	8.5	112.9
35	91.6	3.7	4.7	105.7
50	95.2	4.8	0.0	95.2
70	94.4	5.6	0.0	94.4
Mean	91.5	4.5	4.0	103.5
Standard deviation	3.4	0.7	3.9	8.4
R between spreading disc speed and share of correctly gathered seeds	0.9	–	–	–
*R** between spreading disc speed and share of voids	–	0.84	–	–
*R** between spreading disc speed and share of double gathering	–	–	–0.94	–
*R** between spreading disc speed and share of sowing standard execution	–	–	–	–0.95

*R** – coefficient of correlation

disc has the highest (average 95.2) percentage of single seeds sucked to the sowing holes. The number of empty holes (voids), as well as the holes filled with two seeds, amounted to only about 2%. The discs with 35 holes, having a diameter of 6.0 mm, and the disc with 45 holes, having a diameter of 3.0 mm, showed much worse results (Table 1). For correct sowing, it is important that the seeds sucked into the holes do not come into contact with each other. This condition is fulfilled by the discs with 35 holes.

Analysis of the impact of the rotational speed and vacuum of the disc on the correct gathering of the seeds allows for the conclusion that the best results were achieved for the rotational speed of the disc amounting to 50 and 70 rev min^{-1} and the pressure of 600 and 700 mm H_20 (Table 2).

Research results included in Table 3 show that an increase of the spreading disc rotational speed leads to an increase of correctly filled holes, i.e. filled with single seed; however, to some extent an increase of voids takes place as well. The negative statistical correlation was showed by the impact of the rotational speed of the disc on the number of double fillings and the total number of seeds sown (the sowing standard) (Table 3).

3.2. Seed outlet point

Determined on the basis of the film analysis, the point of outlet of seeds from the disc was characterised by a high stability for all of the sowing speeds; the average standard deviation for all analysed points was, respectively, in the direction of the *x* axis: 4.1 mm, and in the direction of the *y* axis: 4.6 mm. For the seed outlet point determined in this way, the average outlet angle was determined as $\alpha = 29°$.

3.3. Seed flight trajectory

Analysis of the trajectory of seeds for different circumferential speeds of the spreading disc allowed for obtaining seed flight trajectories that clearly differ from each other (Fig. 4 and 5). The path of the seed in the direction of the *x* axis increases with an increase of

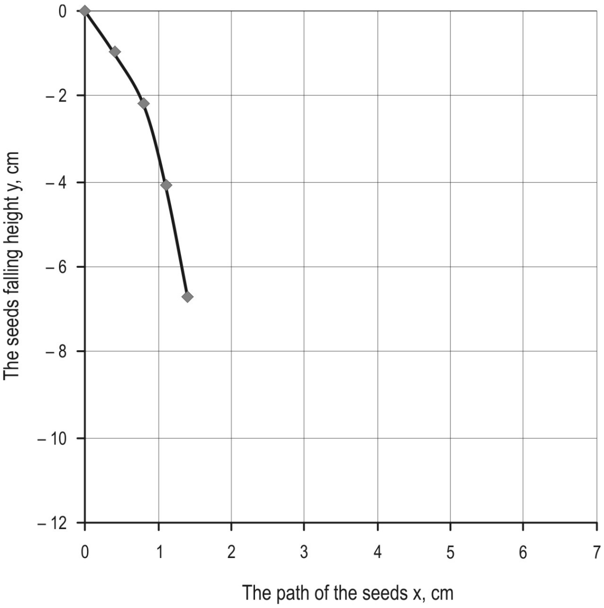


Fig. 4 Seed flight trajectory for the disc speed: $v_1 = 0.166$ m s^{-1}

the circumferential speed of the spreading disc and, therefore, it should be taken into account during the construction of the coulter and the selection of its placement relative to the sowing set of the seeder. The result of the theoretical calculations of the seed path in a horizontal direction only slightly differs from the result of measurements obtained during the analysis of the film (Table 4).

Hence the conclusion that the effect of air resistance and the way of sucking a seed into the spreading disc hole do not significantly alter its flight. For the seeder construction purposes, this path may be determined theoretically.

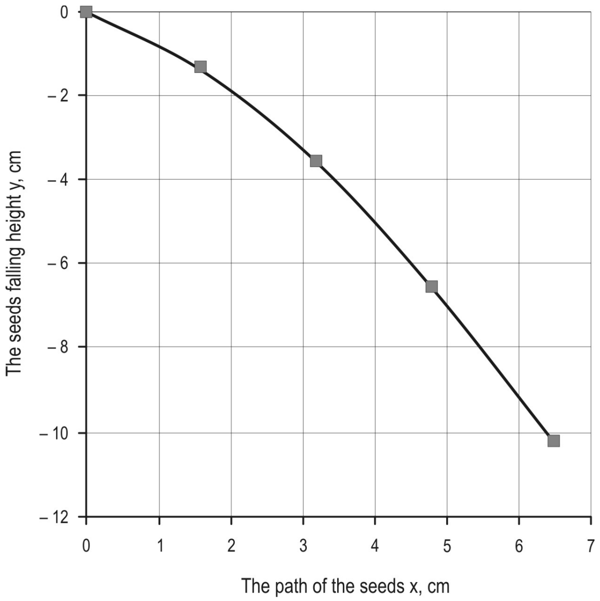


Fig. 5 Seed flight trajectory for the disc speed: $v_4 = 0.664$ m s^{-1}

4. Discussion

Based on the results of the laboratory tests, after modification, the disc pneumatic seeder of the Agricola Italiana PK proved to work well as a machine for sowing European beech seeds. When equipped with a mixer, the examined seeder allowed for the sowing of European beech seeds (*Fagus sylvatica* L.) that meets the requirements of the Polish standard (PN-88/R-36573). The best sowing parameters were obtained for the spreading disc with 5 mm diameter holes, at a vacuum of 800 mm H_2O. On the basis of the measurements, it can be stated that the frequency of unfilled spreading disc holes for beech seeds depends more on the value of the applied vacuum than on the rotational speed of the spreading disc.

During the sowing in the field, it is very important to ensure proper filling of the spreading disc, which is done by a properly chosen working vacuum and disc holes. Correct operation of the seeder should be checked in each case by making a generally known sowing test.

Another important issue is to properly secure the coulter relative to the sowing set of the seeder. For this purpose, it is necessary to know the point of seed outlet from the disc and the path travelled by a seed from the time of its outlet from the disc until its fall to the bottom of the furrow. In practice, this path is also influenced by the seeder travelling speed, which is normally directed opposite to the seed flight speed; and ideally they should be equal. Then the seed falls vertically to the bottom of the furrow, which prevents its rolling and improves seeding precision. In general, it may be stated that the coulter wings should extend slightly beyond the point of the seed fall to the bottom of the furrow. This ensures good covering of a seed and prevents its possible rolling in the furrow. The present study provides data on the parameters of the seeder operation settings and it may be helpful for the determination of the coulter attachment point relative to the sowing set. For the purpose of the seeder con-

Table 4 Comparison of the seed flight trajectory in the horizontal direction s (cm) obtained on the basis of film analysis, with the path s_t (cm) designated on the basis of theoretical calculations, for the disc hole-diameter of 5 mm and vacuum of 800 mm H_2O

Time of flight *t*, s	$V_1 = 0.166$, m s^{-1}		$V_2 = 0.332$, m s^{-1}		$V_3 = 0.469$, m s^{-1}		$V_4 = 0.664$, m s^{-1}	
	*x*1	*xt*1	*x*2	*xt*2	*x*3	*xt*3	*x*4	*xt*4
0.000	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
0.025	0.4	0.36	0.8	0.73	1.1	1.03	1.6	1.45
0.050	0.7	0.73	1.6	1.45	2.4	2.05	3.2	2.91
0.075	1.1	1.09	2.5	2.18	3.5	3.08	4.8	4.36
0.100	1.5	1.45	3.3	2.91	4.6	4.10	6.5	5.81

struction, it is possible to use the theoretically calculated trajectory of the seed flight, which is close to the trajectory obtained based on the analysis of the film.

Application of film technology in this kind of research (Karaye et al. 2006, Walczyk and Tylek 1997, Walczyk 2005) allowed not only for quantitative analysis of the seeder sowing set operation, but also for qualitative analysis. Thanks to using film technique, it was possible to detect the phenomenon of suspending the seeds in the seed chamber, which periodically worsened the seeder operation.

5. Conclusions

After modification, the Agricola Italiana PK disc pneumatic seeder turned out to be suitable for sowing European beech seeds.

The best sowing results were achieved when the holes of the spreading discs were five millimetres wide, at a vacuum of 600 and 700 mm H_2O.

The frequency of unfilled spreading disc holes for beech seeds depends more on the value of the applied vacuum than on the rotational speed of the spreading disc.

For the purpose of the seeder construction, it is possible to use the theoretically calculated trajectory of the seed flight, which is close to the trajectory obtained based on the analysis of the film.

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