Study of the Process of Furrow Formation by a Skid-shaped Coulter of a Transplanting Machine

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Abstract: *This study examines the patterns of influence of the parameters of formation of planting furrows by a snake-shaped coulter on the survival rate of vegetable crop seedlings. An analysis of the interaction between the working tool and the soil was conducted, examining the processes of deformation, compaction, and movement of soil mass during furrow formation. It was established that planting quality is determined by the consistency of the coulter's depth, the density of the formed planting bed, and the absence of furrow wall collapse. Analytical relationships are proposed for assessing coulter traction resistance, furrow bottom pressure, and soil shedding coefficient. Recommendations are developed for selecting optimal operating modes for transplanting machines, ensuring a seedling survival rate of 95-98%.*

Keywords: *TRANSPLANTING MACHINE, SKID-SHAPED COULTER, PLANTING FURROW, DEPTH, SEEDLING SURVIVAL RATE.*

Introduction

The most effective agricultural method for achieving high yields in a short time is the seedling method for growing various crops, including vegetables. Modern seedling cultivation technologies are promoting new methods for cultivating crops from seedlings in open ground.life of the harrow working parts [1, 2, 3].

At the same time, the development of increasingly sophisticated planting machine designs addresses issues related to the mechanization of technological processes [1, 2, 3]. This also addresses the issue of increasing yields from large cultivation areas. In Moldovan agriculture, modern vegetable production technologies include the widespread use of seedling cultivation.

Analysis of recent research and publications

One of the most critical and labor-intensive stages of the seedling planting process is transplanting seedlings into open ground [3, 4]. The success of this operation largely determines plant survival, uniformity of development, and final yield.

When mechanized seedling planting, the formation of the planting furrow plays a crucial role. It is in the root zone that conditions are created for watering the plants in the first days after transplanting. This is accomplished either by watering the plantings immediately after planting the seedlings in the field, or by incorporating a mechanism into the design of the transplanting machine for batch watering of the seedlings during operation, simultaneously with planting [3, 5, 6]. Violation of the geometry of the open furrow, as well as insufficient compaction of its bottom or crumbling of the walls during the process of furrow formation can significantly reduce the contact of the root system with the moist soil layer and lead to a deterioration in the main quality indicators and, first of all, the survival rate of seedlings [7, 8].

The most successful and widely used seedling machine operating tools are skid-shaped or runner coulters, which create a narrow furrow with a compacted bottom [9, 10]. This is due to the shape of the seedling cassette, the size of the substrate with which the seedlings are planted, and its parameters [11, 12, 13]. However, the influence of coulter operating parameters on plant survival rates has not been adequately studied.

The aim of this study is to establish patterns in the influence of furrow formation parameters using a runner opener and planting depth on the survival rate of vegetable crop seedlings.

The scientific novelty of this study lies in its comprehensive assessment of the influence of planting depth, planting bed density, and furrow wall stability on seedling survival rates. This paper:

- clarifies the mechanisms by which furrow geometric parameters influence plant rooting conditions;
- proposes a furrow shedding coefficient as an indicator of the performance of a runner opener;
- develops a mathematical model for predicting seedling survival vegetable crop seedlings;
- formulates recommendations for adjusting the operating elements of transplanting machines.

Materials and Methods

The object of this study is the process of forming a planting furrow with a runner-shaped opener when planting vegetable seedlings.

The study was conducted on medium-loamy soils with a topsoil moisture content of 18-22% and a bulk density of 1.15-1.25 g/cm³.

The following factors were adopted as variation factors:

- opener depth (a), cm;
- machine speed (V), m/s;
- vertical load on opener (F_v), N.

The following key parameters were assessed during the research:

- actual planting depth;
- degree of furrow wall collapse;
- soil density at the bottom of the furrow;
- plant survival rate.

The survival rate was determined by the formula:

$$K_S = \frac{N_S}{N_{pl}} \cdot 100,\% \quad (1)$$

where: N_S - number of surviving plants;
N_{pl} - number of planted plants.

The runner-shaped coulter forms a furrow by pushing the soil apart and compacting the bottom layer; the formation of a compacted bed helps draw moisture from the lower soil horizons directly to the plant's root system. The spreading and compaction of the lower soil layer by a skid-type coulter during the formation of a furrow by a seedling translanting machine is accompanied by energy costs, for the assessment of which the following relationship was used [14, 15]:

$$R_t = Gf + kab + \varepsilon abV^2 \quad (2)$$

where: R_t - traction resistance of the coulter, N;
G - weight of the coulter section, N;
f - coefficient of friction of the runner on the soil;
k - specific resistance of the soil to deformation, N/m²;
a - furrow depth, m;
b - furrow width, m;
ε - dynamic impact coefficient;
V - speed of seedling translanting machine, m/s.

According to formula (2), increasing the planting depth and speed leads to an increase in traction resistance [15].

The pressure P_v exerted on the bottom of the furrow by the translanting machine determines the degree of compaction of the planting bed. This force is determined by the formula:

$$P_b = \frac{F_v}{L \cdot B} \cdot 100,\% \quad (3)$$

where: L - runner length, m;
B - width of the coulter at its lower part, m.

It should be noted that increasing the force on the bottom helps improve the capillary flow of moisture, but excessive compaction can limit the development of the root system [2, 13].

The quality of furrow formation by the transplanting machine was assessed using the shedding coefficient, which depends on the mass of soil that crumbled and the mass of soil removed during furrow formation. Furrow shedding coefficient S is determined by the formula:

$$S = \frac{m_o}{m_f} \cdot 100,\% \quad (4)$$

where: m_o - mass of shed soil, kg;

m_f - mass of soil removed during furrow formation, kg.

The lower the value of the shedding coefficient S, the higher the quality of the formed furrow [16]. The quality of the formed furrow is also affected by the wear of the working surfaces of the coulter, which can be strengthened by modern spraying methods [17, 18, 19];

The influence of the main factors on the survival rate of plants is described by expression (5), which is a mathematical model of seedling survival:

$$K_{np} = K_0(1-\beta_1\Delta a)(1+\beta_2\rho_d)(1-\beta_3 S) \quad (5)$$

where: K_0 - basic survival rate under optimal conditions, %;

Δa - deviation of planting depth from optimal, cm;

ρ_d - relative soil density at the furrow bottom;

S - furrow wall shedding coefficient;

$\beta_1, \beta_2, \beta_3$ - empirical coefficients.

From formula (5) it follows that the greatest negative impact on survival rate is exerted by crumbling furrow walls and deviation of the planting depth from the established one.

Rezults and discussions

Field observations have shown that if the planting depth is insufficient (less than 60-80 mm), the root system is located in a rapidly drying soil layer, resulting in a 70-80% reduction in survival. If the seedlings are planted too deep (more than 140 mm), the soil's aeration regime deteriorates and the risk of apical rot increases.

Table 1. *Effect of planting depth on seedling survival*

Planting depth, mm	Survival rate, %
50	74
70	89
90	96
100	98
110	97
120	95
140	88
160	80

Table 1 shows the effect of seedling planting depth on plant survival.

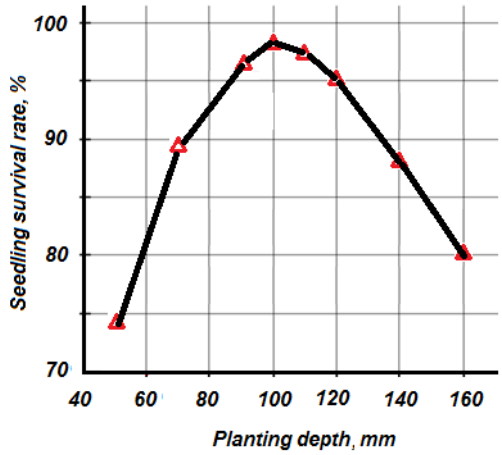


Figure 1. Dependence of plant survival rate on the depth of seedling planting

The most favorable conditions are observed at a planting depth of 90-110 mm. Based on the data presented in Table 1 and the graph in Fig. 1, the maximum survival rate of 98% is achieved at a seedling planting depth of 100 mm. It was also found that increasing the planting speed of the planting unit increases the shedding of furrow walls.

Table 2. *Effect of travel speed on the shedding coefficient*

Travel speed, m/s	Shedding coefficient
0,6	0,03
0,8	0,05
1,0	0,08
1,2	0,10
1,4	0,14
1,6	0,18

The speed limitation of semi-automatic transplanting machines depends on the operator's ability to insert seedlings into the seedling holder [4, 20, 21]. However, the data in Table 2 indicate that the speed of semi-automatic transplanters is also limited by the furrow wall shedding coefficient (Table 2).

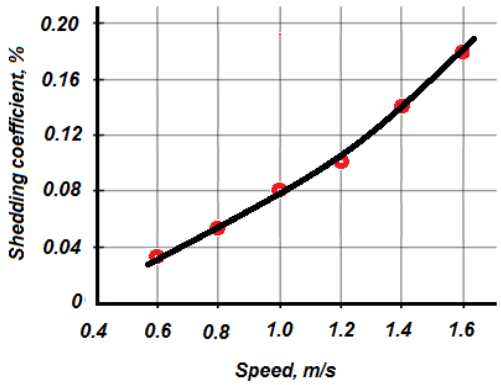


Figure 2. Dependence of the furrow wall shedding coefficient on the seedling planting speed

Thus, to ensure high seedling survival rates, it is recommended to:

- select the most suitable precursor for the agricultural crop and soil cultivation methods to prepare the field for seedling planting [22];
- maintain planting depth within 90-110 mm;
- limit depth deviations to ±10 mm;
- ensure coulter pressure on the soil within 250-400 N;
- maintain the unit's speed within the range of 0.8-1.2 m/s;
- use a coulter engagement angle of 18-22°;
- use gauge wheels and a parallelogram suspension of the sections;
- monitor the wear of the coulter's working surfaces [23];
- use adjustable press rollers to eliminate air pockets around the root system.

The practical significance of this work lies in the application of the proposed recommendations, which allow:

- to increase seedling survival by 10-18%;
- to reduce the need for replanting;
- to improve the uniformity of plant establishment and development;
- to reduce operating costs for growing vegetable crops and other crops grown from seedlings.

Conclusions

1. It has been established that the performance of a skid-shaped coulter has a decisive influence on the survival rate of vegetable seedlings. The key factors are planting depth, the degree of compaction of the planting bed, and the resistance of the furrow walls to crumbling.

2. The most favorable conditions are created with a planting depth of 90-110 mm, a coulter pressure of 250-400 N, and a machine speed of 0.8-1.2 m s^{-1}. These conditions ensure the formation of a stable planting furrow with a compacted bottom and a minimum number of air pockets in the root zone.

3. The obtained results can be used in the design and improvement of seedling planting machines, as well as in the development of technologies for mechanized planting of vegetable crops.

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