

# Mathematical model of collision process of seeder coulter with stones

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**Abstract.** The article presents the results of scientific-theoretical research on the development of mathematical modeling of the process of collision of the seeder coulter with stones and the introduction of new technologies for sowing seeds of agricultural crops on stony soils to improve the performance of seeding units.

## 1 Introduction

In the agricultural production system, the work on developing new lands clogged with stones plays an important role as a reserve for increasing agricultural production. About 4.5 million hectares of agricultural land in Uzbekistan are littered with stones [1].

The analyses show that in the works of S.M. Dzhibilova and L.R.Gulueva, it was determined that stone contamination was located from top to bottom and averaged 37.2, 45.6, and 52.0 percent of the area of the plot. It is also noted that collecting stones before sowing crops provides water saturation and increases the productivity of fields [2].

The presence of stony inclusions in the soil negatively affects the operation of agricultural machinery and reduces the productivity of tillage and sowing machines. Due to the presence of stones, the dynamic loads on the working tools increase sharply, leading to their wear and breakdown, and machinery downtime is up to 60% of the shift time. An increase in traction resistance and dynamic loads reduce units' productivity by 10-39 % [3, 4].

The wear rate of implements depends on the mechanical composition and moisture of the soil, as well as the presence of stony inclusions in it. On soils clogged with stones, the service life of working tools mainly depends on the strength of the nose part. The given data show that as the wear of coulter skids increases, the depth of seed embedding decreases, and the agrotechnical requirements for sowing crops are violated [3].

Problems and issues of mechanized stone harvesting in conditions of irrigated lands of Uzbekistan, sowing of agricultural crops, method of seeding seeds into stony soil and device for its implementation, and principles of stony land use were studied by many researchers [4 - 8].

Existing technologies of seeding crops slightly and medium clogged soils working bodies - seeder coulters collide with stones, resulting in the transition over them reduces the

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depth of seeding and thus sharply worsens the seeding quality and violates agricultural requirements by reducing the depth of seeding.

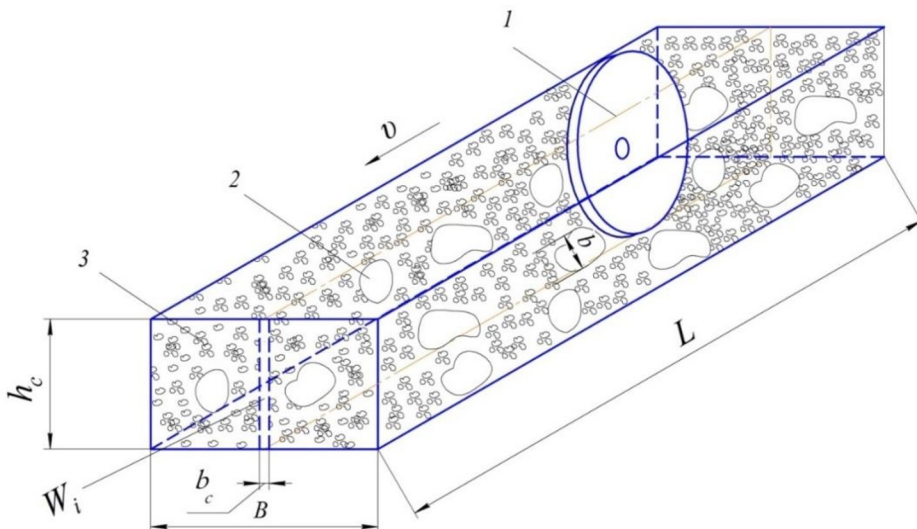
It is noted in the works that the installation angle in the longitudinal direction of the coulter should ensure the passage of particles with sliding [9, 10].

Currently, the diagnostics of the stoniness of soils is carried out by the point excavation method, which is labor-intensive and requires significant manual labor. Due to the lack of preliminary information about the location of stones, their fractional composition is carried out by continuous processing with multiple passes. Therefore, determining the number of collisions of the seeder coulter with stones by mathematical modeling method increases productivity and reduces labor costs of seeding and tillage units.

Based on the conducted research, it is marked [11 - 13] that at the normative operating time of seeder, 150 hectares each coulter about 10000 times will meet a stone with the size more than 100 mm and with stones more than 330 mm in diameter - 150 times. For this reason, when designing the seeder's coulter linkage mechanism for soils clogged with stones, it is advisable to know the maximum values of the forces that can be encountered during the seeder's operation. Consequently, it is proposed at least the general laws influencing the value of these forces. The results of theoretical and experimental studies of the force interaction of working elements of agricultural machinery with stones made it possible to estimate the factors influencing the forces acting on working elements when hitting stones. The basic laws of soil mechanics were also used to optimize the parameters and operating modes of the coulter. In this case, the main components of the equation of motion of the coulter were determined [14].

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When sowing, the coulter can collide with stones of cross-sectional dimension  $b$ . The collision of the coulter with stones at the seed placement depth  $h_c$  is the untreated area of size  $W = h_c b_c$  (Fig.), and the area  $\Sigma W_i$  on the whole cultivated map.



**Fig.1.** Mathematical model of stone counting by the colliding coulter: 1 is coulter; 2 is stone; 3 is soil;  $h_c$  is seeding depth;  $b_c$  is coulter width;  $L$  is coulter path length.

## 1.1 Problem statement

Our task is a mathematical description of the number of collisions of the coulter with stones and the intensity of the flow in the field, which is clogged with them; the flow intensity  $\lambda$  is determined by the average number of stones of the above size, located on one hectare of arable land. Chosen as a mathematical model for counting the number of stones colliding with the coulter as a mass service system [15].

## 2 Methods

Coulter of the seeder is a service system with one input, where applications - stones- collide with the coulter at random moments when it moves across the field, as the speed of the seeding unit can be taken as a constant value  $v_m$ . Thus the path  $L_i$ , passed by the coulter before the collision with  $i$ -th stone, is directly proportional to time  $t_i$ , then  $L_i = v_m t_i$ . Let the applications of stones entering the system be described as  $t_1, t_2, t_3$ ; the time interval between the services of application  $t_{i-1}$  and  $t_i$  will have the form:  $\tau_i = t_i - t_{i-1}$

The values  $\tau_1, \tau_2, \dots, \tau_i$  are random variables. When the stones are located uniformly on the field, this model is called stationary, and if the stones are located non-uniformly on the field - non-stationary. If the simplest flow of the number of requests to the serving (machine) system at time intervals  $\tau$  is distributed according to Poisson's law (stationary model), the probability is defined by the formula

$$P_{(k,\tau)} = \frac{(\lambda\tau)^k}{k!} \cdot e^{-\lambda\tau} \quad (k=0, 1, 2, \dots) \quad (1)$$

where  $\lambda$  is flow intensity, i.e., the average number of events in the flow per time unit. The average number of events in the stream per time interval is determined as follows:

$$\nu = \lambda\tau$$

where  $\tau$  is the time interval between the last two applications of the simplest molasses. Then the distribution function will have the form:

$$F_1(t) = P(\tau < t) = 1 - e^{-\lambda t} \quad (2)$$

probability density

$$P_1(t) = \lambda e^{-\lambda t} \quad (3)$$

mathematical expectation

$$m(t) = \frac{1}{\lambda} \quad (4)$$

Dispersion

$$\sigma^2(t) = \frac{1}{\lambda^2} \quad (5)$$

As noted above, as a factor of time, you can take the path taken by the coulter across the field  $L$  or the value  $S_0$ , i.e., the area of cultivated land on the map, because  $S_0$  is proportional to  $t$ , since the speed of the seeding unit is constant.

The simplest flow of events has the properties of stationarity, lack of aftereffects, and ordinality.

The property of "stationarity" is expressed as

$$P(k, \tau_1) = P(k, \tau_2) \quad (6)$$

If, i.e., the probability of occurrence of field events in any time interval of the same duration is the same value. In this case,  $\tau$  corresponds to the value  $S$  of the area cultivated by the coulter. This property consists of the fact that in any part of the field, the probability that  $k$ - stones will occur depends on the value  $S_0$  of the area of the cultivated field and not on the place from which the cultivation of the field began. If  $[\tau_1] = [\tau_2]$ , i.e., the probability of occurrence of field events in any time interval of the same duration is the same value. In this case,  $\tau$  corresponds to the value  $S$  of the area cultivated by the coulter. This property consists of the fact that in any part of the field, the probability that  $k$ - stones will occur depends on the value  $S_0$  of the area of the cultivated field and not on the place from which the cultivation of the field began.

The 'no-sequence' properties consist of the probability of  $K$ -events appearing at any time interval does not depend on whether the events appeared or did not appear at points in time before the beginning of the interval in question. In our interpretation, the probability of collisions with  $K$ -events depends on how many stones lie in the field up to the point from which the unit operates.

The property of "ordinariness" depends on the occurrence of 2 or more events in a short period, which are impossible, i.e., in our interpretation, collisions with other stones are practically zero.

It is known from probability theory [15] that the Poisson flow of applications has these properties of the simplest flow of events and is a mathematical model of our problem, expressed by the formula:

$$P(k, S) = \frac{\lambda \cdot S}{k_i} e^{-\lambda S} \quad (7)$$

The formula calculates the probability that when processing a field with an area, the coulter will collide with  $k$ -stones.

Let  $S_1, S_2, S_3, \dots$  be the sizes of the areas processed by the unit before the 1st, 2nd, 3rd, etc., collisions with stones. The stream  $S_1, S_2, S_3, \dots$  is a stream of random events.

Let's denote by  $Y$  the random value representing

$$Y_i = S_i - S_{i-1}$$

The value of  $Y_i$  represents the area processed by an aggregate that did not encounter any stones. It follows from probability theory that the probability that not a single stone is encountered in the area processed by an aggregate of size  $Y \leq S$ . is determined by the formula

$$F(S) = P(Y \leq S) = 1 - e^{-\lambda S} \quad (8)$$

where  $\lambda$  is the infestation of the field, pcs/ha;

The probability density of the random variable Y is determined by

$$f(S) = F(S) = (1 - e^{-\lambda S}) = \lambda e^{-\lambda S} \tag{9}$$

The mathematical expectation is:

$$m = \int_0^{\infty} S f(S) dS = \int_0^{\infty} \lambda S e^{-\lambda S} dS = \lambda S \dots \tag{10}$$

### 3 Results and Discussion

Analysis shows that about 4.5 million hectares of agricultural land in the Republic of Uzbekistan is littered with stones. The efficiency of using tillage and seeding machines is significantly affected by the stoniness of the soil, that in 75% of the littered area, there are stones of two or more fractions. The presence of stony inclusions in the soil negatively affects the operation of agricultural machinery and reduces the productivity of tillage and sowing machines. Small stones under the influence of the working bodies may be pressed into the soil, contributing to intensive wear. Medium-sized stones affect the depth of cultivation or embedding of working tools due to their inability to sink into the soil. As a result, the implements slip off when encountering stones. Medium stones also cause frequent breakage of implements.

We present the degree of infestation of the field (table).

**Table 1** Degree of infestation of the field

Degree of weed infestation, pcs/ha	An area where there are no stones, ha
1	1.00
2	0.50
3	0.33
5	0.20
10	0.10
100	0.01
1000	0.001

The table shows that there is "weak" clogging when the field is clogged with a value of  $1 \leq \lambda \leq 10$ , because, in this case, the aggregate will not encounter stones in the cultivation area of  $0.10 \leq m \leq 1$

A field blockage of  $10 \leq \lambda \leq 100$  is a "medium" blockage because, with this blockage, the unit will not encounter stones in the area of cultivation  $0.01 \leq m \leq 0.10$ . A field is considered "strong" if  $\lambda \leq 1000$  because, at this infestation, the unit will not encounter stones on an area  $m \leq 0.01$ .

In the case of the non-uniform distribution of stones on the map of the cultivated field, naturally, the first property of the simplest stream of random events is violated, i.e., the equality is not fulfilled:

$$P(k, S_1) = P(k, S_2) \tag{11}$$

where  $S_1$  and  $S_2$  are areas of the same size that are not in different parts of the processed field map. In this case, according to the probability theory [ ], for the non-standard Poisson flow, the expression

$P(k, t), F_1(t), P_1(t), m_1(t), \sigma^2(t)$  will have the form:

$$P(k, t, t_0) = \frac{\nu^k}{k!} e^{-\nu} \tag{12}$$

$$F_1(t, t_0) = 1 - \exp \left[ - \int_{t_0}^{t_0+t} \lambda(t) dt \right] \tag{13}$$

$$P_1(t, t_0) = \lambda(t_0 + t) \exp \left[ - \int_{t_0}^{t_0+t} \lambda(t) dt \right], t > 0 \tag{14}$$

where  $\nu = \int_t^{t_0+t} \lambda(t) dt$  is the mathematical expectation of the number of bids at the site from  $t_0$  to  $t_0+t$ .  $\lambda(t)$  is instantaneous flow intensity.

The interpretation of the value of  $t$ , as the processed area  $S$ , changes the formulas in this way:

$$P(k, S, S_0) = \frac{\nu^k}{k!} e^{-\nu}, \text{ where } \nu = \int_{S_0}^{S_0+S} \lambda(y) dy \tag{15}$$

In this case, the probability that the coulter will encounter  $k$ -keys of the above sizes when cultivating a section of the field of size from  $S_0$  to  $S_0 + S$

$$F_1(S, S_0) = 1 - \exp \left[ - \int_{S_0}^{S_0+S} \lambda(y) dy \right] \tag{16}$$

The distribution functions of the random value of the treated area  $S$  between two neighboring collisions with stones ( $S_{i-1} < S < S_i$ ), then

$$P(S, S_0) = \lambda(S_0 + S) \exp \left[ - \int_{S_0}^{S_0+S} \lambda(y) dY \right] \quad S > 0 \tag{17}$$

In contrast to the stationary flow, here  $\lambda(y)$  is the probability density of the number of collisions with stones on an area  $Y$ . Performing static data processing (representative measurement of the number of stones per 1 ha in  $n$ -different parts of the field of size  $S$  ha) with the help of calculators, we obtained information about the form of the law  $\lambda(y)$  with the reliability 0.95.

The mathematical expectation of the quality of stones on the map of area  $S$  and clogging  $\lambda(y)$  will be

$$\nu = \int_{S_0}^{S_0+S} \lambda(y) dy \quad (18)$$

Using calculators with a given accuracy, the numerical method of the Symptom integral is calculated. Thus, for each map, we can calculate  $\nu$  is the mathematical expectation of the number of collisions with stones when the aggregate treats the field area  $S$ .

## 4 Conclusions

1. It is found that if the field is uniformly littered with stones, it is upgraded with a Poisson stationary flow of random events; if the field is non-uniformly littered with stones, it is upgraded with a non-stationary Poisson flow of random variables.

2. The probability of calculating collisions with  $k$ -rocks when treating a field with area  $S$  and field clogging  $\lambda$  is carried out according to the formula

$$P(k, S) = \frac{(\lambda S)^k}{k!} \exp^{-\lambda S}$$

at irregular clogging:

$$P(k, S, S_0) = \frac{\nu^k}{k!} e^{-\nu}$$

3. The mathematical expectation of the number of collisions when processing a field of area  $S$  with a distribution of stones  $\lambda$  is calculated by the formula:

in case of uniform clogging

$$m = \lambda S$$

in case of irregular clogging

$$\nu = \int_{S_0}^{S_0+S} \lambda(y) dy$$

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