Evaluating the distribution of sugar beet seeds at sowing

V V Vasilenko¹, S V Vasilenko² and N N Achkasova³

¹Department of Agricultural Machines, Tractors and Cars, Voronezh State Agrarian University, 1, Michurina str., Voronezh, 394087, Russia
²Department of Applied Mechanics, Voronezh State Agrarian University, Voronezh, 1, Michurina str., 394087, Russia
³Language Training Department, Financial University under the Government of the Russian Federation, 49, Leningradsky ave., Moscow, 125993, Russia

E-mail: vladva.vasilenko@yandex.ru

Abstract. A mathematical model is proposed for the formation of a uniform row of seeds in the sowing furrow in order to place them at the same intervals. A key role in this process is played by the random deviation of each seed from the intended place of laying. A mathematical model using probability theory was developed based on the results of laboratory experiments with sugar beet seeds sown onto sticky tape. The consistency of spacing between seeds is influenced by seed rate, i.e. seed number per one meter length of row, the speed of the seeders and the speed of rotation of a seed disc in the machine of exact seeding. Studies have shown that a sufficiently high accuracy of seed placement is achieved if the seeding disc rotates at a speed of 0.24-0.27 m/s, the speed of the drill is not more than 6 km/h, and the seeding dose is not higher than 8 pcs/m. In the field, the coefficient of variation of intervals is higher than on sticky tape, but does not exceed 0.33. There is no seed inversion, and the yield level is more than 98% of the maximum possible. Further improvement in seeding quality can only be achieved by further reducing the speed of precision seeding drills or by design upgrades to align the speed of the seeding machine and the rotation speed of the seeding disc.

1. Introduction

The technical capabilities of seeders, sowing tilled crops, should ensure the equality of the areas of supply for all sown seeds. Numerous studies of the level of yield of sugar beets prove that the main factors are the number of plants per hectare and the uniformity of the intervals between plants in the sowing row. The number of plants per hectare is a process factor that is easily regulated over a wide range. This factor is also easily controlled, so its effect on the crop has been determined for a long time and specified for various soil and climatic conditions, seed varieties, the amount of fertilizers and other related factors.

Usually recommended planting density does not exceed 100 thousand plants per hectare [1]. The authors of publications [2, 3] adhere to the same opinion. They recommend planting density of 95-98 thousand plants. The lower limit of rational planting density is 80 thousand plants per hectare, since with less density the crop begins to decline [4–6]. There are recommendations on the limits of variation of the rational planting density, for example, 80-105 thousand [7] or 80-125 thousand plants per hectare [8].

According to our research, in the conditions of the Voronezh region of Russia, the maximum yield of sugar beets is achieved with a planting density of 90 to 130 thousand per hectare. Such wide limits...
indicate a good adaptability of the culture to the density of accommodation [9]. It is much more difficult to estimate another crop increase factor, which is the accuracy of the distribution of plants along the sowing row. As it turned out, this factor is more influential than the density of plantings [9, 10].

Usually, the quality of seed distribution along a sowing row is estimated by the numerical characteristics of a random variable - the interval between seeds. These include the mathematical expectation \( m_0 \), the standard deviation \( \sigma_0 \) and the variation coefficient \( V_0 \). In case of poor quality of sowing, the percentage ratio of the number of double placement and the number of gaps can also be taken into account.

The mathematical expectation characterizes the seeding rate, or planting density, it is easily regulated when sowing. The standard deviation is calculated as a result of numerous measurements of the intervals between seeds and is crucial for the coefficient of variation. The coefficient of variation acts as the main indicator of the accuracy of seed distribution, but it has a significant disadvantage in that it depends on the seeding rate. Therefore, without knowledge of the seeding rate, it cannot characterize either the quality of the sowing or the dignity of the seeder.

2. Method and materials of calculation

To visualize the process of forming the intervals between seeds in the sowing row, we use the methods of probability theory. If the planter throws seeds at the same intervals \( m_0 \), then in the furrow these intervals become random values \( x_i \), since each seed rolls in the furrow by a random value \( \delta \) (figure 1). This value depends on the height of the seed fall, the speed of the seeder, the speed of rotation of the dosing element in the sowing machine and other factors.

For mathematical analysis it can be assumed that the mathematical expectation of a random variable \( \delta \) is zero, and the mean square deviation is \( \sigma' \). Each interval between seeds has the sum of two random variables \( \delta \). Summarizing them, the mathematical expectations are summed up, the dispersions are also summarized, so the mathematical expectation of the intervals \( m_0 \) will remain the same, but they will have a standard deviation \( \sigma_0 = 1.41 \sigma' \). If the seeding rate is small with significant intervals \( m_0 \), and the seeds almost do not roll in the furrow, that is, the indicator \( \sigma' \) is insignificant, then it may be that \( 3\sigma_0 < m_0 \), or \( 4.23 \sigma' < m_0 \) (figure 1.1). In this case, the random variable — the interval between the seeds — corresponds to the normal law of probability density distribution. But if the seeds roll in the furrow more, and the seeding rate is increased, that is, \( t_0 \) decreases, then there may be \( 4.23 \sigma' > m_0 \) (figure 1.2), and then the seeds violate the order of their placement, that is, negative intervals appear. This phenomenon is called seed inversion. This is low quality sowing.

Mathematics allows for the existence of negative intervals, but in our view they are always positive. Therefore, in this case, the normal probability density law is conditional (figure 2.1). We will not be able to isolate negative intervals for quality control of sowing. We will consider all intervals positive, that is, zone \( a \) on the graph we transfer to zone \( b \).

At the same time, the number of long intervals is reduced. Then the conditionally normal law with numerical characteristics \( m_0, \sigma_{con} = 1.41 \sigma' \) and \( V_{con} \) turns into some other law with an asymmetric graph (figure 2.2). In this law, the mathematical expectation remains unchanged, since the number of plants in the field does not change, but the standard deviation \( \sigma_0 \) and the variation coefficient \( V_0 \) change. To search for the mathematical dependence of \( V_0 \) on \( V_{con} \), we carried out experiments in the soil channel. At first, a sowing furrow was formed in the soil by advancing the seed coulter. A board with a marked scale was installed over the furrow. The seeds were laid out on the board with equal intervals of \( m_0 \). Then the board was turned, and the seeds fell into the furrow (figure 3).
Figure 1. Diagram of the formation of random intervals $x_i$ in a sowing row without inversion (1) and with inversion (2) seeds

$\delta$ - negative intervals in the conditionally normal distribution; $\delta$ - transferred intervals in the positive zone; 1 - conditionally normal law; 2 - real seed distribution

Figure 2. Transformation of the law of normal density; the distribution of intervals in the case of seed inversion at $m_0 = 0.1$ m and $\sigma_{\text{con}} = 0.1$ m

$\delta$ - negative intervals in the conditionally normal distribution; $\delta$ - transferred intervals in the positive zone; 1 - conditionally normal law; 2 - real seed distribution

Figure 3. Diagram of the experiment to determine the empirical interdependence of the numerical characteristics of random variables
There were already random intervals in the furrow. They were measured, the array of these data was entered into the PC, which gave the numerical characteristics of the real distribution of the random variable - the interval between the seeds in the furrow: \( m_0, \sigma_0 \) and \( V_0 \). Of these, the coefficient of variation \( V_0 \) was of particular interest. In this distribution, the conditionally normal law with the coefficient of variation \( V_{con}=1.41\sigma' m_0^{-1} \) was hidden, and it could be calculated knowing \( \sigma' \). To determine \( \sigma' \), an experiment was performed with an increased interval \( m_0 \), in which there was clearly no seed inversion in the furrow. From the obtained value of \( \sigma_0 \), \( \sigma' \) was calculated by the expression \( \sigma_0=1.41\sigma' \). To obtain empirical dependence, the initial intervals \( m_0 \) and the height \( h \) of the fall of seeds were changed, which influenced the coefficients of variation of both the conditional and real distributions.

3. Results and discussion
When processing the results of the experiments, it turned out that with an increase in the height of the fall of seeds, their standard deviation \( \sigma' \) from the place of fall increases. This indicator makes it possible to calculate all other numerical characteristics of conditionally normal and real distributions. Before the appearance of seed inversion, that is, with the coefficient of variation of intervals \( V_{con} = 0 \) ... 0.33, the real distribution has the same coefficient of variation as the conventionally normal one. In this area, the graph has a linear dependence from zero to point \( A \) (figure 4), and the conditionally normal distribution is really normal.

![Figure 4](image)

**Figure 4.** Plot of mutual dependence of the coefficients of variation of the intervals between the seeds of conditionally normal and real distributions

In general, the entire curve with a high degree of accuracy corresponds to the empirical dependence

\[
V_0 = 1 - \exp(-1.1V_{con}),
\]

where \( V_0 \) is the coefficient of variation of intervals between seeds in their real distribution; \( V_{con} \) - coefficient of variation of intervals between seeds in a conditionally normal distribution.

As for the probability density law of intervals in the real distribution (curve 2 in fig. 2), the law of the gamma distribution of a random variable is most appropriate

\[
f_0(x) = \frac{\beta^\alpha}{\Gamma(\alpha)} x^{\alpha-1} e^{-\beta x},
\]

where \( \alpha \) is an indicator of the accuracy of the gamma distribution, \( \alpha=(m_0)^2/(\sigma_0)^2 \); \( \beta \) is the flow density indicator, \( \beta=(m_0)/(\sigma_0)^2 \); \( \Gamma(\alpha) \) is the gamma function of \( \alpha \).

The results of the experiments confirm that the coefficient of variation of the intervals between the seeds cannot fully characterize the dignity of a single-grain seeder. According to figure 1 it is possible to conclude that this coefficient depends not only on the accuracy of fixation of each seed in the
furrow, but also on the size of the interval $m_0$, that is, on the seeding rate per hectare. Indicator $\sigma'$, which characterizes the deviations of each seed from the calculated point of its fixation in the sowing furrow, is more stable. From the expression (1) it follows that it can be calculated using the numerical characteristics of the intervals during the quality control of sowing:

$$\sigma' = 0.64m_0 \ln (1-V_0)^{-1},$$

where $\sigma'$ is the average square deviation of the seed from the place of laying in the furrow, m; $m_0$ is a mathematical expectation of intervals between seeds, m.

The peculiarity of the indicator $\sigma'$ is that it does not depend on the seeding rate, if it is regulated by changing the number of cells on the metering element of the sowing apparatus. But if the seeding rate is adjusted by changing the rotational speed of the metering element, this affects the accuracy of laying each seed, that is, the $\sigma'$ value. To evaluate this effect, another series of experiments was carried out with seeding seeds onto a moving adhesive tape with a cellular disk and pneumatic sowing devices. Tables 1 and 2 show the results of these experiments.

### Table 1. Indicators of the accuracy of distribution of sugar beet seeds on a sticky tape (cellular-disk device of the SST-12B seeder)

| Disk rotation speed, m/s | Mathematical expectation of intervals, m | Coefficient of variation of intervals $V_0$ | The indicator $\sigma'$, m |
|--------------------------|----------------------------------------|---------------------------------------------|---------------------------|
| 0.075                    | 0.0562                                 | 0.61                                        | 0.0339                    |
| 0.10                     | 0.0430                                 | 0.56                                        | 0.0226                    |
| 0.15                     | 0.0289                                 | 0.55                                        | 0.0148                    |
| 0.20                     | 0.0215                                 | 0.61                                        | 0.0130                    |
| 0.25                     | 0.0172                                 | 0.60                                        | 0.0101                    |

### Table 2. Indicators of accuracy of distribution of sugar beet seeds on a sticky tape (Pneumatic device of the pneumatic seeder)

| Disk rotation speed, m/s | Mathematical expectation of intervals, m | Coefficient of variation of intervals $V_0$ | The indicator $\sigma'$, m |
|--------------------------|----------------------------------------|---------------------------------------------|---------------------------|
| 0.075                    | 0.0677                                 | 0.24                                        | 0.0119                    |
| 0.10                     | 0.0508                                 | 0.24                                        | 0.0089                    |
| 0.15                     | 0.0357                                 | 0.28                                        | 0.0075                    |
| 0.20                     | 0.0274                                 | 0.311                                       | 0.0065                    |
| 0.25                     | 0.0219                                 | 0.31                                        | 0.0052                    |

Seeding onto the adhesive tape eliminates the effect of rolling seeds in the furrow and shows the spread of the values of the intervals only from inaccuracies in the operation of the sowing apparatus. The processing time of each seed varies due to the position of the seed in the cell, its shape, delays with the exit of the cell, etc. With a high speed of rotation of the disk, these delays are reduced, as a result, the device serves the seeds quickly and accurately. It turned out that the indicator $\sigma'$ is inversely proportional to the speed of rotation of the disk.

If this speed is kept high, on the verge of permissible according to the condition of filling the cells, and the seeding rate is regulated by changing the number of cells, then the accuracy indicator in actual sowing conditions will remain at 1-2 cm for the cellular-disk apparatus, and at 0.5-1.0 cm for pneumatic devices. This will allow obtaining high quality seed distribution without inversion at seeding rates with mechanical devices less than 11 pcs / m, and pneumatic - less than 20 pcs / m.

For currently existing seeding rates of sugar beet seeds from 6 to 8 pieces / m, the coefficient of variation of intervals for cellular-disk apparatus will be about 0.10, and for pneumatic devices - 0.05. Naturally, these results can be obtained by sowing seeds on adhesive tape. In the field, the influence of the speed of the drill is added. It should not exceed 6 km/h. The coefficient of variation of intervals is
higher than on sticky tape, but does not exceed the value of 0.33. There is no seed inversion, and the yield level is more than 98% of the maximum possible [9].

Further improvement in the quality of seeding can only be achieved by further reducing the speed of single-grain seeders, which is clearly undesirable, or by design upgrading to align the speed of the seeder and the speed of the metering element.

4. Conclusion

The deterioration in the quality of single-grain seeding occurs when the accuracy of the layout of each seed is disturbed and with an increase in the seeding rate. The probability density of the distribution of intervals between seeds can be approximated by the law of the gamma distribution of a random variable both in the case of the appearance of seed inversion with the coefficient of variation of intervals more than 33%, and with their more accurate placement. As an indicator of the accuracy of placement, it is most convenient to take the standard deviation of the seed from the estimated fixation position in the seed furrow. This deviation decreases with increasing speed of rotation of the sowing element and does not depend on the seeding rate, if it is regulated only by the number of cells on the sowing disc. The speed mode of operation of the sowing apparatus should be as admissible as possible. For cellular disc and pneumatic devices, it is 0.24-0.27 m/s. In this case, the average square deviation of the seed in seeders type SST-12B is 1-2 cm, and pneumatic – 0.5-1.0 cm. At a seeding rate of sugar beet seeds of 6-8 pcs/m, the coefficient of variation of intervals on the adhesive tape will be about 10 and 5%, respectively. In the field, the coefficient of variation of intervals is higher than on sticky tape, but does not exceed 0.33. There is no inversion of seeds, and the yield level is more than 98% of the maximum possible. Further improvement of the sowing quality can be achieved only by an even more significant decrease in the speed of the single-seeder seeders or by constructive modernization to equalize the speed of the seeder and the rotation speed of the metering element.

References

[1] Ahmad Muhammad, Sedaghatjoo Somayyeh and Westphal Andreas 2016 Reproductive capacity of Heterodera schachtii on Thlaspi arvense, Capsella bursa-pastoris and varying populations of Chenopodium album Journal of plant diseases and protection 123(1) 37-42
[2] Probsa-Bialczyk Urszula, Sacala Elzbieta, Wilkosz Malgorzata et al 2017 Impact of seed stimulation and foliar fertilization with microelements on changes in the chemical composition and productivity of sugar beet Journal of Elementology 22(4) 1525-1535
[3] Cakmakci R, Oral E and Kantar F 1998 Root yield and quality of sugar beet (Beta vulgaris L.) in relation to plant population Journal of agronomy and crop science 180(1) 45-52 (in German)
[4] Jaggard K W, Qi A, Milford G F J et al 2011 Determining the optimal population density of sugarbeet crops in England International Sugar Journal 113(1346) 114-119
[5] Bavorova M, Stockfisch N and Koch H J 2000 Effect of plant density on harvesting quality of sugarbeet Sugar Industry 125(11) 890-897 (in German)
[6] Bavorova M and Koch H J 2002 Effect of plant density and lifting speed on harvest losses of sugar beet Listy cukrovarnicke a repaske 118(9-10) 208-209
[7] Tirczka I and Kondora C 1999 Yield and quality of sugar beet as a function of region, plant density and harvest time Novenytermeles 48(3) 289-299
[8] Minx L 1992 Yield utilization of distances in the row by sugar-beet plants Rostlinna Vyroba 38(6) 511-515
[9] Vasilenko V V, Vasilenko S V and Achkasova N N 2018 The impact of precision seeding on yield of sugar beet International Scientific and Practical Conference "Agro-SMART - smart solutions for agriculture" (Agro-SMART 2018) 151 776-778
[10] Pochi D and Fanigliulo R 2011 Seed Spacing Uniformity of 4-6-8 Rows Precision Drills for Sugar Beet Sowing XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010): International Symposium on Engineering the Modelling, Monitoring, Mechanization and Automation Tools for Precision Horticulture 919 131-138