Estimation of Seed Distribution Uniformity over an Area

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Schätzung der Gleichmäßigkeit der Saatgutverteilung über eine Fläche

1. Introduction

The uniformity of the seed distribution over an area is a moderate factor influencing crop yields. Sowing methods produce an effect on this factor. Therefore there is a need of a unified measure, which is suitable for different seeding methods and rates. One of the measures was considered, and corresponding calculations were made by HEEGE (1993). This measure is the mean distance from each seed to the nearest neighbour. It will be suitable for comparing different seeding methods providing a rate of sowing is fixed. When analyzing drilling with high seeding rates the nearest neighbour may be found in the same row. So in this case the measure does not estimate the seed distribution uniformity over an area but in the row.

Another relative measure M (KHOMENKO et al., 1989) was offered which allows making comparative estimates for seeding methods under different seeding rates. It is the ratio of the sum of conditional circles of plant root nutrition Q to the sown area F:

$$M = Q/F \qquad (1)$$

The radius of the circles is:

$$R = \sqrt{F/(\pi \times n)} \qquad (2)$$

where n = a number of seeds (plants) sown over the area F.

Zusammenfassung

Betrachtet wird die Gleichmäßigkeit der Verteilung von Saatgut auf einer Fläche. Als Maß dient das Verhältnis von der Summe jener Kreisflächen, die von der Ernährung der Pflanzenwurzel bedingt sind und die nur einmalige gegenseitige Überlappungsflächen sicherstellen, einerseits zur Saatfläche andererseits.

Entwickelt werden ein Problemaufriss und ein Computerprogramm zur Berechnung von Messzahl-Werten für verschiedene Saatverfahren und Saatdichten. Das Programm erlaubt die Simulation von Saatverfahren und deren Einschätzung durch die Messzahl ebenso wie die Einschätzung von Versuchs-Daten. Präsentiert werden mit Hilfe des Programmes ermittelte Ergebnisse eines theoretischen faktoriellen Experiments. Die günstigste Saatgutverteilung ist mit Einzelkornsaat (im Abstand gleichschenkeliger Dreiecke) oder gleichmäßiger Breitsaat zu erzielen. Diesfalls liegt der Maximalwert der Messzahl bei 0,97. Mit Breitsaat bekommt man eine exponentielle Verteilung in Fahrtrichtung sowie senkrecht zu dieser und das Maß nimmt den Mittelwert von 0,57 an.

Schlagworte: Saat, Verteilung, Gleichmäßigkeit, Fläche, Simulation.

Summary

The seed distribution uniformity over an area is considered. As a measure the ratio of a sum of areas of conditional circles of plant root nutrition, providing that the area of their mutual superposition is included once only, to a sown area is used. A problem set-up and a computer program for calculation of values of the measure under different seeding methods and seeding rates were developed. The program provides simulation of seeding methods and their estimation by the measure as well as estimation of experimental data. The results of a theoretical factorial experiment obtained through use of the program are offered. The best seed distribution is achieved with precision drilling (equilateral triangular-spacing) or uniform broadcast sowing. In this case the maximum value of the measure is 0.97. With broadcast sowing which gives the exponential distribution in the direction of travel and perpendicular to it the measure assumes the mean value 0.57.

Key words: Seed, distribution, uniformity, area, simulation.

2. Method

Applying this measure to a certain framed area sown under different sowing methods the uniformity of the seed distribution may be determined, and therefore a comparative analysis may be carried out. Having chosen the dimensions of a frame and a rate of seeding with the aid of the equations (1) and (2) a visual view of the applied method can be presented (fig. 1).

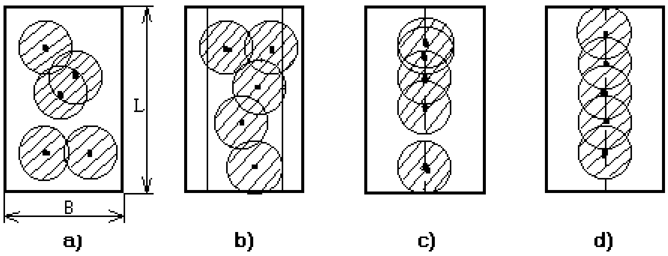

Figure 1: Schematic interpretation of using the measure M: a – broadcast sowing; b – band sowing; c – drilling; d – precision drilling.

Abbildung 1: Schematische Interpretation des Maßes M: a – Breitsaat; b – Bandsaat; c – Drillsaat; d – Einzelkornsaat.

The section-lined area is represented by Q, and the whole area by F, which is equal to the product of B into L, where B is the width of the frame, and L the length of the frame.

It is evident that this measure or the coefficient of the seed distribution uniformity can vary over the range: $0<M<1$. A developed computer program was used to calculate values of the coefficient for precision drilling. The measure acquires the highest value 0.97 independent of the seeding rate when precision drilling is used with equilateral triangular-spacing. Precision drilling provides the measure values 0.33, 0.40, 0.49, 0.64, and 0.89 when sowing is performed with a rectangular arrangement and row spacings 0.15, 0.125, 0.1, 0.075, and 0.05 m correspondingly (the seeding rate – 5 million seeds per hectare). At the rate 2 million seeds per hectare the measure takes the following values respectively: 0.52, 0.61, 0.74, 0.91, 0.74. Hence it appears that in precision drilling with rectangular spacing the maximum value of the measure (0.91) will be achieved in the case when the seed distance in the row is equal to the row spacing, i.e. in the case of square spacing. Therefore the coefficient M varies over the range 0.91 ... 0.97 when precision drilling is applied, and the seed distance in the row is equal to the row spacing. Otherwise it will be less than 0.91.

For precision drilling these results can be obtained also by using mathematical equations. However, when bulk metering is performed, the placement of seeds within the row, and within the band in the direction of travel follows the exponential distribution [1]. It is described by the equation:

$$P(z) = (1/m) * e^{-z/m} \qquad (3)$$

where P(z) is the distribution density and m is the mean distance between seeds in the z direction. We will use in our computer program symbols m_x and m_y for labelling the mean distances in the x direction and the y direction respectively.

When seeding in a band the seed distribution perpendicular to the direction of travel may be different. Producers are striving to make it the uniform distribution or approach it as near as possible. The seed distribution in the case of broadcast sowing follows the Poisson-distribution [1]. So another computer program is needed for computing values of the measure under such conditions. Prior to the development of the computer program a general scheme of seeding was worked out (fig. 2).

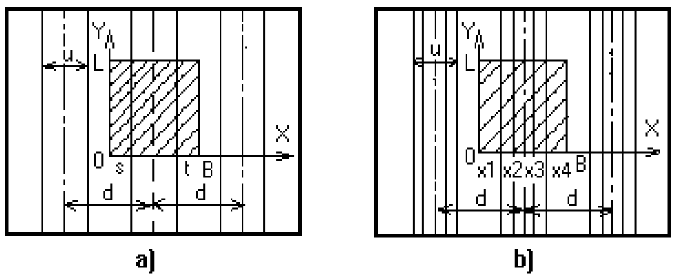

Figure 2: General schemes of seeding grain crops: a – seeding in a band of the width u; b – seeding in a group of rows (e.g. x1, x2, x3, x4).

Abbildung 2: Generelles Schema der Saat von Körnerfrüchten: a – Aussaat im Band mit der Breite u; b – Aussaat in Gruppen von Reihen.

A rectangular frame (B = width, L = length) is used, which has such dimensions so that a sown area under it may represent a whole seeding scheme. The section-lined frame denotes the unit of a sown area. Variable quantity u is the symbol for the band width (fig. 2a) or the outer rows spacing (fig. 2b). A row spacing, band spacing or group-of-rows spacing are labelled by d. Quantities x1, x2, x3, x4, and s, t denote the X-coordinates of rows and borders of a band, respectively. The width of the frame B is equal to d. The frame size is dependent on seeding schemes, and also on seeding rates. The frame is intended for determination of coordinates of seeds or plants. When the band width u = 0 we will have the case of drilling, and when u = d then band sowing transforms into broadcast sowing.

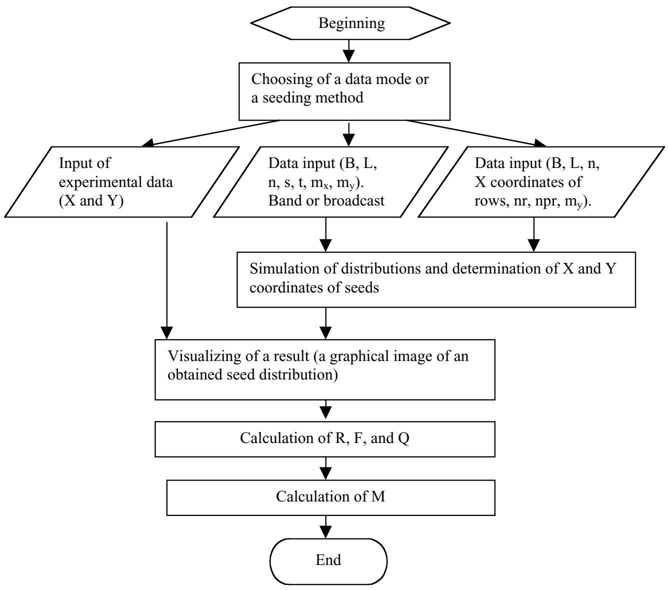

Figure 3: The scheme of the algorithm
Abbildung 3: Das Schema des Algorithmus

The coordinates of seeds may be obtained by simulation of a seed distribution over an area, and also by experimental data gained as a result of measurements accomplished in a field with young growth or stubble within the given frame.

Using the specified schemes and the mentioned notation an algorithm was synthesised. Figure 3 shows the simplified scheme of the algorithm.

In line with the algorithm a computer program was developed using the programming language Turbo Pascal 7.0.

3. Factorial experiment

With the aim of determination of the relationship between the coefficient M and the seeding rate N, the band width u, and the row spacing d a statistical simulation of seeding methods (fig. 2a) and their estimation by the coefficient M was carried out, using 3^3 factorial design of Box-Benkin (table 1) on the basis of the exponential distribution for the frequency of the distances between seeds in the direction of travel, and the random number generator of Turbo Pascal (the function Random) perpendicular to the direction of travel.

Table 1: Levels of factor variation
Tabelle 1: Niveaus der Faktorvariation

Factors	Levels of variation		
	Lower	Zero	Upper
N, million seeds per hr	1	3	5
w	0	0.5	1
d, m	0.1	0.25	0.4

The levels of variation of the band width u is represented in per-unit (labelled w*)*, namely in fractions of the row spacing d. The simulation was performed for n = 120 plants or seeds, i. e. the size of the frame was changed as a function of the seeding rate and the row spacing.

As a result of the simulation a regression equation was obtained with specified risk level 0.95 in the form of a polynomial of 2 – power.

$$M = 0.75 - 0{,}04\,N - 1.44\,d + 0.05\,Nw - 0.14\,w^2 + 1.19\,wd + 0.80\,d^2 \qquad (3)$$

The coefficient of multiple determination is D = 0.974. It is significant with a probability of P = 1.0000. The calculated F-test is equal to 233.6. Every coefficient of the regression is significant with the critical value 2.013 of the two-sided t-test with the confidence probability P = 0.95.

4. Discussion

It is detected that M plotted against N yields a straight line provided that d and w remain constant, and there is M dependence of squared d and w squared. It should be admitted that the coefficient M does not depend on the seeding rate in the case of the uniform distribution of seeds over an area. Graphical representation of the equation gives better insight into the response surface (figures 4 and 5).

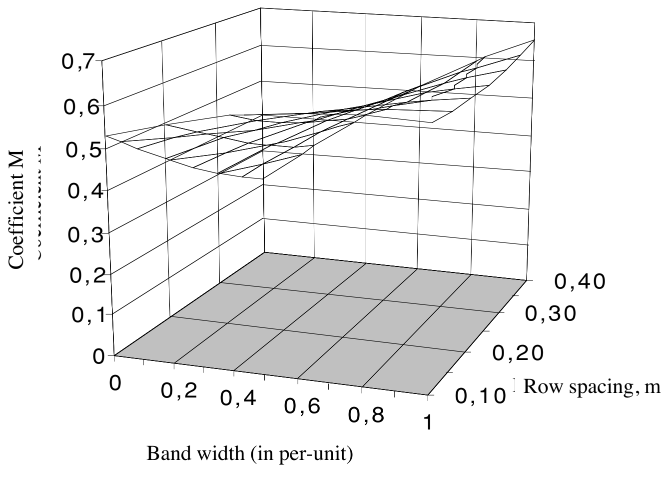

Figure 4: The coefficient M due to variations in the band width and row spacing (the seeding rate 2 m/hr).
Abbildung 4: Der Koeffizient M in Abhängigkeit von der Variation der Bandweite und des Reihenabstandes (Saatdichte 2 m/h).

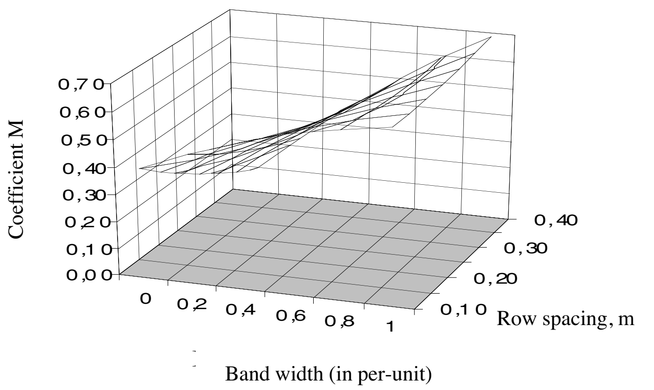

Figure 5: The coefficient M due to variations in the band width and row spacing (the seeding rate 5 m/hr).
Abbildung 5: Der Koeffizient M in Abhängigkeit von der Variation der Bandweite und des Reihenabstandes (Saatdichte 5 m/h).

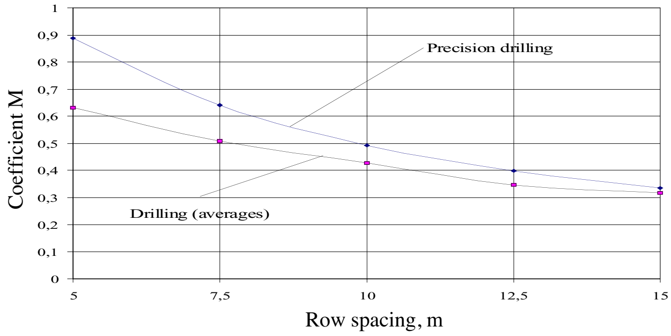

Figure 6: Graphic analysis of relationship of the coefficient M with the row spacing (the seeding rate 5 m/hr).
Abbildung 6: Graphische Analyse des Zusammenhanges zwischen dem Koeffizient M und dem Reihenabstand (Saatdichte 5 m/ h).

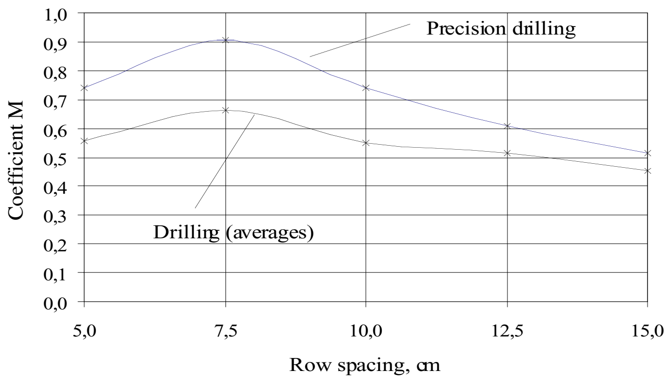

Figure 7: Graphic analysis of relationship of the coefficient M with the row spacing (the seeding rate 2 m/hr).
Abbildung 7: Graphische Analyse des Zusammenhanges zwischen dem Koeffizienten M und dem Reihenabstand (Saatdichte 2 m/h).

A polynomial equation may be received for the zone of row spacings less than 10 cm using this computer program for an additional simulation. It would be a different equation, so the widening of d to lower values (table 1) could cause a less exact presentation of the event.

The response surface under the seeding rate 5 million seeds per hectare (m/hr) (fig.4) is less "twisted" than the corresponding surface under the seeding rate 2 m/hr (fig. 5). Therefore the seed distribution uniformity over an area is the more susceptible (sharply decreasing) to seeding methods the higher seeding rates are in the zone with narrower band widths, expressed on the per-unit basis, and the greater row spacings are. Higher values of the coefficient M are received with narrower row spacings and broader band widths or by joint influence of these factors.

Figures 6 and 7 show the results of separate (additional) calculations carried out with the aid of the computer program to elucidate the plot of M against smaller row spacings with drilling (the exponential distribution) and precision drilling. Under the seeding rate 5 m/hr (fig. 6) there is a continuously increasing gap between the two curves with the diminishing row spacing. But under the seeding rate 2 m/hr (fig. 7) there is a different relationship. Approximately with the row spacing 7.5 cm there is a maximum, and with the row spacing 5 cm the coefficient M is decreasing. The maximum is formed providing that the mean distance or the distance (precision drilling) between seeds in the row is approximately equal to the row spacing. There may be the square-spacing or equilateral triangular-spacing in this case. With further diminishing of the row spacing the coefficient M is decreasing because of the rectangular-spacing (the longer side lies along rows) or isosceles triangular-spacing. So it depends on the seeding rate at what row spacing the maximum will be viewed.

Another separate computation was made to ascertain the trend of a curve of the connection between the coefficient M and the band width u (fig. 8). In this particular case the row spacing and the seeding rate were assumed to be equal to 30 cm and 5 m/hr correspondingly. The seed distribution in the direction of travel and perpendicular to it were adopted the same as when carrying out the factorial experiment. Figure 8 shows that the experimental averaged curve approaches the mean value of M = 0.61 asymptotically with increasing order of the band width to the value 30 cm or 1 on the per-unit basis.

The limits of confidence (P=0.95) show that in a particular case the results may be equal for different values of the

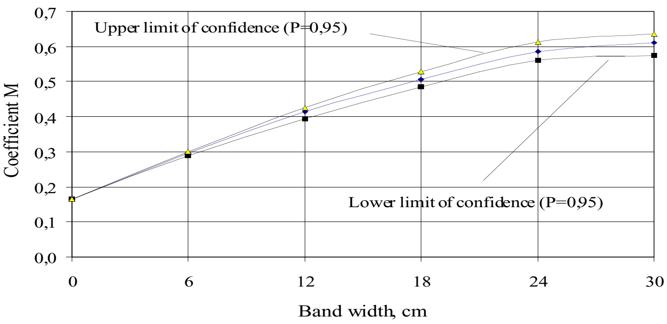

Figure 8: Graphic analysis of relationship of the coefficient M with the band width (the row width 30 cm, the seeding rate 5 m/hr).

Abbildung 8: Graphische Analyse des Zusammenhanges zwischen dem Koeffizienten M und der Bandbreite (Reihenweite 30 cm, Saatdichte 5 m/h).

band width, e.g. 24 cm and 30 cm (or 0.8 and 1.0 in per-unit respectively). The similar curve we can receive by passing a section through the response surface (fig. 5) obtained by carrying out the factorial experiment.

The computer program allows making calculations under several combinations of types of the seed distribution in a band or with broadcast sowing in the direction of travel (Y-axis) and perpendicular to it (X-axis) (table 2, the number of combinations may be increased).

Table 2: Simulation of a seed distribution over an area
Tabelle 2: Simulation der Saatgutverteilung über eine Fläche

The number of a combination	A distribution	
	X-axis	Y-axis
1	Random	Random
2	Random	Exponential
3	Exponential	Exponential

It also offers the determination of the coefficient M under different schemes of drilling. In this case the exponential distribution (the function Random is also offered) may be used for simulation of seed distribution in the direction of travel.

The determination of the seed distribution uniformity over an area when broadcast sowing simulation is performed under the combination 3 and the seeding rate 5 m/hr was made. The average of the coefficient M is 0.57, the standard deviation – 0.0156, the standard deviation of the estimate of the mean – 0.0064.

The computer program has the block for processing experimental data. To derive these data the frame should be superimposed on a field with shoots or stubble, and coordinates of every plant should be determined. The coordinates are entered into the program through a keyboard.

5. Conclusions

1. The developed problem set-up and program for simulation on a computer allow making various calculations for determination of the seed distribution uniformity over an area under different seeding methods and seeding rates. With the aid of the computer program theoretical calculations and the evaluation of experimental data may be carried out, and therefrom specified equations may be obtained for practical use.
2. Calculations of the coefficient M with the aid of the computer program offer ample scope for carrying out purposeful experiments for the determination of the relationship between this coefficient and the crop yield.
3. Already obtained and supposed results would be useful in designing new seeding machinery especially when choosing a particular seeding method. Improvement of the seed distribution is possible by moving down in the row spacing, broadening the band width or by combined effect of these two factors. The highest value 0.97 is acquired by precision drilling (equilateral triangular-spacing) or by uniform broadcast sowing. Under low seeding rates decreasing the row spacing may result in worsening of seed distribution even with precision drilling.

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