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Comparison of Coefficient of Variation with Non-uniformity Coefficient in Evaluation of Grain Drills

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ABSTRACT

External fluted feed rolls are commonly used in grain drills. The fluted feed roll meters a volume of seeds and does not singulate the seeds as do the precision planters; therefore, there will be inherent variation in the number of seeds delivered per unit of time. This research was conducted to investigate the effect of seed meter drive shaft and ground speeds and outlet positions in a grain drill on the variation in wheat seeding rate and seed flow evenness from various outlets in short time intervals using the coefficient of variation (*CV*) and the non-uniformity coefficient (NU_C). In this study, a grain drill with straight fluted metering mechanisms was evaluated on a test rig. Two rotational speeds of 16 and 23 rpm and two speeds of 2.5 and 3.6 km h^{-1}were selected for the seed meter drive shaft and the movement of the test rig, respectively. The results showed that, for a given test rig speed, the seeding rate changed proportional to the seed meter drive shaft speed, whereas for a constant speed of seed meter drive shaft, the seeding rate decreased as the speed of the test rig increased. Also, the seeding rates from all outlets were not the same. Outputs of some of the outlets were autocorrelated, for which selecting 12 or 24 seed samples randomly out of 36 consecutive samples were not essentially non-autocorrelated. Increasing rotational speed of seed meter drive shaft significantly increased the coefficient of uniformity of all outlets. The seed breakage was significantly increased with the speed of seed meter drive shaft. The *CV* and NU_C exhibited similar trends. It can, therefore, be concluded that in grain drill evaluation, either *CV* or NU_C could be used as an index of seed flow non-uniformity.

Keywords: Autocorrelation, Coefficient of variation, Grain drill, Non-uniformity coefficient.

INTRODUCTION

The growth of a new crop begins with the planting of seeds or transplanting of seedlings. A seeder can affect seed emergence rate and initial plant growth by affecting the uniformity of seeding depth and seed distribution in the furrow as well as the degree of soil compaction around the seeds. The four main methods of seed planting are: seed spreading, drilling, precision planting, and hill-drop planting, which are different in their seed scattering or planting patterns. The grain drill, which is widely used in seeding small grains, measures and scatters the seeds into the furrow and covers them with soil. In this method, the seeds are planted on lines located at predefined intervals, but no uniform intervals exist between the planted seeds in any furrow (Srivastava *et al.*, 1993).

The two types of metering mechanisms commonly used in grain drills are external fluted and studded feed-rolls. The fluted wheel seed metering system has been used on grain drills for over 300 years (Brown, 2003). This system is a simple mechanism and is adequate for seeding small grains such as wheat (*Triticum aestivum* L.). The basic concept of the fluted wheel system is to deliver an "average population" as opposed to metering individual seeds (Ess *et al.*, 2004). The seed flow per revolution of the feed roll

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is obtained as the sum of the seeds displaced by the flutes and the seeds scattered by the active layer between the bottom flap and the roll. The quantity of seeds displaced by the flutes of the roll depends upon seed bulk density, the coefficient of filling of the flutes, the cross sectional area of the flutes, the number of flutes on the roll, and the active length of the roll. The quantity of seeds displaced by the active layer varies almost linearly with the active length of the roll (Klenin *et al.*, 1986).

The uniformity of seed intervals on the planting lines generally depends on the metering roll designs, the method of seed transfer from discharging tubes to the furrow, and on the travel speed (Bernacki *et al.*, 1972). Guler (2005) investigated the effects of fluted-roll diameter as well as the active roll length and speed on the flow rate and flow evenness of alfalfa seeds. By measuring the flow rate and its coefficient of variation, he concluded that the fluted-roll diameter should vary between 6 to 8 mm and the roll should also be run using active lengths of 15 to 25 mm at fluted roll speeds of 20 to 40 rpm. In a laboratory experiment, Boydas and Turgut (2007) studied the effects of four different vibration levels on flow evenness of wheat and barley using three studded feed roll designs and two seeding rates. Their results showed that vibration levels had no significant effect on the flow evenness of wheat; however, the flow evenness of barley was significantly affected by vibration. Increasing seeding rate significantly improved seed flow evenness.

There is no standard for determining the seed distribution uniformity from different outlets of a grain drill. Prairie Agricultural Machine Institute (PAMI) has accepted a maximum coefficient of variation (*CV*) of 15% for grain-drills. In order to observe variations in seed delivery of any metering mechanism, measurements should be made at short time intervals (Bashford, 1993).

Maleki *et al.* (2006) reported that *CV* is not an appropriate parameter in grain drill evaluation because the seed flow rates from each outlet over short time intervals are not independent and are probably autocorrelated as in a time series. As a result, they introduced a new index named coefficient of uniformity (U_C) to evaluate the uniformity of the number of delivered seeds from each metering mechanism. They found that U_C was less sensitive to data outliers than *CV*. Their results also indicated that a consecutive sampling scheme should be considered during the grain drill feeding system evaluation instead of randomly selected samples. In their tests, however, they only evaluated a single auger-type metering mechanism and there was no delivery tube under their metering outlet. The least absolute value method is one of the variability robust methods that have the property of being less sensitive to outlying data and to variation around the mean (Neter *et al.*, 1990). Endrerud (1999) showed that for inclination of delivery tubes larger than the material's dynamic coefficient of friction, the seeds not only travel down the tube by pure translational movement, but by a transversal movement as well. The second part is analogous to turbulent flow in a fluid. Therefore, the results of Maleki's experiment (Maleki *et al.*, 2006) could be different if they had delivery tube on the seed metering mechanism.

In evaluation of grain-drills, the width-wise (row-to-row seed variation; seed discharge flow rates from different outlets) and lengthwise (within-row variability; seed discharge flow rates from each metering unit in short consecutive time intervals) seed distributions should be determined. Along these lines, the objectives of the present study included: 1) to investigate the effects on seeding rate of seed meter drive shaft as well as ground speeds and outlet positions in a grain drill, 2) to study the variations in seeding rate and seed flow evenness from various outlets over short time intervals using the coefficient of variation (*CV*) and non-uniformity coefficient (NU_C=1-U_C), and 3) to determine the amount of seeds damaged and percentage of reduction in seeds germination as affected by the rotation speed of the metering mechanisms.

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MATERIALS AND METHODS

Seed Specifications

In this study, wheat (*Triticum aestivum* L.) seeds with purity and germination percentages of 99% and 98%, respectively, were used. The bulk density and 1000-seed weight were 800 kg m^{-3} and 43.5 g, respectively. The initial moisture content of seeds was 7.8% on the wet basis.

Grain Drill Specifications

For this research, a Hassia grain-drill (Model no. DU100) with an external straight fluted feed-roll type metering mechanism was used. This grain drill had 19 planting rows with the row spacing of 16 cm. The power for the seed meter drive shaft was provided by drive wheels via a sprocket-chain and a gear-box. The gear-box with the cam and a follower mechanism using a one-directional ball-bearing made it possible for the metering mechanism to have different seeding rates at a constant ground speed.

Laboratory Evaluation of Grain Drill

In order to investigate the seed distribution patterns of the metering mechanisms, laboratory tests were carried out using a test rig (Figure 1a) with a width of 1m and a length of 8 m to simulate the ground speed of the grain drill. The drive pulley of the test rig was powered by a variable speed motor (with a rated power of 10 hp) and a gear-box. The grain drill wheel was powered by an electrical motor (with a rated power of 2 hp) and a gear-box and the rotational speed of the motor was also adjusted by an inverter. On the test day, half of the grain-drill hopper was filled with the seeds and at least 10 minutes was allowed for the seeds to settle down in the hopper. Considering the width of the test rig, only 5 metering devices (No. 3 to 7) were evaluated. Along each row, 12 boxes (14×14×10 cm each) were placed on the test rig (Figure 1b). The seeds in each box were counted and weighed separately. The seed weight in each box was divided by the box cross sectional area and, then, the data were converted to kg ha^{-1}.

Two rotational speeds of 16 and 23 rpm were selected for the seed meter drive shaft. These rotational speeds were equivalent to 7 and 10 km h^{-1} ground speeds for planting 160 kg wheat seed per hectare when the seed meter drive shaft was driven by the grain drill drive wheel. Speeds of 2.5 and 3.6 km h^{-1} were chosen for the movement of the test rig, which were equal to the ground speeds of the grain drill. These speeds were considered due to the limitations in controlling the test rig speed. Before starting each test, the drill wheel was rotated to ensure a uniform seed discharge flow.

Seed Damage

Percentages of seed breakage and reduction during seed germination of the collected seeds in the boxes were determined. In order to obtain the percentage of wheat seeds breakage, the broken grains in all 12 boxes for each outlet were counted manually and separated from apparently undamaged seeds. The reduction in wheat seeds germination was measured by collecting 100 seeds randomly from the apparently undamaged and intact seeds in each experiment and compared to that of the reference seeds i.e., the seeds that had not passed through the metering mechanism. For the germination test, seeds were placed under moist conditions on rolled towels at 25 °C in a germinator. The germinated seeds in each dish were counted after seven days.

Indices for Seed Distribution Uniformity Evaluation

In this study, the coefficient of variation (*CV*) and the coefficient of non-uniformity (NU_C) were used to evaluate the seed metering accuracy of the grain drill. The

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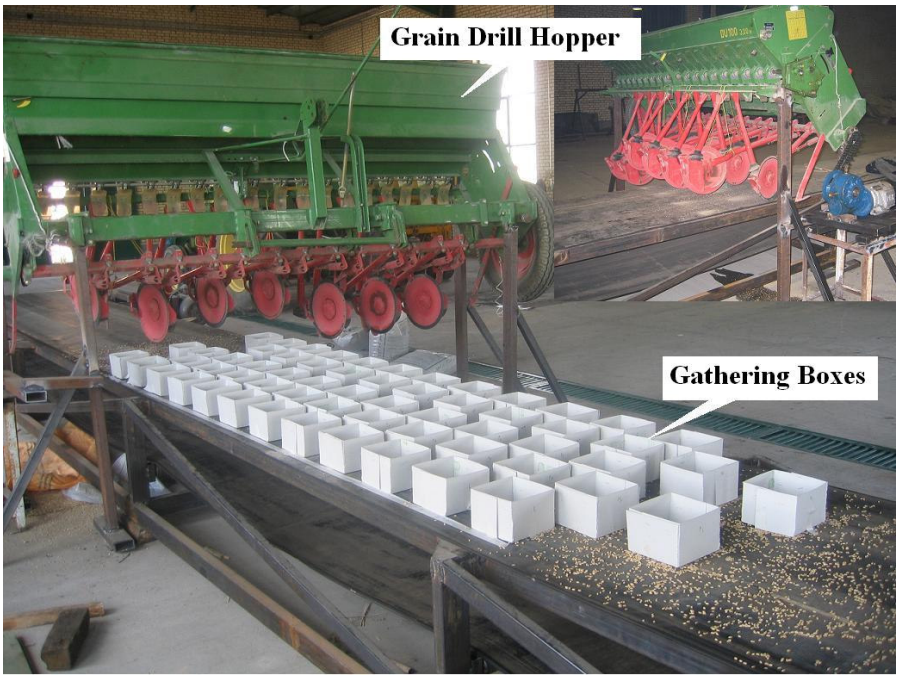
(a)



(b)

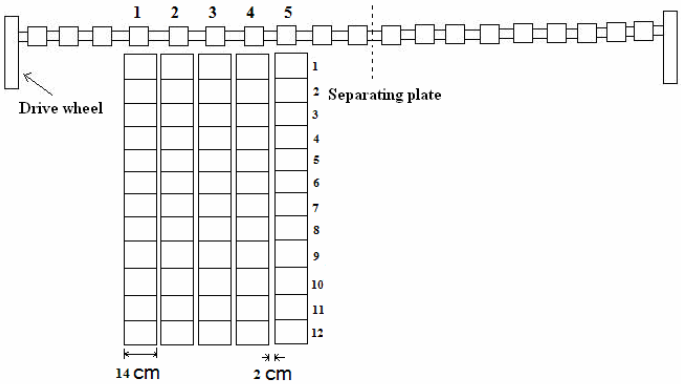


Figure 1. a) Illustration of the arrangement of the gathering boxes on the test rig used to measure seed output during laboratory test; b) numbering of outlets and the gathering boxes.

coefficient of variation (*CV*) is based on the sample standard deviation divided by its mean and can be expressed as a percentage. The *CV* is widely used for evaluating fertilizer and seed spreaders.

The coefficient of uniformity (U_C), as defined by Maleki *et al.* (2006), can be calculated as follows:

$$U_c = \frac{1}{n}\sum_{i=1}^{n} F_{ci} \qquad (1)$$

Where, U_c is the coefficient of uniformity and F_{ci} is the coefficient of the ith box that is calculated using the following equation:

$$F_{ci} = 1 - \left| \frac{S_{fi}}{S_{pf}} - 1 \right| \qquad (2)$$

F_{ci} is box coefficient, S_f is the number of seeds collected in the given box (equivalent to X_i), and S_{pf} is the average number of seeds in each box and is calculated as follows (S_{pf} is equivalent to the sample mean, $\overline{X}$):

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$$S_{pf} = \frac{T_S}{F_n} \quad (3)$$

Where, T_S is the number of seeds collected from any outlet in a given time interval; F_n represents the number of boxes on the test rig for each outlet.

On the other hand, the coefficient of non-uniformity (NU_C), which is defined as 1-U_c, can be stated by Eq. 4:

$$NU_C = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{X_i - \overline{X}}{\overline{X}}\right| \quad (4)$$

Where, X_i is a random variable taking from n values and $\overline{X}$ is the mean. Equation 4 shows that the restrictions i.e. the normality and independence assumptions, are the same for using NU_C instead of *CV*.

Data Independence Evaluation

To use the *CV* in the evaluation of grain drill performance, the number of collected seeds from each outlet at varying time lags should be independent; otherwise, the data would be autocorrelated and the average and standard deviations would not be independent. Hence, they cannot be used for the calculation of *CV* (Maleki *et al.*, 2006). Autocorrelation plots are the commonly used method for checking randomness of a data set. The randomness is ascertained by computing autocorrelations for data values at varying time lags. If random, such autocorrelations should be near zero for any and all time-lag separations. If non-random, then, one or more of the autocorrelations will be significantly non-zero (Box and Jenkins, 1976). In this experiment, randomness or autocorrelation of the consecutive seed counts from each outlet at varying time lags was investigated. For each outlet, the *CV* and NU_C were computed for each of the12 consecutively collected data.

To assess the autocorrelation among the drill outputs, mean square successive difference test, a test that assumes normality in the data distribution, was used. The mean square successive difference test considers the one-tailed alternative hypothesis that measurements are serially correlated. The initial value computed in conducting the mean square successive difference test is the estimated population variance:

$$s_*^2 = \frac{\sum_{i=1}^{n-1}(X_{i+1} - X_i)^2}{2(n-1)} \quad (8)$$

Where, s_*^2 is the estimated population variance; n represents the number of values in the series; and X_i and X_{i+1} are the ith and $(i+1)^{th}$ values of the series, respectively. Then, the sample variance (s^2), which is an estimate of population variance (σ^2), is calculated as follows:

$$s^2 = \frac{\sum_{i=1}^{n}(X_i - \overline{X})}{n-1} \quad (9)$$

Where, s^2 represents the variance of the sample and $\overline{X}$ is the mean of values in the series.

Therefore, the ratio s_*^2 / s^2 should be equal to 1 when null hypothesis (H_0) is true. The test statistic is:

$$C = 1 - \frac{s_*^2}{s^2} \quad (10)$$

In order to reject the null hypothesis and conclude that the distribution is non-random, the absolute value of *C* must be equal to or greater than the tabled critical value of the $C_{a,n}$ statistic at the pre-specified level of significance. A large absolute *C* value indicates that there is a large discrepancy between the values s^2 and s_*^2 (Zar, 1999). These formulas and table of critical value were written in MatLab® software as two m-files. The validity of the mean square successive difference test results was verified by MatLab® randomness functions i.e. RUNSTEST, and by examining the autocorrelation plots as well. The periodogram of each outlet was also drawn to discover the frequencies of the hidden harmonic in the data. In addition, the cumulative periodogram was plotted to clarify random and autocorrelated data. The bands in

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the cumulative periodogram serve as a sort of test for white noise. When the cumulative periodogram is very close to the diagonal line and within the confidence bands, it means that the process is purely random and does not have any characteristics worthy of modelling with no striking periodicities. An m-file was written in MatLab® software to calculate the periodogram and the cumulative periodogram (Seier, 2003).

Experimental Design

The effect of seed meter drive shaft and test rig (ground) speeds on the seeding rate and the percentage of the damaged seeds were studied using a factorial experiment in a completely randomized design with three replications. Treatment effects were analysed using SAS software (SAS Institute, 1990). When the analysis of variance was significant (P<0.05), Duncan's multiple-range test was used for means comparison of the collected data.

RESULTS AND DISCUSSION

The effects of seed meter drive shaft speed, test rig speed, and the outlet position on the seeding rate were significant (P<0.01). For a constant test rig speed, the seeding rate changed proportional to the rotational speed of the seed meter drive shaft (Figure 2). For a constant seed meter drive shaft speed, the seeding rate decreased as the speed of the test rig increased (Figure 3). The seeding rates of the tested fluted rolls were not uniform.

In all tests, outlets 2 and 3 (central outlets) had the highest seeding rate and outlet 1 (the outlet beside the hopper wall) had the lowest. For outlets 4 and 5 (next to the closed outlets in the middle of the hopper), the seeding rates were significantly lower than those for the two central outlets (Figure 4). In this experiment, outlet 1 had greater inactive zones than outlets 2, 3, and 4. This was due to the fact that the first three preceding seed tubes were closed. The two seed tubes after outlet 5 were also closed. Rong *et al.* (1995) showed that the horizontal velocity of the particles flowing from a bin changes from zero to a maximum according to the distance from the hopper wall. Along the discharge orifice, the horizontal velocity of the particles is almost zero and, at a distance of one-third to the hopper wall, it reaches its maximum value. This velocity becomes zero again on the hopper wall. In the zone with a horizontal velocity of zero, there is no horizontal flow of substances and, consequently, these zones are inactive.

The effect of the seed meter drive shaft speed and the outlet position on the coefficient

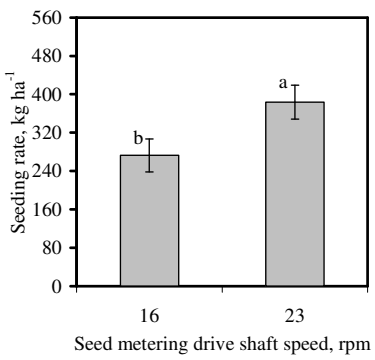

Figure 2. Effect of seed meter drive shaft speed on wheat seeding rate (the test rig speed was 3.6 km h^{-1}). Vertical bars indicate ± 1 standard deviation of the mean. Columns with different letters differ at P < 0.05 as tested by Duncan multiple range test.

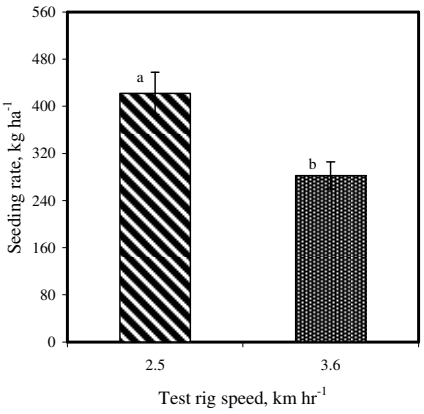

Figure 3. Effect of test rig speed on wheat seeding rate (the seed meter drive shaft speed was 16 rpm). Vertical bars indicate ± 1 standard deviation of the mean. Columns with different letters differ at P < 0.05 as tested by Duncan multiple range test.

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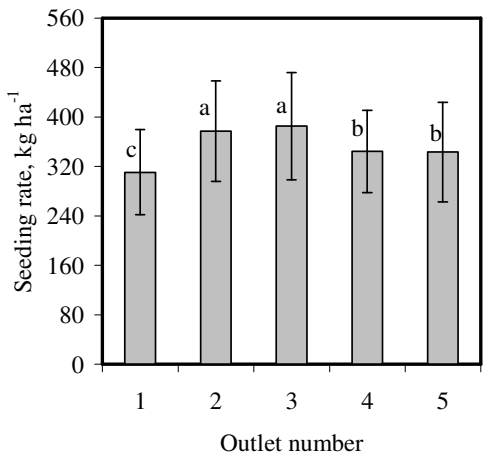
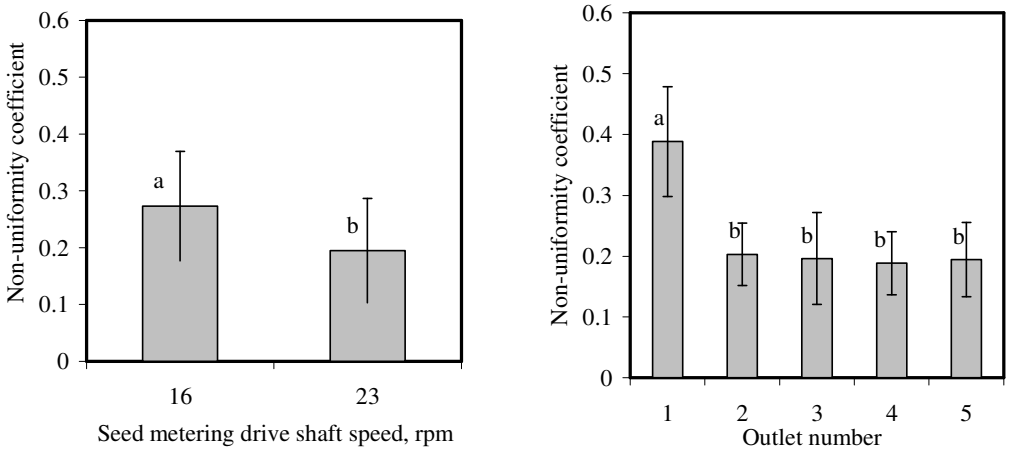


Figure 4. Effect of outlet position on wheat seeding rate (the seed meter drive shaft speed was 16 rpm). Vertical bars indicate ± 1 standard deviation of the mean. Columns with different letters differ at $P < 0.05$ as tested by Duncan multiple range test.

of non-uniformity (NU_C) was significant (P<0.01). As the seed meter drive shaft speed increased, the NU_C decreased (Figure 5a). The pulsation seed rate of the fluted rolls is reduced by increasing the seed meter drive shaft speed (RNAM, 1991). The maximum NU_C was observed for the first outlet near the side wall of the grain-drill hopper (Figure 5b). The effect of the test rig speed on the NU_C was not significant.

The results show that, in addition to row-to-row variations, seeding rate also exhibits within-row variability (Figure 6). Flow evenness of granular material such as seed is affected by physical properties such as size, specific weight, surface characteristics, and angle of repose. The flowability of a material depends upon the seed repose angle (Gaylord and Gaylord, 1984). Wheat is one of the highly flowable materials with a repose angle of around 29 degrees. Such materials usually form some weak bridges due to their internal friction (Gaylord and Gaylord, 1984). Thus, the within-row variability might be due to the sudden collapse of the bridges formed above the outlets and the shape of the fluted rolls used in the grain-drill. The sudden break down of the bridges could boost the filling of the flutes. This could, in turn, increase the filling coefficient of the flutes. The within-row variability (pulsation rate) could be reduced by using shallow flutes and helical-type fluted rolls. It may also be reduced by increasing seed meter drive shaft speed (RNAM, 1991).

The cumulative periodogram showed that data of outlet 1 was autocorrelated and its period was 12 (Figure 7a) whereas data of outlet 3 was random (Figure 7b). The mean square successive difference test showed that a



(a) (b)

Figure 5. Effect of a) seed meter drive shaft speed, and b) outlet position on non-uniformity coefficient of wheat (the test rig speed was 3.6 km h^{-1}). Vertical bars indicate ± 1 standard deviation of the mean. Columns with different letters differ at $P < 0.05$ as tested by Duncan multiple range test.

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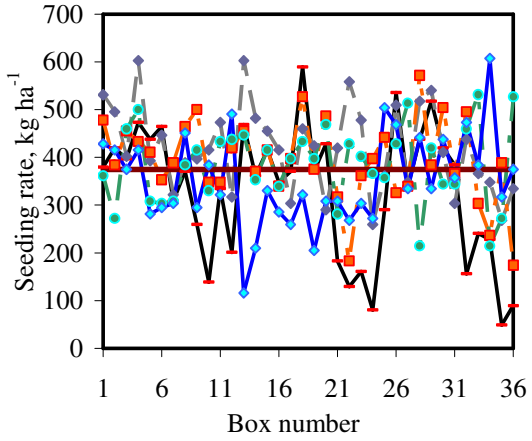

Figure 6. Within-row variability (36 consecutive data) and row-to-row seeding rate variation (5 outlets) for wheat (the seed meter drive shaft speed was 23 rpm; the test rig speed was 3.6 km h^{-1}). outlet 1; outlet 2; outlet 3; outlet 4; , outlet 5; average.

significant autocorrelation was present in the data of some of the outlets. The significant level of autocorrelation among the data using mean square successive difference test, MatLab® randomness functions, and autocorrelation plots were similar. For example, when the rotational speed of seed meter drive shaft was 16 rpm and the test rig speed was 3.6 km h^{-1}, the results indicated significant (P<0.05) autocorrelation for the outlet 2 when all 36 samples were used as the data points (Figure 8a). For 24 or 12 randomly selected samples, the autocorrelation was found to be significant (P<0.05) for outlet 4 (Figures 8b and 8c). Maleki *et al.* (2006) suggested using random samples from the autocorrelated data in order to eliminate autocorrelation among them; however, the results of this study showed that the random selection of the 12 or 24 seed samples out of the 36 consecutive samples was not essentially non-autocorrelated. During random sample selection of the data, some information is lost and, hence, full variability of the collected data will not be represented.

Comparison of the coefficient of variation (CV) and non-uniformity coefficient (NU_C) for different outlets at two seed meter drive shaft speeds is shown in Figure 9. In general, the CV was higher than the NU_C for each outlet. The trend in both coefficients was similar, so that the maximum and minimum coefficients occur at the same outlet. Therefore, either of these coefficients could be used as the repeatability index for grain drill evaluation. The results also showed that using NU_C as an index had no advantage in grain drills evaluation compared to CV. Figure 9 shows that the ratio of NU_C to CV for this grain drill is about 0.8; therefore, since the PAMI has accepted a CV of less than 15% for a grain drill, the acceptable NU_C should be less than 0.12

Effect of the seed meter drive shaft speed on the percentage of broken seeds was significant (P<0.05); but the outlet position had no significant effect on the seed breakage. By increasing the rotational speed, the percentage of broken seeds was increased (Figure 10). The effect of seed meter drive shaft speed on seed germination percentage was not significant.

CONCLUSIONS

The following conclusions can be drawn from the results of this study:

1. For constant test rig speed, the seeding rate changed proportional to the rotational speed of the seed meter drive shaft, whereas

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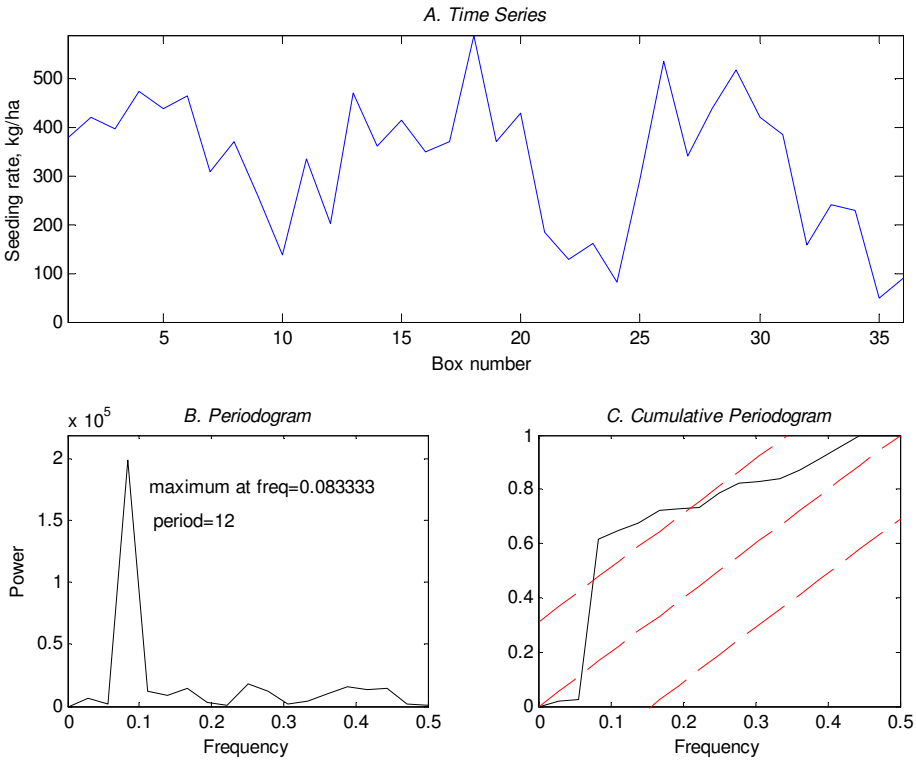
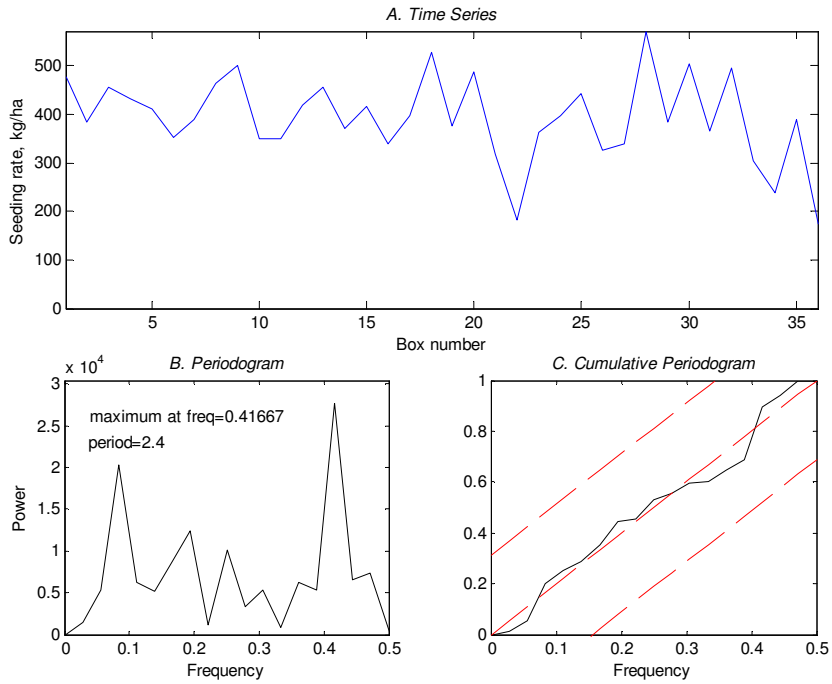


(a)



(b)

Figure 7. Periodogram and cumulative periodogram for two outlets of grain drills . a) outlet 1, and b) outlet 3 (the seed meter drive shaft speed was 23 rpm and the test rig speed was 3.6 km h^{-1}).

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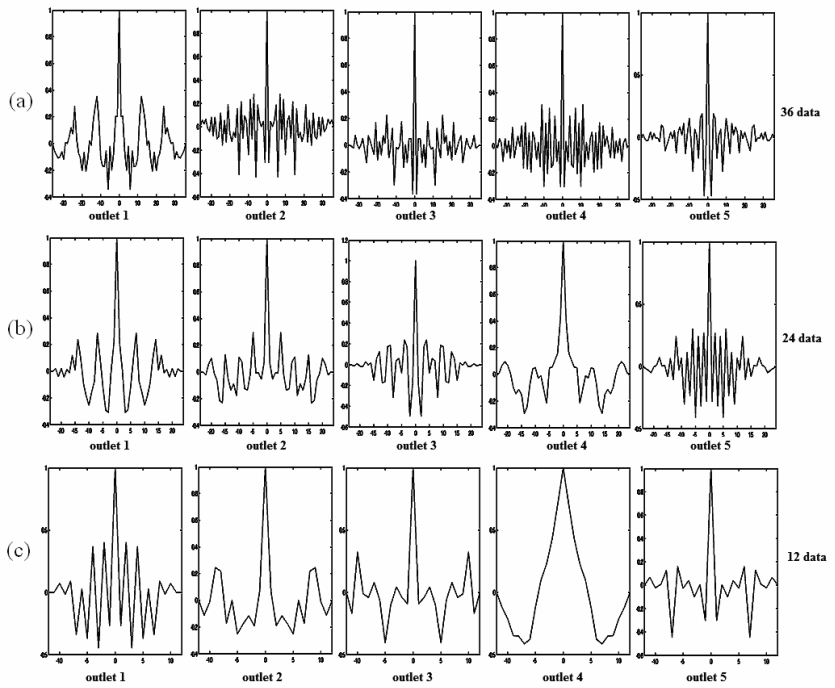

Figure 8. Diagram of autocorrelation between data for a) 36 consecutive data, b) 24 randomly selected data out of 36 consecutive data, and c) 12 randomly selected data out of 36 consecutive data for wheat (the seed meter drive shaft speed was 16 rpm and the test rig speed was 3.6 km h^{-1}).

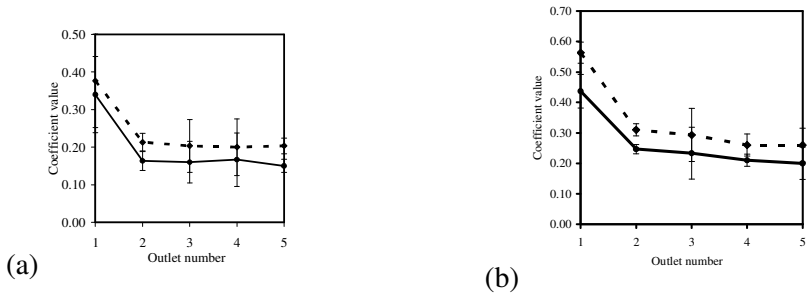

Figure 9. Comparison of coefficient of variation (*CV*;) and non-uniformity coefficient (1-*Uc*;) for the seed meter drive shaft speed of a) 23 rpm, and b) 16 rpm for wheat. (The test rig speed was 3.6 km h^{-1}). Vertical bars indicate ± 1 standard deviation of the mean.

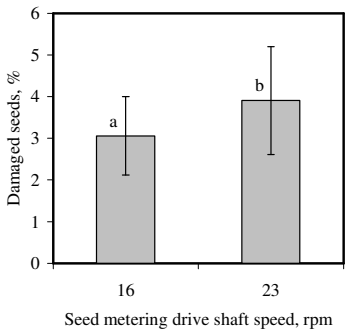

Figure 10. Effect of seed meter drive shaft speed on the number of broken wheat grains (the test rig speed was 3.6 km h^{-1}). Vertical bars indicate ± 1 standard deviation of the mean. Columns with different letters differ at $P < 0.05$ as tested by Duncan multiple range test.

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for constant seed meter drive shaft speed, the seeding rate decreased as the test rig speed increased.

2. The seeding rates of the tested fluted rolls were not uniform. The results showed that seeding rate was location-specific. The seeding rate of the outlets located in the middle of the tested outlets was significantly higher than that of the other ones. Thus, in addition to the within-row variability, crops planted with the grain drill would exhibit row-to-row plant stand variation.

3. The mean square successive difference test showed that a significant autocorrelation was present in the data of some outlets.

4. The number of broken seeds increased with an increase in the rotational speed of the metering mechanism.

5. As the rotational speed of the metering mechanism increased, the coefficient of non-uniformity (NU_C) decreased.

6. Similar trend was observed for the variation of both *CV* and NU_C for each outlet

7. In grain drill evaluation, either of *CV* and NU_C indices could be used alternatively.

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مقایسه ضریب تغییرات و ضریب نایکنواختی در ارزیابی خطی کارها

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چکیده

موزع استوانه ای شیاردار به طور معمول روی خطی کارها مورد استفاده قرار می‌گیرد. این موزع برخلاف دستگاه های کاشت دقیق، بذر را به صورت حجمی اندازه گیری می‌کند و بنابراین همواره دارای تغییرات ذاتی در وزن بذور خروجی می‌باشد. در این تحقیق یک خطی کار با موزع استوانه ای شیاردار بر روی تسمه نقاله متحرک جهت بررسی اثر سرعت دورانی محور موزع، سرعت حرکت تسمه نقاله و موقعیت خروجی ها روی نرخ بذرکاری گندم مورد ارزیابی قرار گرفت. تغییر در نرخ بذرکاری و یکنواختی جریان بذر از خروجی های مختلف در بازه های زمانی کوتاه با استفاده از ضریب تغییرات (CV)و ضریب نایکنواختی (NU_C) مطالعه شد. به ترتیب دو سرعت دورانی ۱۶ و ۲۳ دور در دقیقه و دو سرعت پیشروی ۲/۵ و ۳/۶ کیلومتر در ساعت برای حرکت محور دورانی موزع و تسمه نقاله انتخاب شد. نتایج نشان داد که در سرعت پیشروی ثابت ، نرخ بذرکاری متناسب با سرعت دورانی محور موزع تغییر می‌کند. همچنین در شرایطی که سرعت دورانی محور موزع ثابت باشد، نرخ بذرکاری با افزایش سرعت پیشروی کاهش می‌یابد. خروجی های خطی کار از نظر تحویل یکسانی حجم بذر با هم تفاوت داشتند. برخی خروجی‌های خطی کارها خود همبسته بودند. نتایج نشان داد در خروجی های خودهمبسته انتخاب ۲۴ یا ۱۲ داده تصادفی از ۳۶ داده متوالی، لزوما تصادفی نمی باشد. با افزایش سرعت دورانی محور موزع ضریب یکنواختی همه خروجی ها به طور معنی داری افزایش یافت. روند تغییرات ضریب نایکنواختی و ضریب تغییرات مشابه بود. در نتیجه می توان نتیجه گرفت که در ارزیابی خطی کارها هر دو ضریب تغییرات (CV)و ضریب نایکنواختی(NU_C) می‌توانند به عنوان شاخص ارزیابی نایکنواختی جریان بذراستفاده شوند.

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