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Determination of in-row seed distribution uniformity using image processing

Engin ÇAKIR[1,*], İkbal AYGÜN[1], Arzu YAZGI[1], Yiğit KARABULUT[2]

[1]Department of Agricultural Engineering and Technology, Faculty of Agriculture, Ege University, İzmir, Turkey

[2]Department of Electric and Electronic Engineering, Faculty of Engineering, Celal Bayar University, Manisa, Turkey

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Abstract: The objective of this study was to determine the seed distribution uniformity of seeding machines using a low sensitivity (maximum 300 frames per second (fps)) high-speed camera and image processing method for corn, cotton, and wheat seeds under laboratory conditions. For this purpose, a high-speed camera with 100, 200, and 300 fps was used to measure the seed drop from the seeding tube onto the sticky belt. Video images then were transferred to the image processing algorithm, from which seed distribution can be calculated. The calculated measurements were compared statistically with the measurements obtained from sticky belt tests. According to the results for determining corn and cotton seed spacing by high-speed camera, the camera was successful only for corn seeds. For cotton seeds, camera readings were significantly different from the readings from the sticky belt due to the fact that capturing the cotton seed trajectory was not sufficient compared to the corn seed trajectory. Measuring the wheat seed spacing by high-speed camera was impossible with lower speeds of the camera. Wheat kernels could not be captured successfully by the camera at speeds of 100 and 200 fps. Therefore, only 300 fps speed was used to measure the seed spacing of wheat.

Key words: Corn, cotton, high-speed camera, image processing, seeders, wheat

1. Introduction

Uniform seed distribution is considered an important criterion for the evaluation of the performance of a seeder. For this purpose, the seed distribution of seeding machines should be determined under laboratory conditions. Although the sticky belt method is the most common method used for the determination of in-row seeding distribution in the laboratory, it is a tedious and exhausting procedure to measure the seed spacing from the sticky belt.

To measure seed distribution uniformity in a fast and accurate way, electronic devices were started to be employed. Electronically measuring and determining the seed distribution uniformity of corn and cotton seeds by image processing does not cause any problems but it is not satisfactory for wheat and barley. High-speed cameras are used for measuring the seed distribution uniformity accurately for wheat and barley. Although it is costly to use electronic devices, it is worth doing research to develop such a system since high-speed cameras are the only sources so far to measure the seed distribution uniformity fast and accurately.

One of the first studies in Turkey on the subject of using image processing for measuring the seed uniformity of a seeder on a sticky belt was performed by Dursun and Dursun (2000). They successfully measured the in-row seed distribution uniformity of wheat, corn, carrot, and potatoes seeders, first by taking pictures of the seeds on the belt and then by evaluating the pictures with an image processing system.

Önal and Önal (2009) measured the in-row seed distribution uniformity of seeds on the sticky belt by using a laser pointer and mouse instead of a meter and ruler.

Lemans and Destain (2007) worked together on the subject of determining seeding at desired amount by seeders and they determined the performance of the seeder by using a camera. For this purpose, they used a high-speed camera and image processing system for measuring the seed uniformity of the seeder.

Karayel et al. (2006) determined the in-row seed distribution uniformity of wheat and soybean with 96% accuracy using a 750 frames per second (fps) speed camera compared to sticky belt measurements under laboratory conditions.

Cameras and image processing technologies, which have recently developed rapidly, are often used in agriculture, especially in spraying and fertilizing. The amount of spray and the distribution of fertilizer in the field are measured by cameras and evaluated by image processing. Many of the processes in agriculture such as

* Correspondence: engin.cakir@ege.edu.tr

determining the amount of spraying in viticulture and counting the heads of wheat in the field are done well by image processing (Hijazi et al., 2012).

In agriculture, some applications such as determination of the fertilizer distribution uniformity of fertilizer spreaders and spraying with the exact desired amount to get the pesticide to the target and to prevent excessive pesticide use are made faster and easier by using digital cameras and image processing systems (Cointault and Vangeyte, 2005; Villette et al., 2007; Hijazi et al., 2012).

Generally, a high-speed camera with sensitivity of 750 frames per second (fps) and over was used to determine the seed distribution uniformity of seeding machines successfully under laboratory conditions. This required an expensive and very sensitive high-speed camera.

The objective of the present study was to determine the seed spacing of seeding machines by using a less sensitive (the maximum 300 fps) high-speed camera and image processing for corn, cotton, and wheat seeds under laboratory conditions. For this purpose, a high-speed camera with 100, 200 and 300 fps was used to measure the seed drop from the seeding tube to the sticky belt. Video images then were transferred to the image processing algorithm, from which seed distribution can be calculated. The calculated measurements were compared statistically with the measurements obtained from sticky belt tests.

2. Materials and methods

The research was conducted at the research laboratory of the Department of Agricultural Engineering and Technology, Faculty of Agriculture, Ege University, in 2013 and 2014. A sticky belt was used to compare the measurements made by high-speed camera for determining in-row seed spacing of corn, cotton, and wheat seeds. The sticky belt was powered by an electric motor and its speed was adjusted by a speed reducer. The physico-mechanical properties of the seeds used in the experiments are given in Table 1.

For determining the in-row seed spacing of corn and cotton, a vacuum-type precision seeder equipped with a new flush-face seed tube was used. The seeder was hitched to a New Holland TM-175 for powering the seeding fan by PTO. Vacuum pressure was adjusted at 32.4 mbar (13 inches of water) with 540 rev/min of tractor PTO. A domestic-type seed drill that provides random seeding was used for seeding wheat. The technical specifications of the seeding machines are given in Table 2.

During seeding, a high-speed camera with 300 fps capacity was used to observe the kernels falling from the seeding disk onto the sticky belt (Figure 1). The technical parameters of the high-speed camera are given in Table 3.

The high-speed camera was positioned on a platform located close to the seeding tube over the sticky belt to observe the kernels falling from the seeding disk onto the sticky belt (Figure 2). To get the best picture, the location from which the camera took pictures was lightened.

Table 1. Physico-mechanical properties of the seeds (average of four measurements of 100 kernels).

Seed	Length (mm)	Width (mm)	Thickness (mm)	Sphericity (%)	Thousand seed weight (g/1000 kernel)
Corn	10.20	6.60	4.20	64.52	237.30
Cotton	8.30	4.22	3.85	61.75	89.10
Wheat	6.15	3.08	2.79	60.95	39.80

Table 2. Technical specifications of seeding machines.

Machine type	Firm	Number of rows	Working width (m)
Vacuum-type precision seeder	John Deere MaxEmerge 1030 series	6	4.2
Seed drill	Altınöz	17	3.4

Figure 1. High speed camera.

Table 3. Technical parameters of the high-speed camera.

High speed camera	Technical parameters
TELEDYNE Dalsa Genie HM640	--- 640 × 480 resolution --- 300 fps max --- Monochrome sensor --- 7.4 µm, pixel size --- 8-bits pixel depth --- GigE vision output format --- Hirose power cable --- Fujinon Megapixel series lens

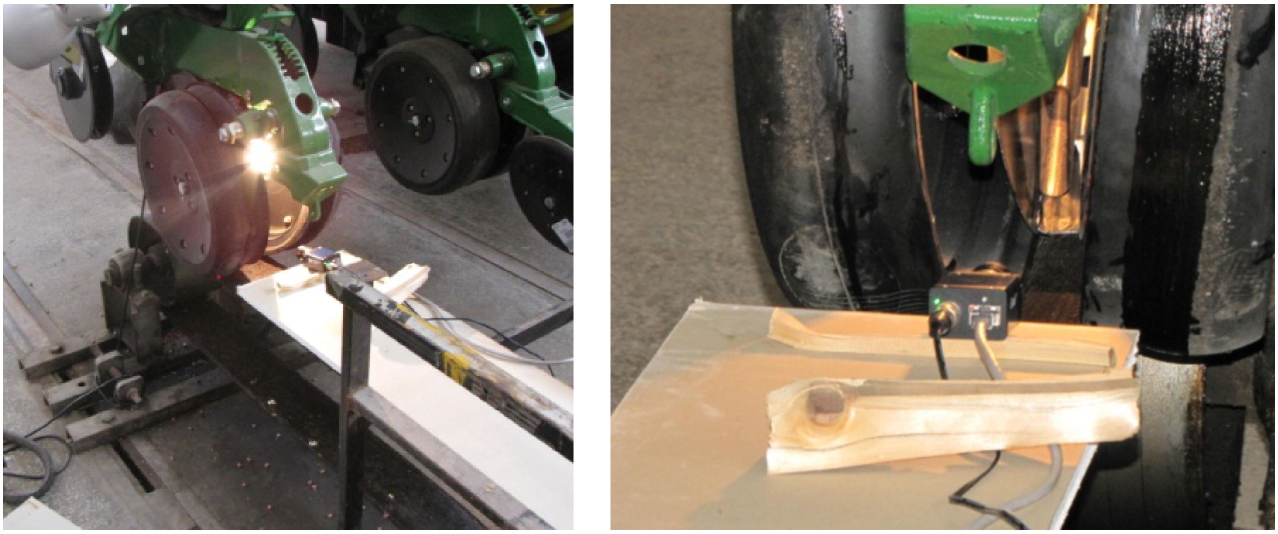

Figure 2. The positioning of the high-speed camera over the sticky belt.

The recordings from the high-speed camera were first stored as AVI files and then moved from the camera to the computer over the internet cable for later analysis.

Each test was run with the high-speed camera and belt measurements were taken at the same time to determine the performance of the camera for measuring the seeding directly from the seeders and to compare the measurements with the measurements made from the sticky belt (Figure 3).

Measurements were taken at 100, 200, and 300 fps camera speeds for testing the effect of speed on the quality of measuring the seeding by camera. All measurements were made at 1 m s^{-1} belt speed to simulate the forward speed of the seeders in the field. The seeder was adjusted so that seed spacing was 5, 10, 15, 20, and 25 cm for corn and 5, 10, and 15 cm for cotton. For seeding wheat kernels, the seeder was adjusted to seed at 150, 200, and 250 kg ha^{-1} seeding rates.

The images taken from the high-speed camera were analyzed by a program written in C++ computer language. With the help of the program, the number of kernels dropping from the seeding tube and their speeds were measured.

The seed spacing of cotton and corn seeds from the sticky belt was compared with the calculated data from the algorithm program by using the Excel statistical package. The seed spacing readings from the sticky belt were compared with the readings from the high-speed camera by t-test, paired comparison design (Montgomery, 1991).

Wheat seed spacing was evaluated based on the goodness criteria (λ), which represent the percentage of bands with 1, 2, and 3 seeds. The average seed number for this evaluation is chosen as μ ≈ 2. The length of the band is calculated according to the equation given below. In the present study the length of the band was chosen as 3 cm and seeds were counted in each 3-cm band (Önal, 2011).

$$a = \frac{10 \cdot \quad \cdot}{b \cdot N}$$

Figure 3. Sticky belt measurements.

The measured number of wheat kernels from the sticky belt was compared with the calculated data from the algorithm program using SPSS. The measurements made by the sticky belt and the high-speed camera were analyzed with Wilcoxon's signed-rank test since it is a nonparametric statistical hypothesis test used when comparing two related samples' measurements on a single sample to assess whether their population mean ranks differ (Montgomery, 1991). For evaluation of the statistical data for all seeds, statistical significance is attained when a P-value is less than the significance level, $\alpha = 0.05$.

2.1. Image processing algorithm for corn and cotton kernels

First, the region of interest (ROI) on which the image processing algorithm would be performed was selected over the 8-bit monochrome images from the high-speed camera. This selection was made manually by entering the coordinates in the system. For the image processing area, the region between the starting point of the seed tube and the place where the corn or cotton kernels meet the sticky belt was selected (Figure 4).

After selection of the ROI, the static background should be taken out. The Gaussian Mixture-based Background/Foreground Segmentation algorithm, which is used often for background segmentation, was selected (Zivkovic, 2004) (Figure 5). The background, which is taken from each 30 pictures, is renewed itself by using the Gaussian Mixture probability density method.

A connected component algorithm was used to select the selected corn or cotton kernels in the background image. The region belonging to the kernel is taken out by merging pixels neighboring with each other. From this,

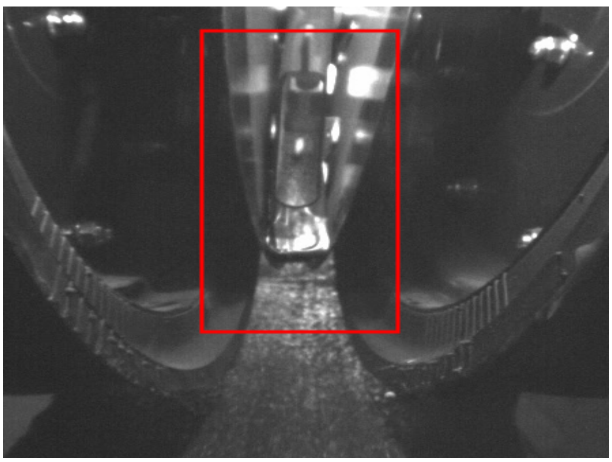

Figure 4. Selection of ROI in the image processing algorithm.

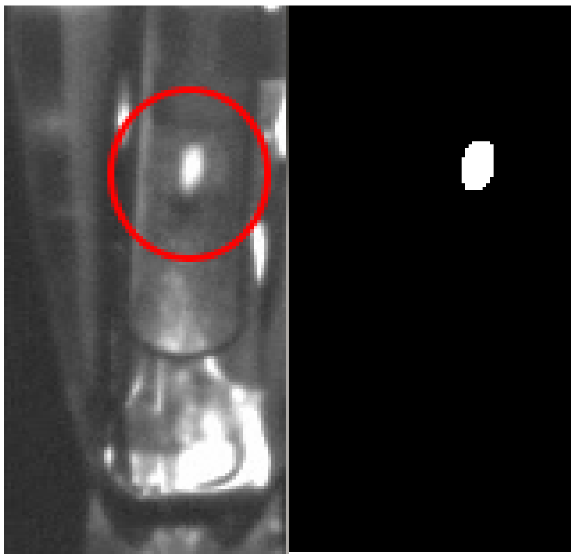

Figure 5. Application of background segmentation.

the information about the region and first and second moments of kernels can be gathered (Gonzales et al., 2008) (Formulae 1 and 2). The coordinates of the center of mass of pixels can be found by dividing the moments by area (Formula 3).

Spatial Moment (Formula 1)

$$mu_{ji} = \sum_{x,y} \left(array(x,y) \cdot (x-\bar{x})^j \cdot (y-\bar{y})^i\right)$$

Central Moments (Formula 2)

$$m_{ji} = \sum_{x,y} \left(array(x,y) \cdot x^j \cdot y^i\right)$$

Center of mass (Formula 3)

$$\bar{x} = \frac{m_{10}}{m_{00}}, \; \bar{y} = \frac{m_{01}}{m_{00}}$$

Selected kernels should be followed to determine their velocities and exit region. The velocities on the x and y axes of the selected kernels are determined by following up the kernels. The coordinates about the next place of kernels can be easily determined using the velocities. The determined point and the kernel at that point are matched for accuracy. This process is continued until the kernel is out of the picture and at which picture the kernel falls onto the belt is determined and saved (Figure 6).

The durations between the kernels are calculated by the number of frames in which kernels are located and the velocity of the camera. The duration and speed of the belt are multiplied to get the distance between the kernels, which is the belt on the sticky belt.

2.2. Image processing algorithm for wheat kernels

The Opencv image processing program was used to analyze the images of wheat kernels (Bardski and Kaebler, 2008). Since most of the time wheat kernels are adherent to each other, a specially written algorithm was used in order to separate the kernels from each other (Qufa et al., 2009) (Figure 7).

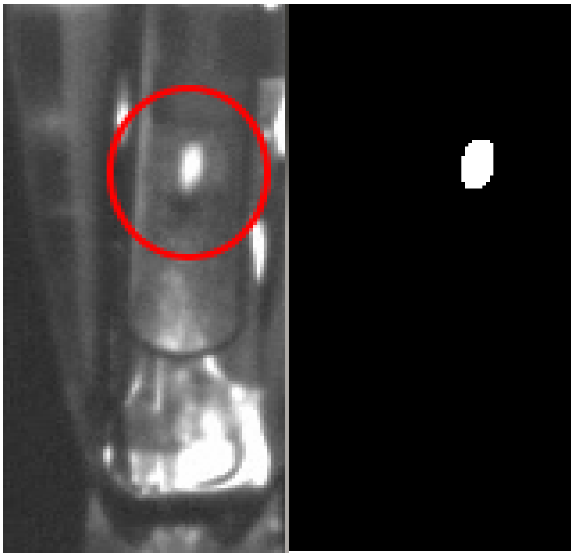

Figure 6. Determining the velocities of corn or cotton kernels.

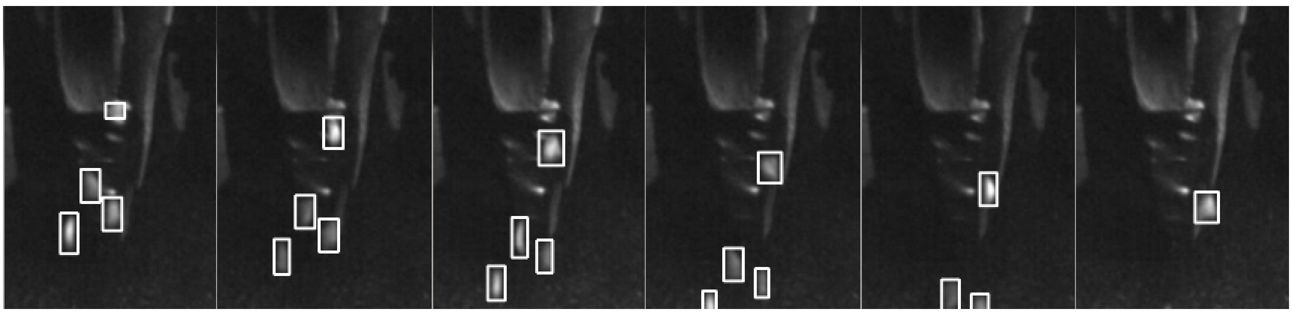

Figure 7. Capturing the wheat kernels by written algorithm.

3. Results

3.1. Seed spacing measurement of corn and cotton

The statistical test results of corn and cotton seed spacing measured by camera and sticky belt are given in Tables 4 and 5. According to the statistical results, the camera readings were much closer for corn seeds but not for cotton seeds at α level of 0.05. Camera speed was also not significant, which proves that a camera with speed of 100 fps even can measure the seed spacing of corn and cotton successfully.

However, there was no clear evidence to interpret the statistical results. For corn seeds, camera readings were similar to those of the sticky belt for each camera speed and seed spacing, whereas for cotton this was not the case. For cotton seed spacing of 5 cm and 300 fps resolution was found successful but not for other seed spacing. For other seed spacing of cotton, 300 fps was not good enough to match the sticky belt readings. On the other hand, 100 and 200 fps speeds were good enough to match the sticky belt's readings for seed spacing of 15 cm. However, again this did not make sense since the expectation of higher speed makes better readings, which this was not the case for cotton seeds.

The graphics for seed spacing measurements made from the sticky belt and by the high-speed camera for corn and cotton are given in Figures 8 and 9. According to the figures, it seems almost all measurements made from the sticky belt and high-speed camera are identical. However, according to the statistical results, there was a difference between the camera and sticky belt especially for cotton seeds.

Table 4. P(T<=t) Two-tail test results for corn seeds.

Corn	Camera speed (fps)		
Seed spacing (cm)	100	200	300
5	0.143	0.972	0.003*
10	0.480	0.392	0.097
15	0.989	0.863	0.728
20	0.815	0.055	0.001*
25	0.004*	0.006*	0.064

*The statistical significance is attained if P-value is less than the significance level α = 0.05.

Table 5. P(T<=t) Two-tail test results for cotton seeds.

Cotton	Camera speed (fps)		
Seed spacing (cm)	100	200	300
5	0.001*	0.023*	0.206
10	0.028*	0.048*	0.002*
15	0.144	0.054	0.026*

*The statistical significance is attained if P-value is less than the significance level α = 0.05.

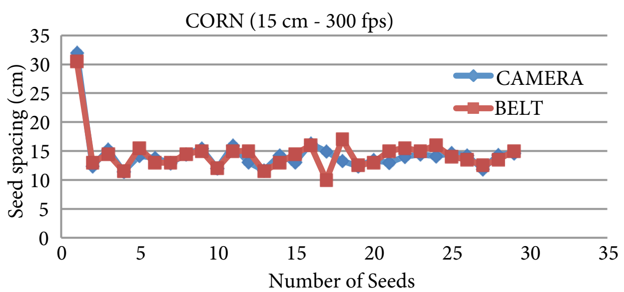

Figure 8. Seed spacing measurements made from sticky belt and by high-speed camera for corn.

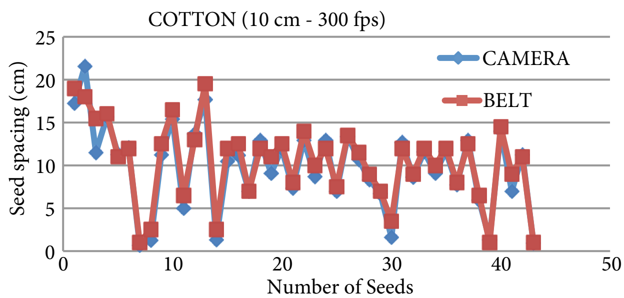

Figure 9. Seed spacing measurements made from sticky belt and by high speed camera for cotton.

For corn seeds, the readings from the camera and the sticky belt were almost identical, whereas there was a significant difference for the measurement of cotton seeds. This tells us the algorithm program is not satisfactory for cotton seeds. This could be the reason why capturing of the trajectory of cotton seeds by the camera was not satisfactory. Since the speed of fall is calculated according to the seed trajectory captured by the camera and the seed trajectory captured is two dimensional real seed trajectory sometimes differs from the measurements, especially for cotton seeds, causing differences between the calculated and the real place of fall of the seed onto the sticky belt. To eliminate this problem, Koller et al. (2014) used a special system to capture seeds in two views. A high-speed camera positioned perpendicular to one of the screens recorded the motion of the seed. A mirror perpendicular to the ground plane and angled at 45° with respect to the second projection screen provided a side view of the seed in the same camera frame.

3.2. Seed spacing measurement of wheat

The test results of measurements of seed spacing of wheat are given in Table 6. In contrast with the measurements made by the camera for corn and cotton seeds, seed spacing of wheat could not be captured by the camera with 100 and 200 fps. Therefore, only 300 fps speed was used to measure the seed spacing of wheat. However, with speed of 300 fps for all seeding rates, Wilcoxon test results were not significant at α level of 0.05 according to the measurements taken from approximately 90 wheat kernels.

Karayel et al. (2006) measured the seed spacing of wheat successfully with a 750 fps high-speed camera. In this study, it was shown that a 300 fps high-speed camera also could be used for measuring the seed spacing of wheat kernels.

The frequency distribution of seed number for each 3 cm calculated from the sticky belt and by high-speed camera for wheat is given in Figure 10. When the number of seeds for each 3 cm increased from 4 then the success of measurements by camera decreased as it is seen from Figure 10. The success of the capability of the camera for capturing the seeds decreases when the seed number exceeds 4.

The numbers of seeds at 3 cm length measured from the sticky belt and the camera are given together in Figure 11. As seen from Figure 11, numbers were similar both from the sticky belt and the camera until the number of seeds 4 and over. The numbers do not overlap after the seed number 4 due to the fact that wheat kernels drop suddenly from the seeding tube as a group of 5 and 6, making it difficult for the algorithm program to capture them.

Table 6. P(T<=t) Wilcoxon signed ranks (two-tail) test results for wheat seeds.

Seeding rate (kg/ha)	300 fps of camera speed
150	0.791
200	0.822
250	0.545

The statistical significance is attained if P-value is less than the significance level α = 0.05.

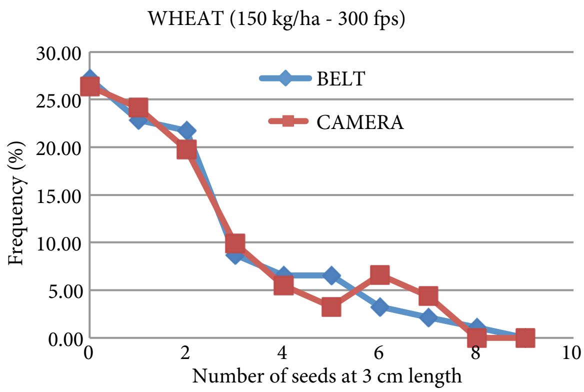

Figure 10. Frequency distribution of seed number for each 3 cm calculated from sticky belt and by high-speed camera for wheat.

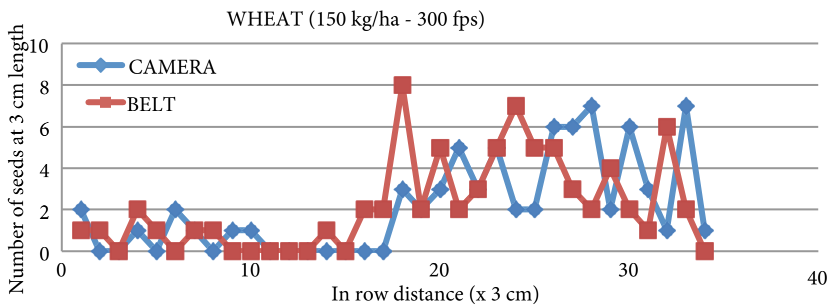

Figure 11. Number of seeds for each 3 cm for wheat.

4. Discussion

According to the results for determining corn and cotton seed spacing by high-speed camera, the camera was successful for only corn seeds. For cotton seeds, camera readings were significantly different from the readings from the sticky belt due to the fact that capturing the cotton seed trajectory was not sufficient compared to the corn seed trajectory.

Measuring the wheat seed spacing by high-speed camera was impossible with lower speeds of the camera. Wheat kernels could not be captured successfully by the camera with speeds of 100 and 200 fps. Therefore, only 300 fps speed was used to measure the seed spacing of wheat.

For determining wheat seed spacing using a high-speed camera, the results were not satisfactory due to the fact that wheat kernels drop suddenly from the seeding tube as a group of 5 and 6, making it difficult for the algorithm program to capture them.

More research needs to be done for both capturing the cotton seeds and wheat kernels at the time of seeding and writing a better algorithm program to be able to capture the seeds before they fall onto the sticky belt.

Overall, we can say that a high-speed camera with 300 fps and appropriate image processing algorithm can be used successfully for measuring in-row seed spacing of a precision seeder for corn and a seed drill for wheat under laboratory conditions. For cotton seeds, a new way of capturing the seed trajectory must be accompanied with a better algorithm program.

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