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INFORMATION PROCESSING IN AGRICULTURE 2 (2015) 169–176

journal homepage: www.elsevier.com/locate/inpa

Information Processing in Agriculture

Design, development and field assessment of a controlled seed metering unit to be used in grain drills for direct seeding of wheat

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A R T I C L E I N F O

Article history:
Received 19 May 2015
Received in revised form
8 July 2015
Accepted 3 August 2015
Available online 21 August 2015

Keywords:
Control box
Seed metering mechanism
Forward speed
Seed drilling
Field operation

A B S T R A C T

A new controlled seed metering unit was designed and mounted on a common grain drill for direct seeding of wheat (DSW). It comprised the following main parts: (a) a variable-rate controlled direct current motor (DCM) as seed metering shaft driver, (b) two digital encoders for sensing the rotational speed of supplemental ground wheel (SGW) and seed metering shaft and (c) a control box to handle and process the data of the unit. According to the considered closed-loop control system, the designed control box regularly checked the revolution per minute (RPM) of seed metering shaft, as operation feedback, using its digital encoder output. The seeding rate was determined based on the calculated error signal and output signal of the digital encoder of the SGW. A field with four different levels of wheat stubble coverage (10%, 30%, 40% and 50%) was selected for evaluation of the fabricated seed metering unit (FSMU). The dynamic tests were conducted to compare the performance of installed FSMU on the grain drill and equipped grain drill with common seed metering unit (CSMU) at three forward speeds of 4, 6 and 8 (Km/h) for DSW. Results of the FSMU assessment demonstrated that an increase in forward speed of grain drill (FSGD) and stubble coverage did not significantly affect the seeding rate in the grain drill for DSW. Using the FSMU reduced the coefficient of variation (CV) by approximately 50%. Consequently, applying the FSMU on the common grain drill led to a desirable seeding rate at different forward speeds of the grain drill and stubble existence.

1. Introduction

The main goal of precision agriculture is to control agricultural inputs such as seeds, fertilizers and herbicides to match the necessities of specific soil fertility levels. Moisture content and fertility are the most important soil variables influencing optimum seeding rate in the field. The optimal seeding rate varies depending on variable parameters, soil moisture and fertility. Maximum yield in farmlands notably occurs in the optimum seeding rates [1].

In many farms, direct seeding is carried out through the conservation tillage and maximal stubble on the land.

Abbreviations: ANOVA, analysis of variance; CSMU, common seed metering unit; CV, coefficient of variation; DCM, direct current motor; DMRT, Duncan multiple range test; DSW, direct seeding of wheat; FSGD, forward speed of grain drill; FSMU, fabricated seed metering unit; GDDW, grain drill drive wheel; GPS, global positioning system; LCD, liquid crystal display; PATA, parallel advanced technology attachment; PID, proportional-integral-derivative; RPM, revolution per minute; SGW, supplemental ground wheel.

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Peer review under the responsibility of China Agricultural University.
http://dx.doi.org/10.1016/j.inpa.2015.08.001

Researchers announced that the planting machines reduced their efficiency on the farm with stubble and the accuracy of their planting decreased severely [2–5]. It occurs due to the lack of suitable traction between the GDDW and soil which leads to decreased seed planting uniformity. Previous studies have shown that the yield will be decreased, when the seed planting is non-uniform [6–8].

In the recent years, main changes have arisen in the seed metering mechanism of grain drills in specific situation. The general and ordinary forms of the seed metering mechanism of the grain drills have been replaced with the pneumatic metering devices [9–15]. However, the GDDWs have been used as a planting mechanism, being a very traditional form of operating the seed metering device. It worked through the GDDW and its transmission was powered by the GDDW and chain, the GDDW and belt or the gearwheel.

One advantage of application of electronic measurements and control systems in the planters is the elimination of the mechanical friction which occurs within mechanical transmission systems. Several studies have aimed at upgrading the mechanical seed metering device to the electrical [16,17].

White et al. [18] designed and built a grain drill which was able to plant different types of cereals in single or multiple furrows. Switching between type of seeds was controlled by a computer which used GPS as a locator. Their results showed that the average accuracy of 5.5 (m) for switching at the forward speed of 7.2 (Km/h) was obtained for the variation of types.

Jafari et al. [19] statically calculated the time of the response to the applied changes for different seeding rates through installing a DCM on the metering device shaft of grain drill and using GPS. Results of their performance trials indicated that the response time of low-to-high and high-to-low transition seed rates were 7.4 and 5.2 (s), respectively.

Kamgar et al. [20] designed and prepared a mechatronic system to improve the performance of row-planter machines. The system used a main processor, an electromotor and an electronic circuit in order to activate the operation of seed metering unit. According to their findings, the mechatronic system had fewer seeding space errors than the mechanical system.

Jianbo et al. [21] built a control system which used a Hall sensor to measure the working speed of planter and employed a single-chip microcomputer system to calculate the rotational speed of seed metering unit. The system effectively reduced the influence of inhomogeneous sowing caused by the GDDW slip.

According to the practical observations for DSW, the main source of error in precise seeding rate and non-uniformly spacing in the use of grain drills was GDDW skidding. GDDW skidding is the result of lack of required traction between GDDW and soil, land topography and high resistant torque on the GDDW axis. In addition, the stepwise output of seed metering unit transmission of conventional grain drills leads to poor seeding rate control.

To beat this conflict, the planter must be modified in order to overcome the GDDW skidding on the stubble. It can be achieved by increasing the synchronization condition between the wheel rotation and the seed metering rotation in the common grain drills for DSW. This crucial problem may occur due to lack of necessary rotation transfer from the GDDW to seed metering device by mechanical joint.

As it can be found from literature review, there is no attempt to optimize the performance of seed metering unit for direct seeding. Thus, the objectives of the present study were design, fabrication and field performance evaluation of a new controlled seed metering unit useable in grain drills to improve the uniformity of seeding space for DSW.

2. Materials and methods

2.1. *Design and fabrication of seed metering unit*

Fig. 1 shows the block diagram of CSMU. The rotational speed of GDDW was transferred to gear box of seed metering unit via sprockets and chain. The gear box changed the rotational speed and delivered it to seed metering device via sprockets and chain based on the gears setting of gear box.

The ordinary mechanical transmission system was eliminated from the grain drill and it was replaced with an electronic system and the SGW. The system worked in a way that the RPM of the SGW was measured with an electrical sensor. After processing and applying some sorts of indices on the measured RPM, it was then sent as a voltage to the variable-rate DCM to rotate seed metering shaft of the grain drill. In present study, the steps of changes in the mechanical seed metering unit were performed as follows:

1. Mounting a SGW on the grain drill. The SGW rotated without skidding. There was no mechanical joint between the SGW and seed metering unit of grain drill.
2. Use of the digital shaft encoder as a sensor on the SGW, in order to sense on-the-go rotational speed of the SGW of grain drill.
3. Installing the variable-rate DCM on the seed metering shaft of the grain drill as the drive force supplier.
4. Applying the digital shaft encoder as a sensor on the seed metering shaft, to sense on-the-go rotational speed of the seed metering device.
5. Fabricating the electronic control system to receive rotational speed data from SGW, commanding the variable-rate DCM of the seed metering device and recording some information such as the FSGD and rotational speed of the seed metering shaft.

Fig. 2 presents the block diagram of the designed seed metering unit. Rotational speed changes of the SGW affected the rotational speed of seed metering device directly. Although the rotational speed of seed metering shaft was precisely determined by the variable-rate DCM, the frictional forces among mechanical joints did not allow the seed metering device to rotate expectedly. Therefore, the mounted digital encoder on the seed metering shaft measured the actual rotational speed of seed metering device. It was sent to control box as the error signal. The control box determined the

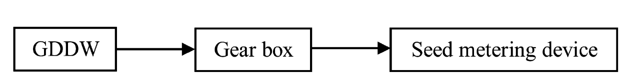

Fig. 1 – Block diagram of CSMU.

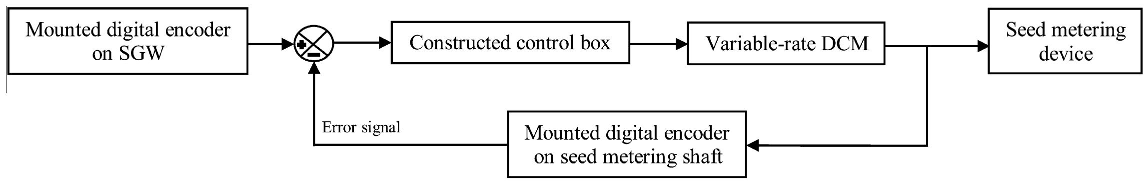

Fig. 2 – Block diagram of designed seed metering unit.

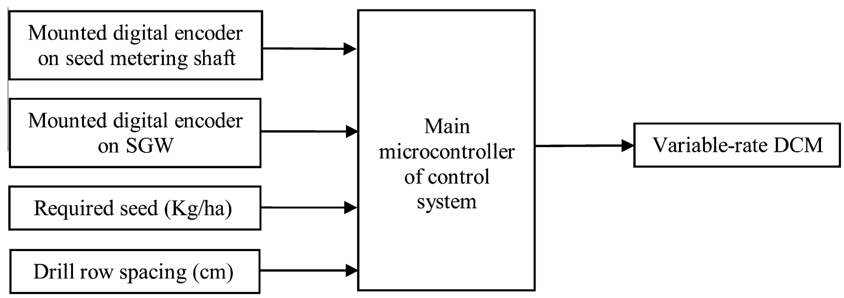

Fig. 3 – Main structure of control system.

desired rotational speed of variable-rate DCM so as to reduce the error signal. The best condition happened when the error signal value tended to zero. The following subsets describe the main component of FSMU.

2.1.1. *Digital encoders*

A device, known as encoder, was employed to measure the RPM of the SGW and seed metering device shaft. One digital encoder was mounted on the SGW and another one for the seed metering shaft. The signal received from the digital encoder of the SGW was used to calculate the actual rotational speed for the SGW of grain drill. Likewise, the output signal of the digital encoder of the seed metering shaft was used as actual rotational speed for the seed metering device. The digital encoder model used in this study was 'Autonics E50S8-1000' (made in South Korea). The digital encoder supported 1000 pulses per revolution of SGW or seed metering shaft. Thus, based on the device diameter, the encoder sensitivity was calculated about 10 (pulse/cm) and 40 (pulse/cm) for the digital encoder of the SGW and seed metering device, respectively.

2.1.2. *Variable-rate DCM*

To convert the controlled electrical power into the mechanical power, a variable-rate DCM (model: D12-8001-45W, made by Kia electromotor company, Iran) was applied. Due to the necessary angular changes in the seed metering shaft and mounted variable-rate DCM on the grain drill, the special mechanical equipment was employed. A gearbox with a reduction ratio of 1:3 was also provided to transfer the mechanical power from variable-rate DCM to seed metering shaft. The rotational speed of variable-rate DCM was determined by the control box of the unit according to the rotational speed of the SGW and some factors which were defined by the operator using 4×4 matrix keyboard device.

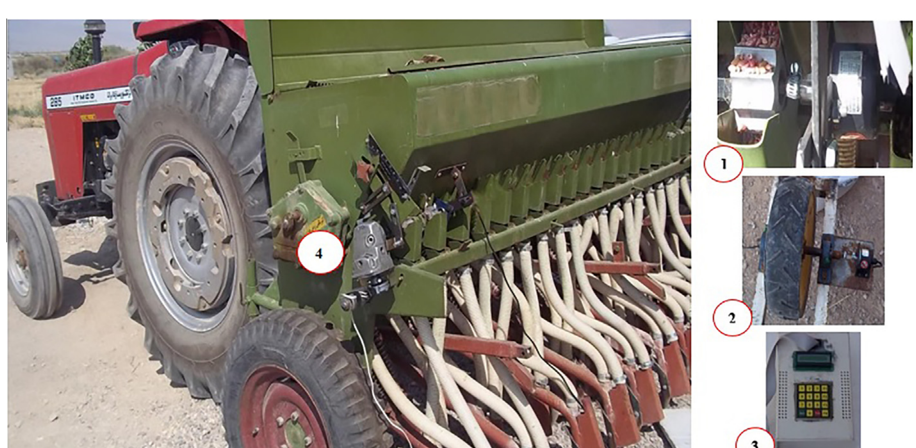

Fig. 4 – Equipped grain drill with new FSMU (1-digital encoder of seed metering shaft, 2-digital encoder of SGW, 3-control box via LCD and keyboard and 4-variable-rate DCM).

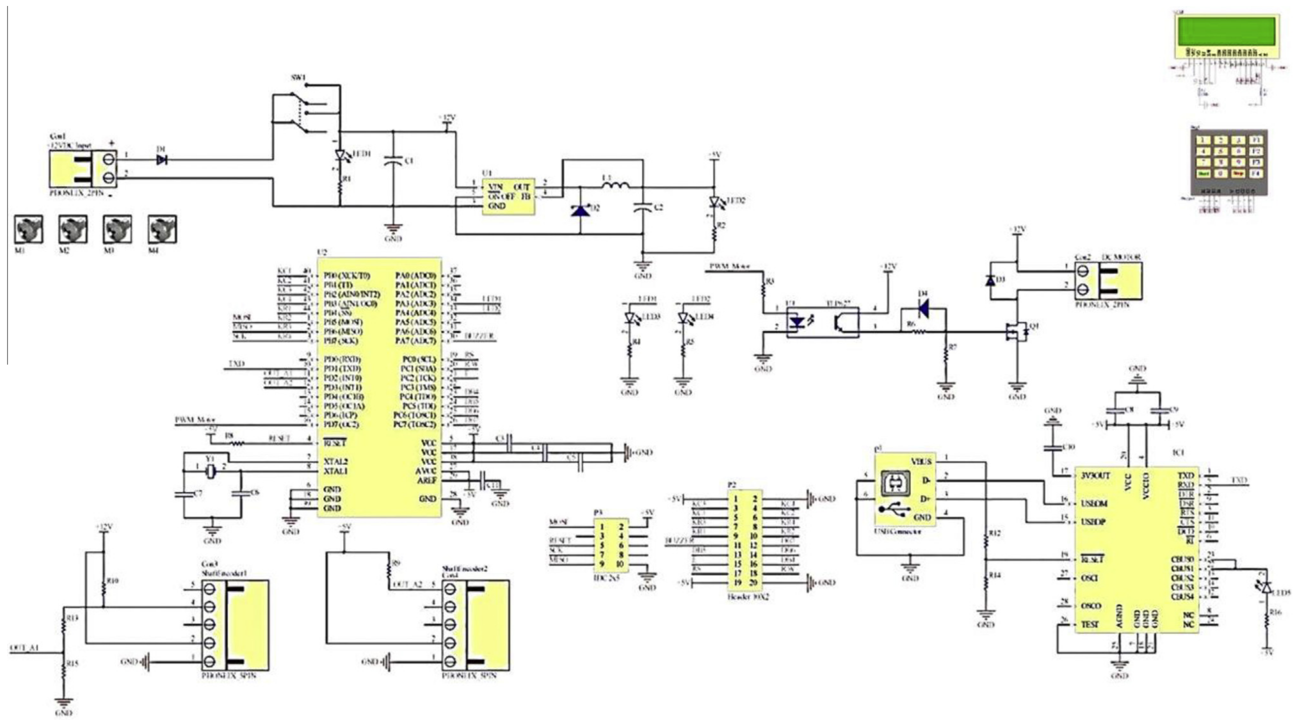

Fig. 5 – Simulated assessment of the designed control system.

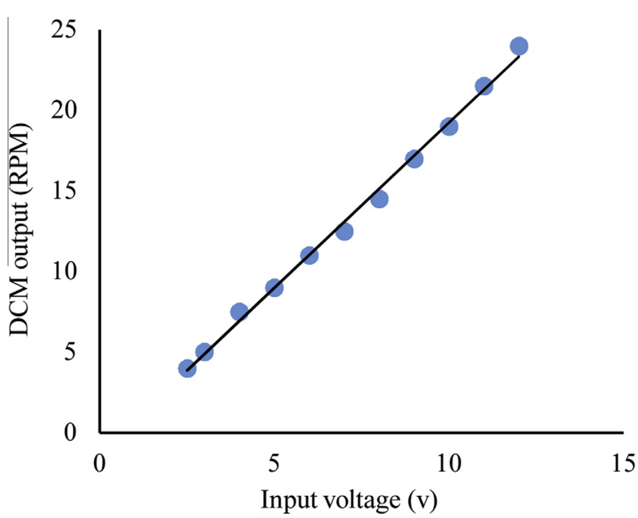

Fig. 6 – Comparison between output and input values of the variable-rate DCM in simulated windows.

2.1.3. Control system

Fig. 3 shows the main structure of the control system. The system used Atmega16 microcontroller made by ATMEL Corporation as its core. The control system could detect the rotational speed of the SGW by the mounted digital encoder on its shaft. The rotational speed data were compared with the reference required seed data (Kg/ha) and drill row spacing (cm). These data were already stored in the microcontroller memory supplied by the grain drill operator using the 4×4 matrix keyboard device of the unit. The input values were displayed on the 16×2 LCD. From these, the appropriate rotational speed of the seed metering shaft was determined. Immediate rotational speed of the seed metering shaft was compared with the desired value to send an appropriate instruction to the variable-rate DCM control circuit via a PATA cable. The PATA cable transferred data in parallel form without time delay and disturbance. The PID controller in control circuit was used to control the variable-rate DCM behavior. The control circuit sent the voltage to variable-rate DCM regarding the proper calculated rotational speed of seed metering shaft. The relationship between the sent voltage and rotational speed of seed metering shaft was obtained and calibrated using laboratory tests for the control system.

2.1.4. Power supply

A direct current voltage transducer was hired to provide the power of control box, 16×2 LCD, variable-rate DCM, digital encoders and 4×4 matrix keyboard. The device obtained the direct current voltage from tractor battery and converted it to the suitable voltage.

2.2. Evaluation of developed seed metering unit

2.2.1. Simulated trails

Initial evaluation was carried out in the simulation windows of Proteus V7 software in order to validate the accuracy of the designed system. The main purpose of the simulation was to check the accuracy of the followings:

1. The output of all two digital encoders in terms of RPM.
2. Proportion of input voltage values of the variable-rate DCM to required rotational speed of seed metering shaft.

Table 1 – The values of CV (%) for experimental trails (1-CSMU, 2-FSMU).

Level of wheat stubble coverage (%)	FSGD (Km/h)					
	4		6		8	
	1	2	1	2	1	2
10	4.188	1.704	2.918	1.664	5.958	1.861
30	3.791	1.725	4.790	1.704	3.328	1.837
40	3.334	1.790	1.545	0.374	3.327	1.937
50	1.860	1.101	3.268	1.768	4.401	1.837

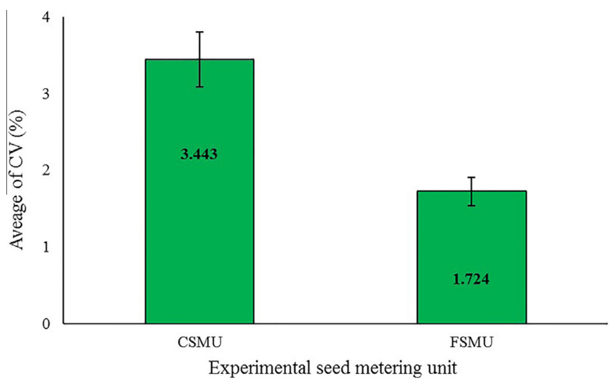

Fig. 7 – Comparison between the CV average of seed metering units.

2.2.2. *Dynamic trails*

2.2.2.1. *Seed characteristics*. Durum variety of wheat (*Triticum aestivum* L.) was used in this study because it is one of the most important varieties grown and consumed in Fars province, Iran. The seed purity and germination percentage was 97% and 96%, respectively. The bulk density and weight of 1000 seeds were 750 (Kg/m^3) and 41.7 (g), respectively. The moisture content of seeds was determined to be 8.15% on the dry weight basis [22].

2.2.2.2. *Grain drill specifications*. A typical grain drill (model: SK3, made by Khaledian company, Iran) was used. This grain drill had 19 planting rows. The drill row spacing was 15 (cm). Its seed metering mechanism was fluted feed roll type and located on a seed metering shaft. The power of the seed metering shaft was supplied by GDDW, end wheel drill, via sprockets and chain to the gear box. The gearbox with a cam and a follower mechanism made it possible to regulate the metering mechanism for various seeding rates at a constant FSGD, via a one-directional ball-bearing.

2.2.2.3. *Tractor characteristic*. A Massey Ferguson 285 (MF-285) tractor was employed according to the required drawbar power to pull the grain drill. To achieve the accurate FSGD attached to the tractor, the standard table of engine speed-gear-forward speed, introduced by the tractor company, was used. In addition, tractor needed time to pass a determined distance was measured using a digital chronometer with an accuracy of 0.001 (s) (JHD, model number: SLT-2004, China) to check the tractor forward speed. Thus, the actual forward speed of tractor was controlled in each test.

2.2.2.4. *Farm preparation*. The farmlands with uniform wheat stubble coverage were selected in Sarvestan city, Fars province, Iran. The farm plots were chosen in a zone with soil texture of clay loam. In order to enter the effect of stubble existence into the FSMU operation, the farms were selected with 10%, 30%, 40% and 50% uniform wheat stubble. To determine the exact value of wheat stubble in each test plot, a square frame with specific dimensions was randomly placed in 50 parts of the field. The amount of confined wheat stubble in the frame was weighed and the average value was applied as percentage of filed stubble coverage based on Eq. (1) [23]:

$$Y = (1 - e^{-0.000644X}) \times 100 \tag{1}$$

where Y is the percentage of wheat stubble cover and X is the dry weight of wheat stubble per unit surface area, (Lb/acre). The equation was solved for Y based on the value of X parameter and Y was found to be 10%, 30%, 40% and 50%. A total of 72 farm plots with specific desired condition were selected. In this investigation, the size of 15 × 4 (m^2) was selected for each test plot.

Table 2 – ANOVA results for the CV values of CSMU.

Source of variation	Degree of freedom	Sum of squares	Mean squares	F value
Stubble	3	2.935E-5	9.784E-6	28.903**
FSGD	2	2.410E-5	1.205E-5	35.604**
Stubble × FSGD	6	2.995E-6	4.991E-7	1.474
Error	24	8.124E-6	3.385E-7	
Total	35	6.458E-5		

** Significant at less than 1% probability level.

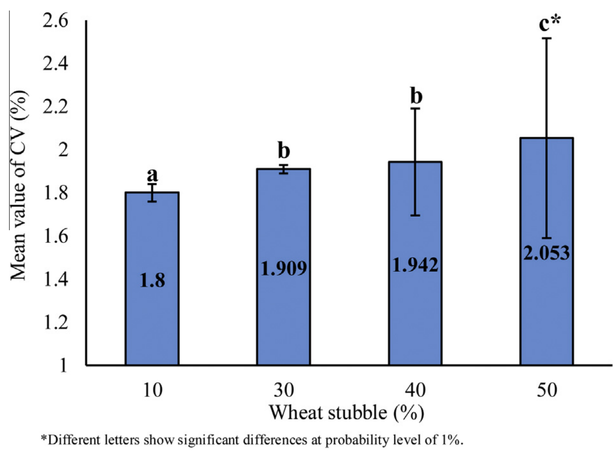

Fig. 8 – Effect of wheat stubble coverage on the CV value using CSMU.

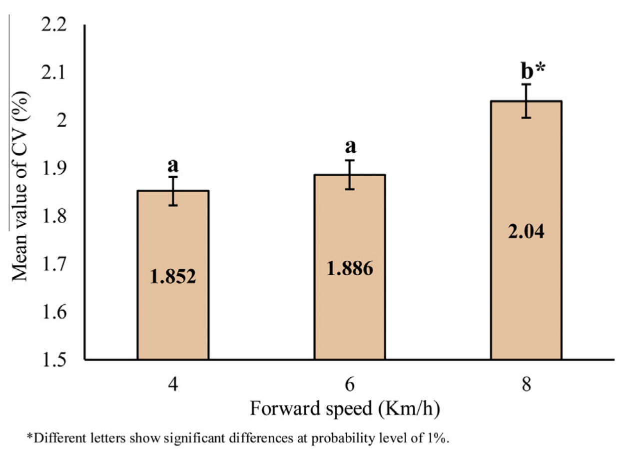

Fig. 9 – Effect of the FSGD on the CV value using CSMU.

2.2.2.5. *Performance tests of FSMU.* The mechanical power transmission system was eliminated from the typical grain drill and the electrical controlled equipment was installed on the seed metering part of the grain drill (Fig. 4). The furrow openers and seed coverings of grain drill were disabled. Therefore, the contact between them and soil was eliminated. The wheat seed was delivered to the seed tube and placed on the farm floor. The seeding rate of the seed metering unit was compared with that of the ordinary mechanical seed metering unit in each seeding experiment. In order to eliminate the effect of seed weight on the seed rating, the seed hopper of experimental grain drill was half filled [24]. The dynamic tests were carried out using the mounted FSMU on the grain drill and CSMU of grain drill, at three forward speeds of grain drill of 4, 6 and 8 (Km/h) in case of four various levels of wheat stubble coverage (10%, 30%, 40% and 50%). Overall 200 (Kg) wheat seeds per hectare and 2.85 (m) width of row space (15 (cm) between two rows) were used as input values for the control box. In order to reduce error, the tests were accomplished in triplicate.

To calculate the exact amount of wheat seeds on the floor of test plots, a square frame with specific dimensions was randomly placed in 50 parts of field. The confined cultivated wheat seeds in the planting row captured by the frame were counted and the distance between two seeds was measured using an electronic digital caliper, reading to an accuracy of 0.01 (mm) (model: Neiko 01409A, made in USA).

2.3. *Data analysis*

To evaluate the performance of the FSMU, the CV value (%) was calculated using following Eq. (2) [25,16,11]:

$$CV = (S/M) \times 100 \tag{2}$$

where *S* is the standard deviation of the seed spacing and *M* is the mean seed spacing. The standard deviation of the seed spacing can be determined by following Eq. (3):

$$S = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(d_i - M)^2} \tag{3}$$

where *N* is number of collected distances and d_i is *i*th distance between two seeds.

Jafari et al. [26] also confirmed that the CV value can be used as an index of seed flow non-uniformity for performance evaluation of grain drills. Thus, the calculated CV values of the two experimental seed metering devices were compared.

A factorial design with three replications was used in four levels of wheat stubble coverage and three forward speeds of grain drill. Obtained data were subjected to ANOVA to study the effect of stubble existence and the FSGD on the CV value. Furthermore, the DMRT was carried out using the statistical analysis system by the SPSS21 software.

3. Results and discussion

3.1. *Evaluation of FSMU*

3.1.1. *Performance simulation*

Fig. 5 shows simulated windows of designed seed metering unit in Proteus V7 software. The developed seed metering unit was validated in the simulator setup in the laboratory with considered conditions. Results of validation presented a very good agreement between designed seed metering unit and desirable performance of all electrical parts. The output of the two digital encoders was continuous. The control result of the rotational speed values of variable-rate DCM shaft versus its input voltage values is presented in Fig. 6. In this figure, the regression line represents coefficient of determination (0.996) for correlation between output and input of variable-rate DCM. There was no significant difference between the observed and expected performance. Similar to our results, some researchers reported the results of performance evaluation of pneumatic precision seed metering device for rapeseed using ANSYS simulator software [27,28].

3.1.2. *Experimental trials*

The results of dynamic tests of the FSMU indicated that the control system could keep the seed metering device synchronized with the FSGD to diminish the effect of non-uniformly seeding caused by GDDW skidding.

There is an ISO standard [29] as proposed by Kachman and Smith [30] for determining the seed spacing uniformity from

Table 3 – ANOVA results for the CV values of FSMU.

Source of variation	Degree of freedom	Sum of squares	Mean squares	F value
Stubble	3	6.436E-6	2.145E-6	5.404^{ns}
FSGD	2	5.468E-7	2.734E-7	0.689^{ns}
Stubble × FSGD	6	4.006E-6	6.677E-7	1.682^{ns}
Error	24	9.528E-6	3.970E-7	
Total	35	2.052E-5		

ns Not significant at less than 1% probability level.

different outlets of a grain drill. The maximum CV value is preferred to be less than 30% [30]. In other words, a smaller value of the CV indicates a higher seed spacing uniformity for the device [25]. Table 1 reports the CV values in each case of experimental trials on the farm. Comparison of tabulated results of the CV values for seed metering units demonstrated that the CV values were diminished as the FSMU was used. The average of the CV values for two types of seed metering unit showed that the quality improvement of uniformly seeding space was achieved using the FSMU (Fig. 7). Decreased CV value (49.94%) approved the properly replacement of CSMU with FSMU in the grain drill. Similar results were reported in development of a computerized measurement system for seeding rate in a seed planter [16].

3.2. Effect of stubble and FSGD on the CV

3.2.1. Application of the CSMU

The results of ANOVA for the experimental data are presented in Table 2. According to the results, stubble existence and the FSGD significantly affected the CV value ($P < 0.01$). The rotation of seed metering device was a function of desired transferred rotation from the end wheel drill of the grain drill. Thus, at the higher FSGDs in constant distance, the FSGD increment led to shorter contact time between end wheel drill and soil. It consequently resulted in lower time of rotation for seed metering device. Therefore, the seed space variation occurred by changing the FSGD. Similar to our findings, another investigator presented his work results for the effects of the FSGD on the sowing uniformity of maize and sunflower [31].

Since the end wheel drill could transfer a limited torque for swirling the CSMU, a mechanical joint was used to transfer torque in the CSMU. The torque was produced by the frictional force between the end wheel drill and the soil. Therefore, the frictional force was reduced as contact between the end wheel drill and soil decreased. The more stubble coverage resulted in lower contact between the end wheel drill and soil. Thus, the torque needed to rotate the seed metering shaft was not provided on the farm covered with stubble.

Figs. 8 and 9 display the results of the DMRT for wheat stubble coverage and the FSGD treatments, respectively. Increment of wheat stubble coverage and the FSGD led to the CV value increment. In the case of wheat stubble coverage, 30% and 40% did not significantly affect the mean CV value because the two wheat stubble coverage percentages were not widely different. Thus, they can apply alternatively. In case of the FSGD, although the mean CV value was not significantly changed in terms of 4 and 6 (Km/h), it was affected at 8 (Km/h). Therefore, the forward speed of 6 (Km/h) was proposed as FSGD attached to the tractor for achieving a higher seeding efficiency with lower CV using the CSMU.

3.2.2. Application of the FSMU

The ANOVA results for obtained data are shown in Table 3. It can be observed from the results that presence of stubble on the farm and FSGD did not significantly affect the CV value ($P > 0.01$). It was concluded that the FSMU eliminated the effect of stubble existence on the farm and FSGD on the CV value. The mechanical load was eliminated from the SGW and the resistant torque for rotating the SGW was skipped by the electrical link being replaced as a mechanical joint. Consequently, the frictional force between the SGW and soil was avoided. Therefore, the SGW without mechanical transmission system, a gearbox with a cam, rotated continuously at each FSGD and level of wheat stubble coverage. The exact on-the-go RPM of the SGW was transmitted to the control box by its digital encoder. Hence, the use of the FSMU instead of the CSMU in the grain drill improved the seeding accuracy and kept the seed spacing uniformity. Moreover, the application of equipped grain drill with FSMU led to planting efficiency increment at the forward speed of 8 (Km/h) in all stubble coverage levels. In previous works, researchers have proposed the use of controlled electrical seed metering unit instead of mechanical seed metering unit in seed planter machines [32–35].

4. Conclusions

The following conclusions can be drawn from our results:

1. The closed-loop control system designed and fabricated to change the seeding rate in seed metering unit operated satisfactorily.
2. In DSW, the FSGD and stubble existence on the farm significantly affected the CV value using the CSMU.
3. A significant difference was observed between employing FSMU and CSMU for seed spacing uniformity in DSW.
4. Applying the FSMU eliminated the effect of the FSGD and stubble existence on the farm and led to reduced CV value by approximately 50%.
5. Precision seeding possibility for the highest FSGD (8 Km/h) was achieved in the field with different levels of stubble coverage using FSMU in grain drill.

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