Development of seeder for mixed planting of corn and soybeans

Seung Min Woo, Daniel Dooyum Uyeh, Moon Sang Sagong, Yu Shin Ha*

(*Department of Bio Industrial Machinery Engineering, Kyungpook National University, Daegu 41566, Korea*)

Abstract: Corn and soybeans should be sown between 5 cm and 10 cm apart in mixed cultivation to increase protein content and improve productivity of the forage. However, existing sowers cannot plant at intervals of less than 20 cm. Consequently, mixed cultivation of corn and soybeans is currently performed by first sowing corn seeds with a tractor and then manually planting soybean seeds. This method results in irregular intervals between the seeds, it is laborious and time consuming. This study aimed at developing a seeder that can simultaneously, precisely and efficiently plant corn and soybean. The geometrical and rheological properties of corn and soybeans were initially measured. The seed conveying equipment were designed using the EDEM software. The sowing interval between seeds, depth of soil over planted seed, and sowing performance were analyzed. The EDEM simulation results indicated that a 6-mm-wide and 3-mm-deep grooved seed-delivering roller had the highest particle mobility of the designs considered, with a 2.5% misplanting rate. A performance test showed that no misplanting occurred in the sections sowed with soybean seeds at a seeding interval that averaged 32 mm (321 seeds sown in 10 m) and that misplanting occurred in one section sowed with corn at a seeding interval that averaged 247 mm (40 seeds sown over 10 m). The sowing efficiency for both corn and soybeans was found to be 0.42 h/hm^2. The average depth of soil over seed was 32.7 mm for soybean and 39.7 mm for corn. These average depths are within the stipulated range for the depth of soil over seed, which is 5 to 10 times the seed size. This study developed an efficient seeding machine that can simultaneously plant soybean and corn precisely, consequently improving forage yield and saving man-hours.

Keywords: corn, geometric characteristics, mixed planting, seeder, soybean

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1 Introduction

Various factors, such as increasing bio-energy production, energy shortages, increasing demand for grains in Asia (particularly China) and climate change, have caused the international prices of grains to rise sharply. This has led to increases in the prices of assorted feeds[1]. Advancing solutions to the high production costs of assorted feeds used by livestock farms involves developing high-quality bulky feed and expanding the base for its production. Mixed cultivation of corn, a gramineous crop used in bulky feeds, with legume crops can correct issues caused by eutrophic environments[2] and chemical fertilizers used to increase output[3-5]. This can increase the quantity and protein content achieved in comparison to single cultivation[6-8]. Mixed cultivation can also increase output by preventing lodging of corn during the rainy season as a result of the vine characteristic of soybean plants. It has been reported that mixed cultivation of corn and soybeans, which can increase output and the value of the fodder

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Biographies: Seung Min Woo, PhD candidate, research interests: processing of agricultural products, machinery and facilities for livestock, bio-energy, Email: woosm7571@gmail.com; **Daniel Dooyum Uyeh**, PhD candidate, research interests: processing of agricultural products, machinery and facilities for livestock, bio-energy, Email: uyehdooyum@gmail.com; **Moon Sang Sagong**, MSc, research interests: processing of agricultural products, machinery and facilities for livestock, bio-energy, Email: mssuh04@hanmail.net.

***Corresponding Author: Yu Shin Ha**, PhD, Professor, research interests: processing of agricultural products, machinery and facilities for livestock, bio-energy. 107, College of Agriculture and Life sciences building 3, Kyungpook National University, 80, Daehakro, Daegu 41566, Korea. Email: yushin72@knu.ac.kr.

produced, achieves high productivity because the soybean vines can climb easily, wrapping around the corn stalks when narrowly seeded at intervals of 5-10 cm[8]. However, a mechanized seeder that can sow both types of seeds simultaneously and control the seeding intervals of both crops has not been developed. Consequently, mixed seeding is currently performed by seeding soybeans after seeding corn, which using the available single seeders that have been developed [9,10]. This is an imprecise and laborious procedure that consumes vital man-hours and produces relatively low yields. Mechanization is therefore needed to achieve precise seeding of the grains at appropriate spacing and make efficient use of time and resources, especially in regions with limited farm manpower.

In a study related to the development of a seeder for coarse fodder seed, Rhee et al.[11] calculated the grain size, a characteristic with units of length that represents the shade factor, and used the grain size parameter to provide data on the size and shape of seeds necessary for designing a seeder. Soybeans were identified as being round in shape, while corn was identified as being a semi-oblate shape. Related studies have been conducted on development of a precision-planting roller-shaped seed-metering device[10,12-14], a seed metering system[15] and a planting-furrow roller-type seed-metering device[9,16,17]. The results of these studies showed that the roller type is the most common type of seeder and that seed metering devices of the vacuum suction type, inclined-plate type, belt type, and vertical rotor type are also often used. A roller-type seeder has furrows cut into the surface of a roller at regular intervals, and these furrows discharge seeds as the roller rotates. This type of seeder, which can be used with different types of seeds by changing the roller, is suitable for speedy seeding and is easy to fabricate because of its simple structure. Use of a roller-type seeder was judged to be appropriate for the purposes of this study.

To improve the output achieved by mixed cultivation of soybeans and corn, the metering rate should be controlled so that one or two grain(s) can be seeded with a grain of corn. Above all, the seeding interval should be maintained within the range of 5-10 cm, and consistent intra-row spacing must also be maintained. This study set out to develop a seeding machine by designing a seed metering device based on an analysis of the geometric and mechanical characteristics of corn and soybean materials and the results of particle behavior simulation conducted using the EDEM software. The results were used to develop a combined seeder that can plant both grains simultaneously. Testing was also conducted to assess the performance of the seeding machine in sowing.

2 Materials and methods

2.1 Test materials assessment

Seed sizes for soybeans (*Glycine max*) and corn (*Zea mays*) vary depending on the species. In general, soybeans are round in shape, while corn seeds are irregular semi-oblate shapes[8]. Considering the suitability of bulky feed seeds used in mixed cultivation, the soybean type selected for use in this study was Chookdu 1 (this was developed from a cross between wild soybean PI483463 and cultivated soybean Hutcheson). The corn cultivar used was P32P75 (Pioneer, USA). The geometric and mechanical characteristics of the soybean and corn seeds used in the study were measured using a Vernier caliper for measuring width and length of the materials, a contact-mode microscope (EGVM-35B, EGTech, Rep. Korea), was used to determine the shape of the materials, a beaker (500 mL), to determine the bulk density and a hardness tester (LTCM-100, Ametek Corp, USA), was used to determine the hardness of the materials.

2.2 Seed metering device simulation

The material conditions were as follows: The hopper part of the seeder was designed to have a Poisson's ratio of 0.29, a shear factor of 7×10^4 MPa, and a density of 7800 kg/m^3, using SM45C elements. The metering roller part was designed to have a Poisson's ratio of 0.4, a shear factor of 1×10^{-6} MPa, and a density of 1500 kg/m^3. The metering roller part was designed to be a Nylon plastic material that would interact with the soybeans in ways such as repulsion, suspension, and kinetic friction (Table 1). The driving conditions were as follows: A seeding speed of 0.26 m/s was selected for a 50-HP tractor (NX490, Daedong, Korea) in second gear. The second gear has a 75% of pull at the maximum power. It has an available power of 31.58-HP compared to the 31.45-HP and 28.58-HP of the first and third gears respectively that are normally used in working[18]. The metering roller, which had a diameter of 63.7 mm and eight furrows, was set up to seed eight times (25 mm) per rotation (200 mm) and was connected to the drive axle of the seeder at a deceleration ratio of 4:1. The seeding ratio and seeding interval were analyzed.

Table 1 Set-up conditions for seeder material

Unit	Material	Poisson ratio	Shear Modulus/MPa	Density/kg·m^{-3}
Hopper	SM45C	0.29	7×10^{4}	7850
Roller	Nylon Plastic	0.40	1×10^{-6}	1500

2.3 Design of seeding machine

The seeding machine consisted of a seed metering device, a seed hopper, a seed delivery device, a furrow opener, a soil covering and compaction device, a seed depth controller, and tractor couplers (Figure 1).

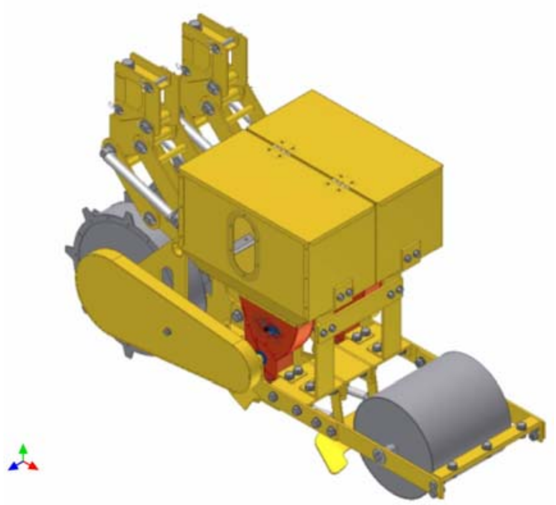

Figure 1 Three-dimensional modeling of a seeder for mixed cultivation

The machine was designed to allow seeding rates to be controlled by the size and number of furrows of the metering roller and for the intra-row spacing to be controlled by the gear ratio between the driving wheel and the seed metering device. The transfer of the seeds in the parallel-type structure and the intra-row and inter-row spacing between the seeds was controlled through the seeder.

2.4 Performance evaluation and method of data analysis

The performance evaluation was carried out in the testing field of the College of Agriculture of Kyungpook National University, located in Hyoryeong-myeon, Gunwi-gun, Gyeongsangbuk-do, Korea. The experimental procedure was as follows: A seeding machine was attached to a tractor (NX490, Daedong, Korea), the work efficiency was measured by conducting seeding in a test field area of 1 hm^2 at work speeds in the range of 0.26-0.39 m/s. Three zones, 10 m each in length, were selected and were divided into units of 1 m. Nine measurement points were set up, excluding the first and the last unit of each zone (Figure 2). The average of row Space and soil covering depth at space between plants of seeding performance and seeding rates points were measured and calculated using Equations (1)-(5)[15].

$$\overline{RS}_{A(B)} = \frac{\sum_{i=1}^{n} A_i(B)_i}{n} \quad (1)$$

where, $\overline{RS}$ is average row space, mm; A is corn row space, mm; B is soybean row space, mm.

$$\overline{SCD}_C = \frac{\sum_{i=1}^{n} C_i}{n} \quad (2)$$

where, $\overline{SCD}$ is average soil covering depth, mm; C is seed soil covering depth, mm;

$$\mathrm{SP} = \frac{A}{T} \quad (3)$$

where, SP is seeding performance, hm^2/h; A is seeding area, hm^2; T is seeding time, h.

$$\mathrm{SR} = \left(1 - \frac{n_0}{\sum_{i=0}^{3} n_i}\right) \times 100 \quad (4)$$

where, SR is seeding rate, %.

$$S = \sqrt{\frac{1}{N}\sum_{i-1}^{N}(x_i - \overline{x})^2} \quad (5)$$

where, S is standard deviation.

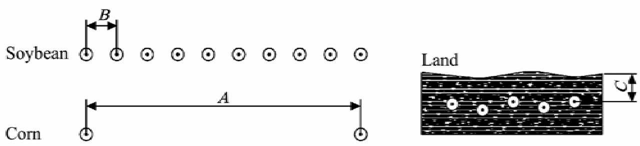

Figure 2 Seeding method for corn and soybean

3 Results and discussion

3.1 Characteristics of test materials

The corn seeds had an average length-to-width (L/W) ratio of 1.04, an average bulk density of 746.4 kg/m^3, and an average strength of 93.3 N (SD=33.9) while the soybean had 1.20, 786.0 kg/m^3 and 39.1 N (SD=13.3) for average-to-width ratio, average bulk density and average strength respectively as shown in Table 2.

Table 2 Geometric and mechanical characteristics of test materials

Seeds	Length/mm	Width/mm	Thickness/mm	L/W ratio	Bulk density/kg·m^{-3}	Maximum load/N
Corn	8.12 ± 0.92*	7.80 ± 1.05	5.64 ± 1.25	1.04	746.4	93.3 ± 33.9
Soybean	5.70 ± 0.38	4.74 ± 0.37	4.19 ± 0.32	1.20	786.0	39.1 ± 13.3

Note: * Mean±S.D.

3.2 Metering characteristics according to size of holes

Planting performance of a seeder mainly depends on the seed metering device that discharges the seeds, so designing a precise seed metering device is important. A hole roller-type seed-metering device has dented holes at uniform intervals on the surface of a roller and discharges the seeds held in the hopper as it rotates. In this study, the diameter of the roller seeding hole was 6 mm, which is similar to the length of a soybean, and three depths (2 mm, 3 mm and 4 mm) were considered in simulations of particle flow conducted using the EDEM program (Figures 3-4).

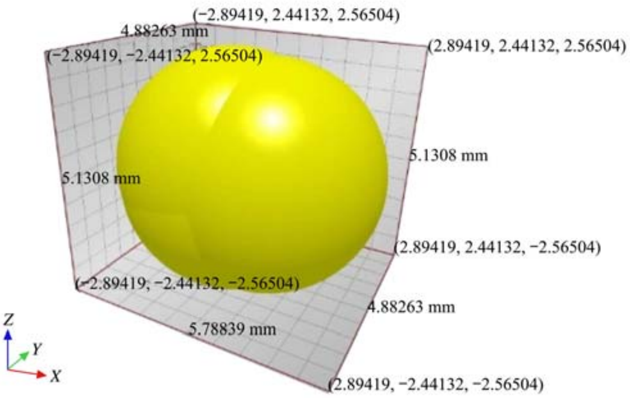

Figure 3 Bean shape design using the EDEM program

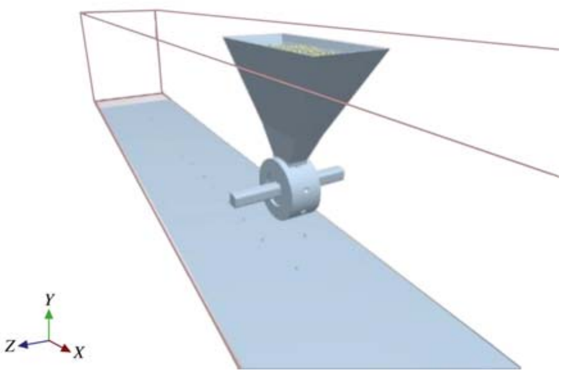

Figure 4 Simulation of seed metering device using the EDEM program

Results of Simulation conducted using EDEM software to examine the appropriate roller furrow depth for the size of the seed used is presented in Table 3. This shows that the best seed flow was achieved when the metering roller furrow depth was 3 mm. The seeding performance achieved was 2.5% misplanting, 92.5% seeding of one or two grain(s), and 5% seeding of three grains. Except in the misplanted section, the seeding interval was 25 mm (SD=22.06), and seeding was performed eight times in 200 mm, which met the design conditions.

Table 3 Metering characteristics according to roller hole depth

Depth of hole /mm	Seeding Rate/%				Row space /mm
	none	1-2	3	total	
2	48.5	51.5	0	100	
3	2.5	92.5	5	100	25 ± 12*
4	0	17.5	82.5	100	

Note: * Mean±S.D.

3.3 Manufacturing of a seeding machine and the result of performance test

Based on the results of the EDEM simulation, a metering roller was produced with holes 6 mm wide and 3 mm deep (Figure 5).

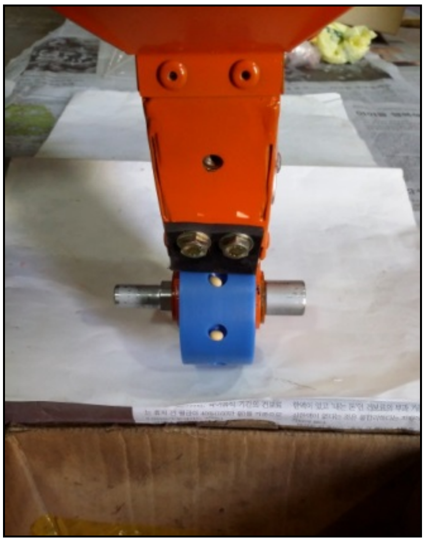

Figure 5 Seed-metering device test

One seeding machine (Type A) was manufactured to seed one or two grain(s) of soybean for each grain of corn, at regular intervals, at a ratio of 1:8 for 200 mm, and a second seeding machine (Type B) was manufactured. Clogging was prevented by adding a plow (Figure 6) to the front of the driving wheel, given the parallel-type structure of the seeder. These results are presented in Table 4.

Figure 6　Plow used on Type B machine

Table 4　Result of seed metering device tests

Time	Seeding Rate/%				Row space /mm
	none	1-2	3	total	
1	0	94	6	100	26 ± 7*
2	2	95	3	100	
3	1	94	5	100	
Ave.	1.00	94.33	4.67	100	

Note: * Mean±S.D.

3.4　Performance test

Performance tests (Table 5) for the Type A and Type B seeding machines (Figure 7), showed that there were no misplanted sections of soybean seeds and one misplanted section of corn seeds.

The two seeders maintained excellent seeding efficiency and soil covering thickness (Figure 8). The intra-row spacing of corn seeds was 247 mm (SD = 40.06) for the Type A seeder, because of clogging between the driving wheels (Figure 9), and the space between plants appeared to be more irregular than that for the Type B seeder 215 mm, (SD = 22.06), to which a plow was added.

Table 5　Results of performance tests

Seeder	Seeding ratio/%				Row spacing/mm		Soil covering depth/mm		Seeding performance/h·hm^{-2}
Corn	none	1	2	total	A	247 ± 40.06*	A	39.7 ± 1.71	0.42
	2.5	75	22.5	100	B	215 ± 22.06	B	41.6 ± 1.22	
Soy bean	none	1–2	3	total	A	31 ± 13.03	A	32.7 ± 1.48	0.42
	0	85	15	100	B	27 ± 8.03	B	28.7 ± 1.12	

Note: * Mean±S.D.

Figure 7　Performance test of the seeder

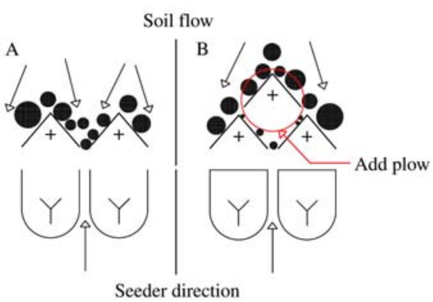

Figure 8　Seeder direction　for Type A and Type B machines

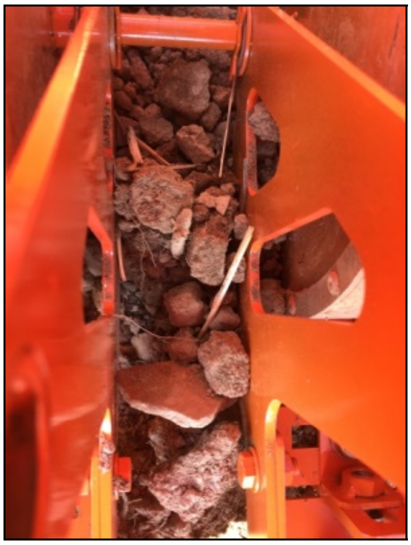

Figure 9　Clogging between the driving wheels

3.5　Performance validation

The results of the seed metering device test and performance tests above showed seeding rate of 94.33% for the seed metering device and row space of 26±7.

The other parameters examined which include seeding ratio were 75% for 1 seed, 22% for 2 seeds of corn respectively. The seeding ratio for soybean was 85% for 1-2 seeds and 15% for 3 seeds of soybeans respectively. Row spacing, seed covering depths and seeding performance showed to be within the recommended standards. These tests were done 5 times, and the tests met all the technical requirements[8,19-22].

However, the Type B seeding machine, which had a plow installed in front of the driving wheel, exhibited less slip by clogging between the parallel-type driving wheels than the Type A seeder. The variation in the space between plants was stabilized, but ultimately, the slip was not resolved. Additional research is necessary to stabilize the variation in the space between plants by changing the structure of the simultaneous seeder from the parallel type to the serial type and vertical type.

4 Conclusions

A simultaneous seeder was designed and manufactured for use in simultaneous planting of corn and soybeans at a seeding interval of 5-10 cm. The performance evaluation results showed that when the seeding speed was 0.26 m/s, there were no misplanted sections of soybean seeds for either seeding machine (Type A or Type B) and there was one misplanted section of corn seeds. The average soil covering thickness over the corn seeds was 39.7 mm (SD = 1.71) for the Type A seeding machine and 41.6 mm (SD = 1.22) for the Type B seeding machine. These results reflect excellent work efficiency.

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