Design and Safety Performance Evaluation of the Riding Three-Wheeled Two-Row Soybean Reaper

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Abstract

Purpose: The purpose of this study was to investigate the key factors in designing a three-wheeled two-row soybean reaper (riding type) that is suitable for soybean production, and ensure worker safety by proposing optimal work conditions for the prototype of the designed machine in relation to the slope of the road. Methods: A three-wheeled two-row soybean reaper (riding type) was designed and its prototype was fabricated based on the local soybean-production approach. This approach was considered to be closely related to the prototype-designing of the cutter and the wheel driving system of the reaper. Load distribution on the wheels of the prototype, its minimum turning radius, static lateral overturning angle, tilt angle during driving, and The working and rear overturning (back flip) angle were measured. Based on the gathered information, investigations were conducted regarding optimal work conditions for the prototype. The investigations took into account driving stability and worker safety. Results: The minimum ground clearance of the prototype was 0.5 m. The blade height of the prototype was adjusted such that the cutter was operated in line with the height of the ridges. The load distribution on the prototype's wheels was found to be 1 (front wheel: F): 1.35 (rear-left wheel: RL): 1.43 (rear-right wheel: RR). With the ratio of load distribution between the RL and RR wheels being 1:1.05, the left-to-right lateral loads were found to be well-balanced. The minimum turning radius of the prototype was 2.0 m. Such a small turning radius was considered to be beneficial for cutting work on small-scale fields. The sliding of the prototype started at 25°, and its lateral overturning started at 39.3°. Further, the critical slope angle for the worker to drive the prototype in the direction of the contour line on an incline was found to be 12.8°, and the safe angle of slope for the cutting was measured to be less than 6°. The critical angle of slope that allowed for work was found to be 10°, at which point the prototype would overturn backward when given impact forces of 1,060 N on its front wheel. Conclusions: It was determined that farmers using the prototype would be able to work safely in most soybean production areas, provided that they complied with safe working conditions during driving and cutting.

Keywords: Overturning, Reaper, Safety, Soybean, Three-wheeled, Tow-row

Introduction

In South Korea, soybeans have been used in large quantities as an ingredient of traditional food products. As such, it remains one of the crops that is being consumed steadily. Despite the role they play, locally grown soybeans make up only 28.2% (approx. 75,242 ha) of total demand, making bulk import necessary (Ko, 2010). Since the majority of imported soybeans are genetically modified foods, it causes consumer anxieties in local markets, thus increasing the demand for locally produced soybeans. Furthermore, South Korea's rice growing area is rapidly declining amid a dwindling consumption of rice. To counteract the trend, since 2002, the South Korean government has implemented campaigns and policies that encourage local farmers to grow soybeans, so as to redefine soybeans as a rice-substituting crop and to help increase the self-sufficiency rate for local soybean production.
(Jun et al., 2006). Most local soybean growers are small-scale with farm land of 1 ha or under. These farmers make up 99% of the total local soybean farm ownership. Their production work is primarily dependent on human labor. As such, 58.3% of total production cost is being spent on labor (Ko, 2010). In particular, the harvesting operation is associated with large shattered losses, depending on the time of harvest. Furthermore, due to soybeans having short harvest seasons, the production necessitates high labor intensity and heavy reliance on human labor, which urgently calls for mechanized harvesting.

In comparison, soybean farmers overseas have developed shattering resistant and mechanization-friendly kindly, thereby relying almost entirely on mechanized production using harvesting machines. One example of such a machine is the combine, which helps minimize shattering losses. However, the performance of combines might be lower for the South Korean soybean production approach, as there are small-scale farms where the ground is covered with plastic film and ridges are created to plant the seeds. Moreover, combine harvesting causes problems of soybean-quality degradation because of the inflow of soil and unripe soybeans. In the local area, a single-row pedestrian-type soybean reaper has been developed and is currently being used by the farmers. However, these soybean reapers require massive labor involvement in the threshing process after reaping work (Jun, 2004; Jun et al., 2006; Jun et al., 2008; Jun et al., 2012). Additionally, a double-row pedestrian-type reaper (wheel type) (Jun et al., 2011) has been developed, but has failed to commercialize. Rather, a two-row pedestrian-type sesame reaper (crawler type), which was developed for sesame farmers, has been applied to other crops, such as soybeans and perillas, to ensure the applicability of the machine (Jun et al., 2015). Furthermore, a soybean combine (pick-up type) has been developed (Yoo et al., 2014(a), Yoo et al., 2014(b)), and is used exclusively to thresh the cut and dried soybeans when the use of the combines becomes difficult because of poor crop growth. Also, for efficient work of a soybean combine (pick-up type), the ground gradient condition has been investigated to ensure safe uses of the riding three-wheeled reaper that are adaptable to the various soybean cultivation styles. Such investigations took interest in increasing the efficiency of the soybean threshers and the use of tractor-type combines on slopes (Jun et al., 2015).

The purposes of this study were to investigate the key factors in designing a three-wheeled two-row soybean reaper (riding type) that is suitable for the local approach to soybean production and to propose the optimal work conditions for the prototype of the reaper in relation to the slope of the ground to ensure worker safety.

### Materials and Methods

#### Conventional Soybean Cultivation Style

Prior to designing the prototype of the riding three-wheeled two-row soybean reaper, investigations were made regarding the soybean cultivation styles that are currently being adopted by local soybean growers. Specifically, investigations were conducted regarding the row spacing, hill spacing, ridge height, and plant width that are closely related to the prototype's cutter and driving and braking system.

The local farmers' approaches to soybean production were investigated so as to incorporate the information into the designing of the driving and braking system, cutter, and minimum ground clearance of the riding two-row soybean reaper (the "reaper") (Table 1, Figure 2). Based on the information, the cutter and driving and braking system of the prototype were designed accordingly. The results of the investigation showed that the plant width ranged between 0.6 and 0.8 m.

#### Setting track width and distance between tow disk saws

The track width of the prototype was set at 1.2-1.6 m, and the distance between its tow disk saws were set at 0.6-0.8 m. The minimum ground clearance of the prototype was set at 0.5 m, in consideration of the height of cut soybeans being

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**Table 1. Cultivation style and plant width**

<table>
<thead>
<tr>
<th>Row Spacing (m)</th>
<th>Hill Spacing (m)</th>
<th>Ridge Height (m)</th>
<th>Plant Width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6-0.8</td>
<td>0.2</td>
<td>0-0.3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

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**Figure 1.** Shape of soybean.
Prototype design

For the designing of the reaper prototype, factors such as track width, distance between tow disk saws, and minimum ground clearance were taken into consideration, along with the local soybean cultivation styles.

Based on the design factors from Figure 2 and Figure 3, the prototype of the reaper was designed and fabricated, as shown in Figure 4.

The designed prototype consisted of a cutter, a driving and braking system, a steering system, and a drive train, such that it was able to cut two rows of soybean stalks with a single cut and combine the cut portions into a single row.

The prototype drove with three wheels (a front wheel and two rear wheels). The rear wheels provided the driving function and the front wheel provided the steering function. The cutter with a guide for crops and two blades, each rotating inward, cut the crops two rows at a time. Depending on the plant width, the distance between the blades' rotating shafts could be adjusted to achieve 600 to 800 mm, a blade height of 30 to 300 mm, and a real wheel track width of 1,400 to 1,600 mm. The steering of the Reaper was achieved by maneuvering the front wheel with the steering handle. The drive train was designed such that the engine power was transferred to the wheels through the transmission, and the cutter (blades) was operated with a hydraulic system. Table 2 presents the specifications of the prototype.

Investigation prototype safety

Load distribution and center of gravity measurement

Load distributions on the wheels of the prototype of the reaper were measured to evaluate the prototype's driving stability. This was done by measuring the wheel load of each wheel using the instrument for measuring center of gravity that was placed at the Department of Agricultural Engineering.
of the National Institute of Agricultural Sciences (NIAS) (Figure 5). Further, the applied load was measured on the front wheel and on the rear wheels (rear-left and rear-right), and the sum constituted the total load. For the purposes of this study, the wheels were designated F (front wheel), RL (rear-left wheel), and RR (rear-right wheel), respectively. An instrument for measuring the center of gravity, composed of four platform scales (Figure 6 and 7), was used for the measurement of each load. The load bearing capacity of each scale was 50,000 N.

**Measurement of prototype turning radius**

The turning radius of the prototype was measured to help increase the operating efficiency of the prototype while sitting on the surface. The measurement involved the maximum-turning of the steering wheel (front wheel), marking the trajectory of movement of the front wheel, and calculation of the shortest distance between the center of the curvature to the trajectory of the front wheel (Figure 8).

**Measurement of prototype overturning angle**

The static lateral overturning angle (Figure 9), sliding angle (Figure 10), rear overturning gradient (Figure 11), and impacting force on the front wheel at driving gradients (Figure 12) of the prototype were measured to identify the optimal working conditions to ensure its driving stability on slopes, as well as the safety of workers. For the gradients, the prototype’s lateral overturning angle and rear overturning angle were measured using the instrument placed at the NIAS Department of Agricultural Engineering. Specifically, two types of tilt angles were measured: the tilt angle when the machine was overturned laterally, and the tilt angle when the machine slid before overturning (the sliding
angle). Additionally, measurements were made of the driving and working stability of the prototype while the machine was being operated on slopes. This was done by having three workers ride the machine and rating their respective level of ride comfort on a scale of 0 to 10 under each gradient condition, and summing and averaging the measures of the self-rated physical sensations.

### Results and Discussion

#### Wheel load distribution and prototype turning radius

The driving stability of the prototype, as per the load distribution, was evaluated by measuring the loads that were applied on the wheels of the prototype. The results found that the loads applied on F and R (right and left combined) were 1,270 N and 3,530 N, respectively—with RL subject to 1,720 N and RR subject to 1,810 N (Table 3).

With the overall load distribution ratio being 1 (F): 1.35 (RL): 1.43 (RR), the driving stability of the prototype was found to be well-balanced. With the ratio between the two rear wheels being 1 (RL): 1.05 (RR), it was determined that a stable lateral load distribution was achieved.

The minimum turning radius of the prototype was found to be 2.0 m and as such, the machine's workability on the ground was considered to be superior.

#### Measurement of tilt angles to ensure safe operation of the prototype

Table 4 summarizes the tilt angle information and static lateral overturning characteristics of the prototype in
consideration of its safe operation on slopes. At a tilt angle of 25°, the prototype started to slide, and the critical tilt angles in the lateral direction were found to be 39.3° (left). Additionally, the maximum tilt angle at which the driver could still operate the prototype on slopes was found to be 12.8°; however, the angle that ensured worker safety was found to be less than 6°, and the critical tilt angle to allow the cutting operation was found to be 10° at the maximum (Figure 13). Furthermore, when receiving impact forces of 1,060 N on its front wheel at the critical tilt angle of 10°, the prototype was found to overturn backwards (Figure 14).

Conclusions

This study investigated the key factors that need to be considered in the designing of a three-wheeled two-row soybean reaper (riding type). Critical safety values of reaper prototype parameters were calculated to propose optimal work conditions similar to the gradients of the farmland under which the prototype of the reaper was to operate, while ensuring driver safety. Results of the study showed that the prototype ensured stability during operation, as well as while driving on slopes in most soybean production sites in the country.

Conflict of Interest

The authors have no conflicting financial or other interests.

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References


