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Prototype Development of a Three-wheel Riding Cultivator and Its Basic Performance

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Abstract

Purpose: The aim of this study is to develop a three-wheel riding cultivator for improving the performance of the current four-wheel riding cultivators in the market. **Methods:** A prototype three-wheel riding cultivator with the rated power of 15.5-kW, a primary hydrostatic and a two-speed selective gear transmission shifts, front/rear three-wheel drive, a hydraulic wheel tread adjustment, and the mid-section attachment of the major implements was designed and constructed. Its specifications and basic performance are investigated. **Results:** The maximum speeds of the prototype at the low and high stages were measured to be approximately 7.31, and 11.29 km/h in forward travel, respectively, and approximately 3.60, and 6.37 km/h in rearward travel, respectively. The minimum ground clearance is shown to be 670 mm. The rotating speeds of the power takeoff (PTO) shaft at the low and high stages are shown to be approximately 795 and 1,140 rpm, respectively. The tread of the rear wheels, the minimum radius of turning, and the maximum lifting height of the parallel link device are measured to be within 1,320–1,720 mm, 2.80 m, and 390 mm, respectively. Approximately 25.3% and 74.7% of the total weight of the prototype are distributed in the front and rear wheels on flat ground, respectively. When the tread of rear wheels increased from 1,320 to 1,720 mm, the left and right static lateral overturning angles increased from 33.4° to 39.1° and from 29.0° to 36.1°, respectively. **Conclusions:** The prototype three-wheel riding cultivator showed a wide range of travel and PTO speeds, high minimum ground clearance, small minimum radius of turning, and easy control of the rear wheel tread. Further, the easy observation of cultivating operations by mid-mounting the implements can improve quality of work. Therefore, the prototype is expected to contribute to the riding mechanization of cultivating operations for various upland crops in Korea.

Keywords: Performance, Prototype development, Three-wheel riding cultivator

Introduction

The mechanization rate of upland farming in South Korea is approximately 58.3% and has increased by more than 10% over the last decade; however, it is insufficient compared to the 97.9% mechanization rate of rice farming that uses rice planting machines and combines. The mechanization rate of upland farms is higher in larger farms, but over 85% of upland farms are small farms of 0.3 ha or less. Further, walking farming machinery is used primarily, apart from tractors used for plowing and land grading tasks. As such, the rate of riding mechanization remains under 28.3% (NIAS, 2016). South Korea's major upland crops use plastic mulch cultivation primarily to keep crops warm, conserve moisture, and render weeding easier. However, the mechanization of the overall task process is highly limited owing to the increase in the cost and required manpower caused by plastic mulch cultivation, as well as difficulties in developing implements for use in plastic removal, sowing, transplanting, cultivation, fertilization, and harvesting. Most of these tasks are being

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performed through walking machines. In bean cultivation, the rate of riding mechanization for each task is 10.4% for sowing, 23.9% for plastic mulching, 10.7% for pest control, 0.7% for weeding, 1.5% for reaping, and 0.0% for topping. These rates are highly limited, and the riding mechanization is an urgent issue (NIAS, 2016).

Particularly in small-to-mid size farm environments where it is difficult to use upland crop tractors and attached implements, it is highly necessary to develop riding cultivators and attached implements for improving work efficiency and worker convenience, as well as reducing cost. In upland crop cultivation, tractors have a limited ability to perform tasks such as sowing and transplanting, cultivating and weeding, pest control, fertilization, etc. owing to limitations in ground clearance, and wheel tread. In South Korea, four-wheel riding cultivators are being developed and commercialized, but the spread of the riding cultivators and attached implements has been extremely slow owing to the machinery's user-unfriendliness and performance inadequacies. These inadequacies cause difficulties in verifying the state of tasks because most of the machinery is attached at the back, as well as difficulties in adjusting the wheel tread in accordance with the variety of cultivation practices that are used even for a single type of crop in addition to working limitations such as plastic mulch cultivation. In Japan, upland farming is moving toward uncovered cultivation through standardized cultivation practices. Japan is currently developing and commercializing three-wheel riding cultivators and attached implements for upland crops (Minoru, 2005; Yanmar, 2017). This machinery is suitable for small- to mid-sized farms and provides work efficiency, work accuracy, and work convenience, because the operator can see and control the states of cultivation practices easy by attaching the major implements to its mid-section, and adjust the wheel tread in accordance with the variety of cultivation practices by the hydraulics. In addition to the studies on pest control implements, none have studied three-wheel riding cultivators and attached implements that are high in efficiency and convenience in many tasks, from sowing to harvesting.

Currently, attempts are performed to spread the domestic development and commercialization of three-wheel riding cultivators and attached implements (Choi et al., 2016 and 2017; Han et al., 2016). In this study, we designed and built a three-wheel riding cultivator prototype that can improve the accuracy and convenience of cultivation tasks through performance improvements in ground clearance, wheel tread adjustment, and steering, as well as the improvement in attaching the implements at the mid-section of the prototype. These improvements allow it to be used as part of the varying small-scale upland crop cultivation practices employed in South Korea to increase the mechanization of upland cultivation tasks, and for the systematic mechanization of all task processes. This study provides the primary specifications of the prototype and evaluates its basic performance.

Materials and Methods

Layout of prototype's primary arts

The three-wheel riding cultivator includes the following primary parts. The engine is a 15.5-kW air-cooled four-stroke gasoline engine. The power transfer unit uses a constant hydrostatic transmission (HST) as the primary transmission shift and a two-speed selective gear transmission as the speed range shift, and transmits the motive power to the front/rear wheel and the implement's power takeoff (PTO) axles. The front/rear wheel of the three-wheel traveling unit is equipped with a front wheel attachment unit to reduce the turning radius, and allows the tread of the rear driving wheels to be adjusted using a hydraulic cylinder to handle various upland crop cultivation practices. The hydraulic unit provides the precise control of implements position and steering using hydraulic devices such as hydraulic cylinders, except for the hydrostatic transmission. The parallel link implement attachment unit improves the precision and convenience of tasks by allowing for easy observation when major implements are attached to the three-wheel riding cultivator's mid-section. The driving controller unit is for driving the three-wheel riding cultivator and controlling the major parts. In addition, the cultivator also includes a frame, cover, etc.

Prototype's primary specifications and basic performance testing

The primary specifications of the three-wheel riding cultivator prototype that was designed and built in this study were evaluated and compared with those of Japan's Yanmar three-wheel riding cultivator and South Korean's four-wheel riding cultivators that are currently in the

Figure 1. Views of split of weight on front and rear wheels, and static lateral stability tests.

market. These primary specifications include the body dimensions and weight, minimum ground clearance, maximum engine output, front wheel drive type, tire dimensions, axle and wheel distance, wheel distance adjustment type, steering type, primary and sub transmission type, number of transmission stages, turning type and minimum turning radius, PTO type, number of stages and rotation speed, and the implement attachment type and control type.

To analyze the basic performance of the three-wheel riding cultivator prototype, its drive performance was examined by measuring the traveling speed, straightness, minimum turning radius, etc. in each transmission stage at the engine's rated rotation speed on a concrete test track at the Department of Agricultural Engineering of the Rural Development Administration in Jeonbuk Province. The traveling speed at each transmission stage was measured on 100 m of flat section by full opening the governor lever and placing the primary transmission lever at low speed, medium speed, and high speed when the sub transmission stage was at low speed and high speed. The minimum turning radius was measured via the most exterior tire contact surface mark during left and right turning. The measurements of the traveling speed at each transmission stage and the minimum turning radius were performed three times (FACT, 2016). In addition, the hydraulic cylinder for adjusting the rear wheel width was operated to measure the minimum and maximum rear wheel treads and to obtain the rear wheel adjustment range. The analysis also found the stage-1 and stage-2 rotation speeds of the mid-section PTO axle for the operating attached implements at the engine's rated rotation speed with no load. Moreover, an analysis was performed to obtain the lifting range of the attachment unit's implement lifting equipment, and to verify if any lifting malfunctions occurred in the lifting equipment when attaching three-wheel riding cultivator implements such as the sowing implement, the cultivating and weeding implement, the cultivating and hilling implement, and the topping implement.

To perform a static stability analysis that accounts for the three-wheel riding cultivator's pavement gradient, this study measured its static lateral overturning angle according to the changes in the real wheel tread, and the load distribution of the front and rear wheel prototypes caused by the front/rear gradient, as shown in Figure 1. The front/rear wheel load distribution was measured by changing the height of the front wheel from 0 to 25 cm in 5 cm intervals. The static lateral overturning angle was measured using the overturning angle testing equipment at the Department of Agricultural Engineering of the Rural Development Administration using three-wheel riding cultivator prototype rear wheel widths from 1,330 to 1,725 mm in 80 mm intervals. The static lateral overturning angle tests were performed according to the farming machinery verification standards (FACT, 2016) by placing a 75 kg sandbag in the driver's seat, and measuring the right and left lateral overturning angles of the test equipment. The line for determining overturning was set as the line that connects the contact points of the front wheel and the gradient plane, and the lower rear wheel and the gradient plane, assuming that the prototype was turning from the gradient.

Results and Discussion

Layout of Prototype Machine's Primary Parts

Figure 2 shows the motive power flow diagram for the three-wheel riding cultivator prototype. It shows the

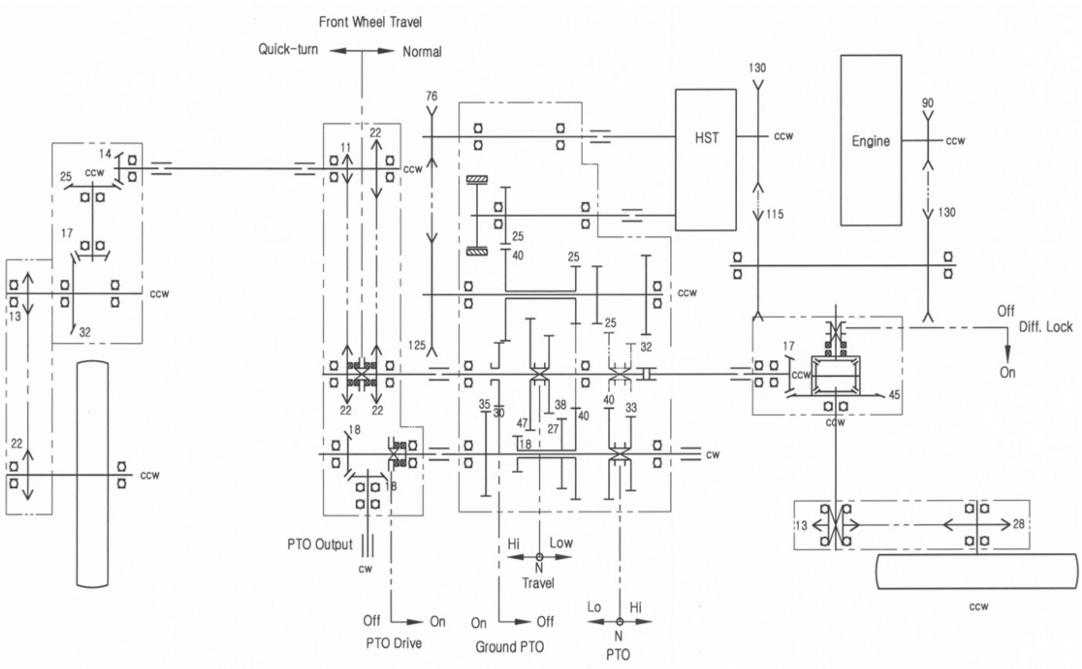


Figure 2. Power flow diagram for the prototype three-wheel riding cultivator.

power flow from the engine to the front and rear wheels, and the implemented mid-section and rear-section PTO axles. It also shows the driving and PTO axle transmission control, front wheel quick-turn control, wheel traveling speed-proportional-type PTO control, and rear wheel differential lock control.

The prototype's air-cooled four-stroke gasoline engine (GX630, Honda, Japan), was measured to exhibit a maximum output of 15.5 kW / 3,600 rpm. The HST (HVFD21F-R23, KYB, Japan) contains a pump and motor discharge volume of 21.5 cm^3/rev., maximum pressure of 23 MPa, and maximum output speed of 0–3,600 rpm.

The prototype machine drives both the front and rear wheels. The front wheel axle's driving power passes through the engine, V-belt drive unit, HST primary transmission, high and low two-stage sub transmission gear box, front wheel quick-turn chain drive unit and transmission clutch, bevel gear box located on the front wheel, and the chain gearing unit. The rear wheel axle's driving power passes through the engine, V-belt drive unit, HST primary transmission, high and low two-stage sub transmission gear box, differential unit, and final deceleration chain drive unit.

The PTO axle for activating the implements and external power takeoff was installed at two places, i.e., on the prototype machine's mid-section and rear-section, and it allows for driving via the engine and proportional speed driving via the wheels. The mid-section PTO axle's driving power passes through the engine, V-belt drive unit, HST primary transmission, V-belt drive unit, sub transmission gear box including a high and low two-stage PTO transmission, PTO clutch and bevel gear gearing unit. The rear-section PTO axle installed on the sub transmission gear box is driven by power that passes through the engine, V-belt drive unit, HST primary transmission, V-belt drive unit, and the sub transmission gear box that includes a high and low two-stage PTO transmission.

When the engine and rear wheel axle were traveling forward, the final deceleration ratio was 0.016 during the sub transmission's low speed and 0.030 during the sub transmission's high speed. The deceleration ratio of the engine and front wheel axle during forward travel was the same as the final deceleration ratio of the engine and rear wheel. However, during turning, the front wheel attached unit is operated to reduce the turning radius, and the front wheel's final deceleration ratio was calculated as 0.032 and 0.060, which is approximately twice higher. Therefore, if we ignore the drive wheel's slip and the deceleration owing to the HST's volumetric efficiency, and consider that the front and rear wheel's radii are both approximately 36 cm, the prototype machine's theoretical forward travel speed is designed to be within 0–7.8 km/h when the sub transmission is in low speed, and 0–14.5 km/h when the sub transmission is in high speed. Similarly, if this is applied to rearward travel, the theoretical rearward travel speed is 0–4.0 km/h when the sub transmission is in low speed, and 0–7.5 km/h when the sub transmission is in high speed.

The final deceleration ratio of the engine and PTO axle was 0.233 when the PTO transmission was in low speed and 0.361 when the PTO transmission was in high speed. Therefore, the theoretical rotation speed of the PTO axis was calculated to be 838 rpm when the PTO transmission is in low speed and 1,300 rpm when the PTO transmission is in high speed. In addition, the final deceleration ratio of the wheels and the speed-proportional PTO axis was 0.0785 when the sub transmission was in low speed, and 0.147 when the sub transmission was in high speed. Considering that the wheel's final deceleration ratios at these times were 0.016 and 0.030, respectively, the speed-proportional PTO's rotation speed was calculated as approximately 4.9 turns for every wheel rotation without regard to the sub transmission stage.

The traveling unit's front wheel is driven to increase its traction, and it is equipped with a front wheel quick-turn unit to perform steering functions and simultaneously reduce the turning radius such that rapid turning is possible.

Figure 3 shows the front wheel's cross section and exterior. The front wheel drive axle is driven by two bevel gears and a chain drive units.

Figure 4 shows the front wheel's steering mechanism. The steering wheel gear attached to the front wheel's axle rotates above the rack gear via a hydraulic cylinder with a stroke of 95 mm to perform steering, and the maximum steering angle was set at 80° for the left and right.

Figure 5 shows the front wheel quick-turn apparatus

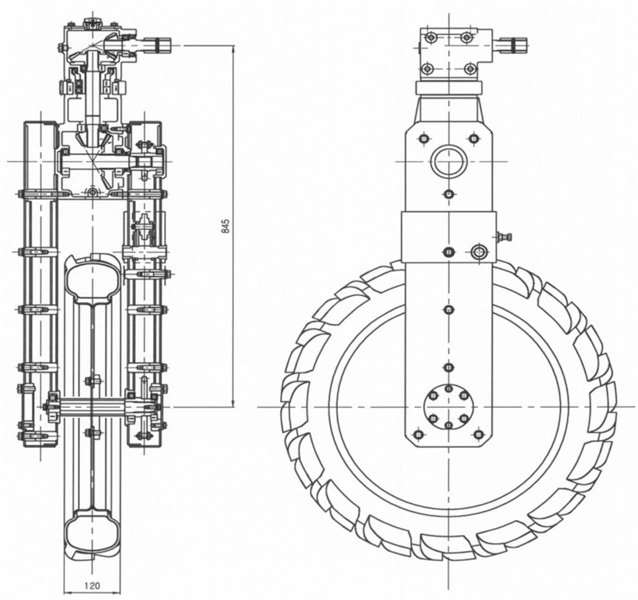


Figure 3. Front wheel driving mechanism.

and its mechanism allows for the automatic change in its chain gearing sprocket combination if the steering angle is more than 25°, to increase the front wheel's rotation speed by a factor of two and reduce the turning radius. As shown in the figure, the diamond-shaped link is rotated by the link connected to the steering mechanism, wire cable, and spring. This moves the transmission fork and clutch that are connected to it, and selects a combination of front wheel chain drive sprockets to drive the front wheel quick-turn.

Figure 6 shows the structural diagrams of the rear wheel power transfer and wheel tread adjustment units. As shown in the figure, the rear wheel's driving power is transferred through the sub transmission gear axle, bevel and ring gear, differential unit, and final deceleration

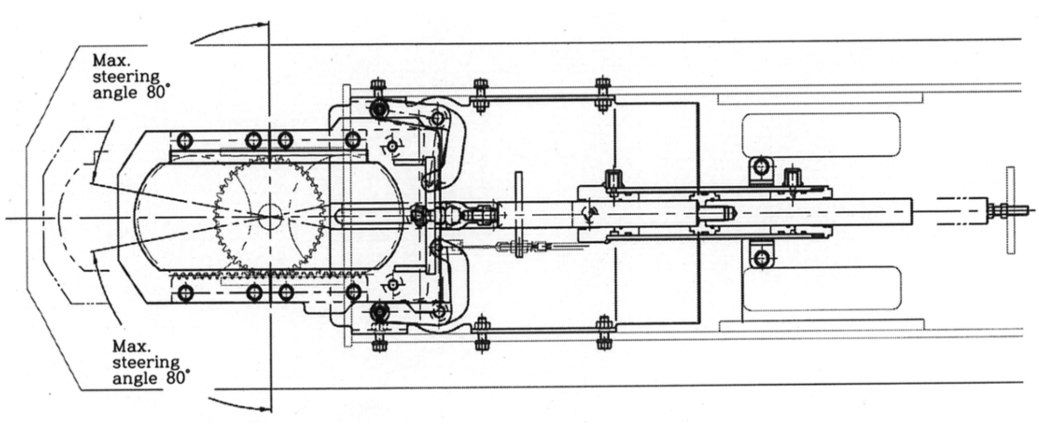
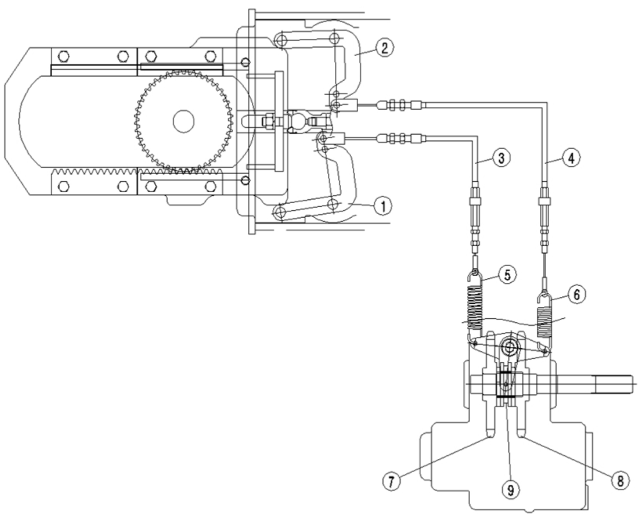


Figure 4. Front wheel steering mechanism.



①②: Links connected with steering unit, ③④: Steel wires, ⑤⑥: Springs ⑦⑧: Chain sprockets, ⑨: Clutch for selecting sprocket

Figure 5. Mechanism for increasing steering speed of front wheel.

chain drive unit to the rear wheel driving axle. The rear wheel tread is adjusted by having the rear wheel and final deceleration chain drive unit slide on the driving axle and rear wheel tread adjustment axle via the left and right hydraulic cylinders. Further, the hydraulic cylinder was set with a stroke of approximately 200 mm such that the rear wheel width's adjustment range is from a minimum of 1,320 mm to a maximum of 1,720.

The three-wheel riding cultivator prototype's hydraulic unit is composed of the HST for the primary transmission shift, the hydraulic part for controlling the position of the implements by lifting the implement attachment unit's parallel link, the hydraulic part for adjusting the rear wheel tread, the hydraulic part for front wheel steering, and two hydraulic pumps for supplying hydraulic power, in addition to the hydraulic pipes, filters, tank, etc., as shown in Figure 7. A hydraulic diffuser is installed in one location for hydraulically driving the external implements. At the engine's maximum rotation speed of 3,600 rpm, the HST hydraulic pump, implement lifting, rear wheel tread adjustment hydraulic pump, and the steering hydraulic pump are driven at a maximum rotation speed of approximately 2,200 rpm. The HST is a model that provides a theoretical flow per minute of approximately 47.3 liters, a maximum pressure of 23 MPa, and a total efficiency of approximately 80% at a maximum rotation speed of 2,200 rpm, considering that the engine output is approximately 15 kW. The implement lifting and fixing is determined by the operation state of the direction control valve solenoid, as shown in the figure. The prototype is equipped with a flow control value to adjust the implement lifting and wheel width adjustment speed. Steering is accomplished through the action of a steering cylinder that is proportional to the rotation of the steering wheel, and uses a proportional control directional valve and a bidirectional hydraulic motor.

As shown in Figure 8, the implement attachment unit

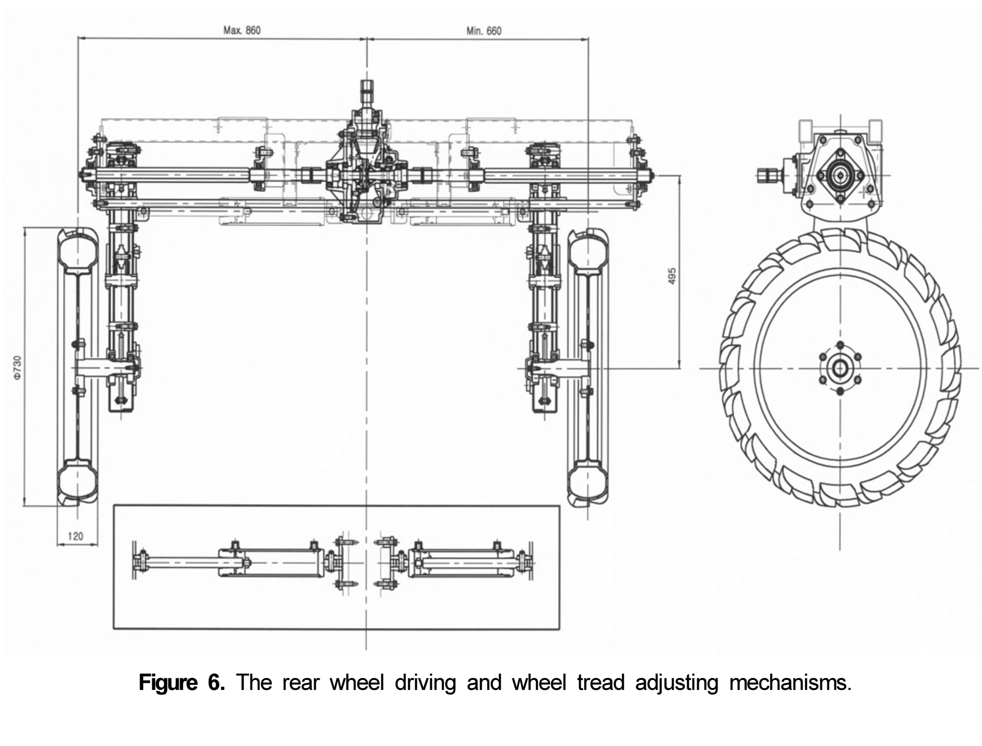


Figure 6. The rear wheel driving and wheel tread adjusting mechanisms.

uses a parallel link style and consists of the hydraulic cylinder for implement lifting, vertical parallel link, implement attachment link. The length of the hydraulic cylinder for implement lifting can be adjusted to within 290–435 mm. In such a case, the implement lifting range is approximately 391 mm, and the hitch point's forward and backward displacements are approximately 50.4 mm. In the implement attachment unit, an implement attachment link installed at the end of the parallel link, and the link is attached to an implement. The implements are easily attached and detached by simply fastening or removing the bolts, respectively, on the left and right sides.

The overall exterior of the three-wheel riding cultivator prototype is shown in Figure 9. As shown in the figure, the prototype was designed and built with overall length ´ width ´ height dimensions of 3,280 mm ´ 1,840 mm ´ 1,525 mm when the rear wheel is set to the maximum tread,

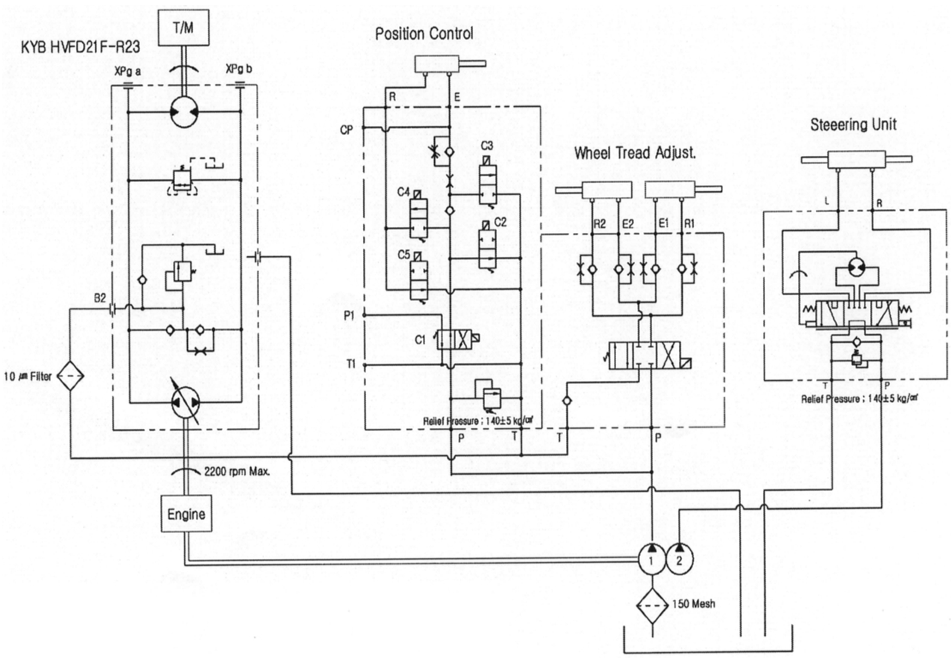


Figure 7. Hydraulic circuit for the prototype.

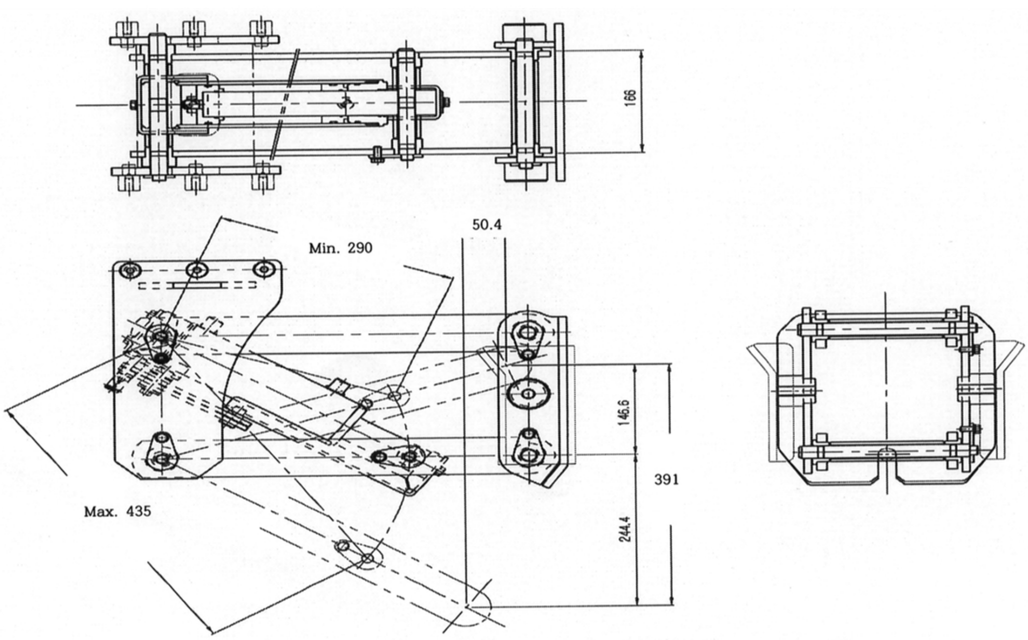


Figure 8. Implements attaching mechanism.

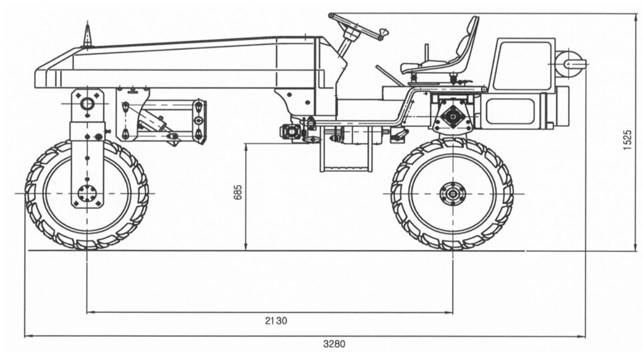


Figure 9. Prototype three-wheel riding cultivator.

excluding any cabin or safety frame.

Primary Specifications of Prototype

Table 1 shows the primary specifications of the three-wheel riding cultivator prototype that was designed and built.

For the prototype's transmission, an all-in-one hydraulic pump and hydraulic motor HST is used as the primary transmission shift, and a low- and high-speed two-stage gear transmission is used as the speed range shift. It was designed to exhibit a forward speed of 0–14.5 km/h and a backward speed of 0–7.5 km/h. These are the maximum traveling speeds that are faster than the Japanese Yanmar three-wheel riding cultivator that is currently in the market and has an HST primary transmission and a one-stage gear-style speed range transmission shifts which exhibit a forward speed of 0–10.2 km/h and a backward speed of 0–4.8 km/h. When compared to the South Korean four-wheel riding cultivators with three- to four-stage constant mesh transmissions and synchromesh gear style transmissions which exhibit forward speeds of 0–14.3 km/h (Dongyang Moosan Co. Ltd., Korea, K1-C), 0-13.8 km/h (Dongyang Moosan Co. Ltd., Korea, K1-HC), 0-13.8 km/h (Kukje Machinery Co. Ltd., Korea, KM-2000), 0-11.5 km/h (Asia Technology Co. Ltd., Korea, CFM-1200), 0-12.6 km/h (Asia Technology Co. Ltd., Korea, CFM-1200H), and 0-11.8 km/h (Asia Technology Co. Ltd., Korea, CFM-1200N), the prototype is almost the same or faster. As such, it can be used for a variety of upland crop cultivation tasks (Yanmar, 2017; FACT, 2018).

In South Korea, cultivation practices vary according to the upland crop and the region; as such, this is a signifi-

Table 1. Specifications of the prototype three-wheel riding cultivator

	Item	Unit	Specifications
Engine	Manufacturer/Model	-	Honda/GX630
	Type	-	Water cooled, four-stroke, gasoline
	Displacement	cc	688
	Maximum power/speed	kW/rpm	15.5/3600
Transmission	Primary shift	-	HST (assembled hydraulic pump and motor)
	Speed range shift	-	Selective gear type : high, low 2 stages
	Theoretical travel speed	km/h	Forward:0–14.5 (high), 0–7.5 (low) Rearward:0–7.5 (high), 0–4.0 (low)
Travel device	Type	-	three-wheel driving
	Tire dimension	-	4.50–19 (outer dia. 720 mm)
	Front wheel drive	-	Gear and chain drive
	Rear wheel tread	mm	1,320–1,720 (continuously variable)
	Front and rear wheel distance	mm	2,130
Steering device	Type	-	Power steering (hydraulic cylinder + wheel and rack gears)
	Quick turn	-	Front wheel speed up
	Minimum radius of turning	m	2.8
PTO	Number of shafts	each	2 (mid and rear)
	Clutch type	-	Tension belt type
	Speed stage	-	2 (high and low)
	Speed	rpm	1,300 (high), 838 (low)
	Ground PTO	-	4.9 rev./1rev. of wheel
Implement hitch	Attaching type	-	Parallel link type
	Implement control	-	Position control
	External hydraulic takeoff	each	1
Dimension	Length x width x height	mm	3,280 ´ 1,840 ´ 1,525 (without cabin)
	Weight	kN	8.75
	Minimum ground height	mm	670

cant impediment to efficient agricultural mechanization. Rear wheel tread adjustment is necessary to adapt to various cultivation practices, and the prototype can perform the continuously variable adjustment of the rear wheel tread from 1,320 to 1720 mm through the hydraulic cylinders. This improves the adaptability and convenience significantly compared to the adjustment methods of the existing riding cultivators that adjust the wheel tread by varying the position of the wheels that are attached to the axle holes.

The prototype's steering equipment consists of the hydraulic cylinder, steering wheel, and rack gear. To reduce the turning radius, it is equipped with a front wheel attachment unit that turns more quickly and smoothly than the side clutch methods of the existing cultivators. The prototype's minimum turning radius was 2.8 m.

The PTOs for driving the implements are installed at two places in the mid-section and rear section to drive a variety of implements, and the transmission operates at two stages: low and high. Speed proportional PTOs are installed to perform tasks that are proportional to the travelling speed such as sowing, etc. The PTO clutch is a tension belt clutch.

The implement attachment unit is of the parallel link style. It attaches major implements to the riding cultivator's midsection, and controls the position of the implements through the hydraulic cylinders. An external hydraulic diffuser is installed at one location to hydraulically drive the implements.

When considering the prototype's overall size when a cabin or safety frame is installed, its width and height are similar to the Yanmar three-wheel riding cultivator, but the prototype's length is relatively larger. The weight of the prototype is 8.75 kN, and its lowest ground clearance is approximately 670 mm, which is heavier than the 6.40 kN weight of the Yanmar three-wheel riding cultivator and slightly higher than the 600 mm ground clearance of the Yanmar (Yanmar, 2017). The lowest ground clearances of the four-wheel riding cultivators that are currently being sold in the South Korean market are approximately 490–530 mm, and their weights are within 6.42–9.59 kN (FACT, 2018). In terms of the lowest ground clearance, the prototype is the best for upland crop cultivation tasks.

Overall, the prototype was designed and built with better specifications than the Japanese Yanmar three-wheel riding cultivator to handle South Korea's various upland crops and the cultivation practices that result from them. Japan is performing significant efforts to reduce production costs by designing a lightweight body; further, the prototype's body must be made lightweight. It is believed that it will be necessary to simplify the structure through the field performance testing of the power transfer unit, steering unit, and PTO equipment to design and build the prototype to the optimal specifications.

Basic Performance of Prototype

Table 2 shows the average travel speed of the three-wheel riding cultivator prototype in each transmission stage at the engine's rated rotation speed. The maximum average travel speed when the primary transmission was in the high-speed stage during forward travel was 7.31 km/h when the speed range transmission shift was at low speed, and 11.27 km/h when the speed range transmission shift was at high speed. During backward travel, it was 3.60 km/h when the speed range transmission shift was at low speed, and 6.37 km/h when the speed range transmission shift was at high-speed. Its ability to travel

Table 2. Average travel speed of the prototype three-wheel riding cultivator by the stage of transmission

Travel direction	Stage of Speed range transmission shift	Stage of primary transmission shift	Average travel speed (km/h)
Forward	Low	Low	2.63 (0.04) [z]
		Middle	4.57 (0.04)
		High	7.31 (0.25)
	High	Low	4.25 (0.14)
		Middle	7.16 (0.11)
		High	11.27 (0.22)
Rearward	Low	High	3.60 (0.04)
	High	High	6.37 (0.14)

[z]Value in parenthesis means standard deviation.

in a straight direction was good. The theoretical-designed maximum travel speed during forward travel is 7.8 km/h when the speed range transmission shift is at low speed and 14.5 km/h when it is at high speed. During backward travel, it is 4.0 km/h when the speed range transmission shift is at low speed, and 7.5 km/h when it is at high speed. Compared to this, the actual travel speed was slightly reduced. The difference becomes larger when the transmission stage is at a higher speed. It is believed that this is because of changes in volume efficiency owing to friction in the HST primary transmission, and speed reductions owing to the slip in the drive wheels.

The minimum turning radius during the left and right turns was approximately 3.45 m when the forward wheel quick-turn unit was not used and approximately 2.80 m when it was used. Rear wheel tread adjustment for adapting to upland crop cultivation practices could be performed continuously via hydraulic cylinders from 1,320 to 1,720 mm, similar to the range in the target design. At the engine's rated rotation speed, the midsection PTO axle's rotation speed was approximately 795 at stage 1, and approximately 1,140 rpm at stage 2. This was reduced from the design rotation speeds for stages 1 and 2 of 838 and 1,300 rpm, respectively, and this appears to be due to the volume efficiency changes caused by friction in the HST. In the results of the tests on the implement lifting unit, the maximum lifting height was approximately 390 mm, and it performed without any malfunctions in tests lifting attached implements such as a cultivating and weeding implement weighing approximately 2.16 kN.

Table 3 shows the distribution of weight on the front and rear wheels according to the three-wheel riding cultivator prototype's front wheel height. The body's overall weight is approximately 8.75 kN; on a flat surface, this was distributed 25.3% to the front wheel and 74.7% to the back wheel. However, as the front-rear gradient was increased, the front wheel weight decreased and the rear wheel weight increased slightly such that the rear wheel's weight distribution ratio increased. Therefore, as the front-rear gradient increases, the risk of rearward overturning increases.

Table 4 shows the results of measuring the static lateral overturning angle according to changes in the rear wheel tread. As shown in the table, when the rear wheel tread was adjusted from 1,320 mm to 1,720 mm, the left lateral overturning angle increased from 33.4° to 39.1°, and the right lateral overturning angle increased from 29.0° to 36.1°. The lateral overturning angles increased as the rear width increased, thus implying that increasing the rear wheel width increases the safety on a sloped land. A slight difference was shown between the left and right lateral overturning angles, and this is believed to be due to the difference in the prototype's left and right weight distribution. The left and right lateral overturning angles of four-wheel riding cultivators being sold in the South Korean market currently are between 39.9° and 46.0° (FACT, 2018). Compared to this, the prototype's safety in regards to lateral overturning is slightly worse owing to the difference in its structure.

Table 3. Split of weight on front and rear wheels by the under-propped height of front wheel

Height of front wheel (cm)	Distribution of mass (kg)	
	Front wheel	Rear wheels
0	226.0	666.0
5	218.5	673.5
10	212.0	680.0
15	203.3	688.7
20	198.3	693.7
25	192.3	699.7

Table 4. Static lateral overturning angle by the tread of rear wheel

Tread of rear wheels (mm)	Static lateral overturning angle (°)	
	Left	Right
1320	31.4	29.0
1420	34.1	30.9
1520	36.6	33.4
1620	37.4	34.4
1720	39.1	36.1

Conclusions

In this study, a three-wheel riding cultivator prototype was designed and built to increase the riding mechanization in upland crop cultivation tasks such that the overall task process was mechanized systematically. The prototype could achieve improvements in driving performance, ground clearance, wheel tread adjustment, and steering performance. By attaching implements to its mid-section, it provided improvements in task precision, convenience, and ease of observation. It is believed that this prototype could be used to benefit South Korea's various upland crop cultivation practices.

Conflict of Interest

The authors have no conflicting financial or other interests.

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