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REVIEW
Development of a Following Type Vegetable Carrier

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Abstract
The purpose of this study was to decrease the labor demands of vegetable harvesting by automatically controlling the vegetable carrier. We developed a prototype of a carrier that had a simple mechanism, but possessed enough functions to follow a vegetable harvester smoothly. The following system automatically controlled starting, acceleration, deceleration, and steering. It was able to follow a cabbage harvester up to a running speed of 0.4 m/s in a performance test on asphalt. It could follow a Welsh onion harvester at 0.02 to 0.04 m/s while providing an effective field capacity of 0.4 to 0.6 a/person·h. The effective field capacity was equal to that of conventional work, but with 20% fewer working hours (e.g., transferring and taking the harvest out). Additionally, the worker did not need to lift the harvest, and could transfer it by moving sidewise because this carrier was able to follow the Welsh onion harvester closely. Compared to a normal carrier without a following system, this carrier reduced the number of times and the distance the workers moved in the field.

Discipline: Agricultural machinery
Additional key words: following system, control, harvest work, harvester, work efficiency

Introduction

Recently, the total area of planted vegetable fields in Japan has been decreasing, due mainly to the aging of farmers and the shortage of workers. Laborsaving mechanization is needed because the harvesting of vegetables is extremely hard work. The mechanization of various aspects of vegetable production has been advanced in manufacturers' and research laboratories[5], and harvesters of vegetables such as the Welsh onion have been developed.[7] Machines have been introduced at various sites, making harvest work more efficient than ever before. However, in order to adapt to small Japanese fields, harvesters must be small, thus limiting the amount of harvest that can be loaded on the loading platform. Since using only a harvester does not save much labor, farmers use harvesters in combination with carriers in the field. However, the farmer must transport the carrier to the harvester, increasing the farmer's moving distance in the field and making harvest work even more complex. Moreover, labor is sometimes increased because an additional worker must operate the carrier that accompanies the harvester.

Additional laborsaving technological development is crucial for vegetable harvesting in the field. Thus far, developments include a conveyer carrier harvester[6] to harvest cabbages and radishes out of the field, and the technology[3, 2] uses a trailer accompanying a cabbage harvester to save labor. However, using these large machines in small fields is difficult, and they have been introduced in only limited areas. Moreover, research has been conducted on the technology of picking up containers using autonomous vehicles[8], but has yet to reach a stage where

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it can be practically implemented. In the past, studies on an automatic follow-up vehicle system[4] using ultrasonic sensors and a straight follower system[1] based on a laser scanner have been conducted. However, these controls with advanced sensors and computers are not a realistic option for a system installed in a carrier for agriculture.

Therefore, we developed a carrier that transports the harvest by automatically following the harvester in an attempt to decrease labor demands in vegetable harvesting. This paper presents an outline of the developed following type vegetable carrier and discusses its performance and laborsaving impact.

Materials and methods

1. Outline of the carrier

(1) Composition of the following system

We developed a vegetable carrier that can smoothly follow a vegetable harvester (Fig. 1). Installed in the carrier is a system composed of a coordinating part, a detecting part, and a control part (Table 1 and Fig. 2). The coordinating part connects the harvester and the carrier by such as a rope, and synchronizes the carrier with the harvester's movements. At the edge of the coordinating part, a safety device is installed. When more than the prescribed tension is added to this part, the harvester and the carrier are disconnected, and the carrier stops. Through the coordinating part, the detecting part senses the starting, stopping, acceleration, deceleration, and steering of the harvester. This part is chiefly composed of a driving command material that transmits the movement of the coordinating part, two limit switches that detect its direction, and a link system (Fig. 3). The link system is chiefly composed of a swing synchronization device that operates simultaneously with the driving command material and limit switch that detects forward movement. The coordinating part is installed at the end of the driving command device. They move together, and their movement is transmitted. The driving command device moves in the traveling direction in response to the tension applied to the coordinating part, and oscillates to the right and left in response to the direction of the coordinating part. In addition, when no tension is applied to the coordinating part, springs keep the driving command device in neutral

Fig. 1. Following type vegetable carrier

Table 1. Main specifications

Type		Following type vegetable carrier
Length×Width×Height, Weight		245×115×135cm, 410kg
Loading platform Length×Width, Max. load		161×104cm, 500kg
Running section		Crawler type (Center distance: 78cm)
Max. engine power		4.4kW
Speed	Steps	Forward: 3 / Back: 2
	Max.	0.9m/s
Max. following speed (Steps)		0.4m/s (2nd)
Following system	Coordinating part	Clip-shaped safety device (Releasable coordinating at a prescribed tension)
	Detecting part	Limit switch, Link system
	Control part	Starting, acceleration & deceleration, steering
Remarks		Low-floor (Min. ground clearance: 15cm)
		Emergency stop switch (In two positions)

position. In the control part, a running clutch and a directional clutch are operated in response to the limit switch signals, using DC motors. This part is chiefly composed of relays, DC motors, and rods that connect the clutch levers and the motors. The relays, motors, and limit switches are electrically wired, and the motors are controlled in response to the limit switch signals by using relays. When the limit switch turns on, the output axis of the motor is rotated 180 degrees, and the clutch is engaged. When the limit switch turns off, the output axis of the motor rotates 180 degrees further, maintains its former position, and the clutch is disengaged.

(2) Operation principle

The following system controls the carrier's starting, stopping, acceleration, deceleration, and steering. The tension in the traveling direction joins the coordinating part of the following system connected with the harvester when the harvester advances. The coordinating part

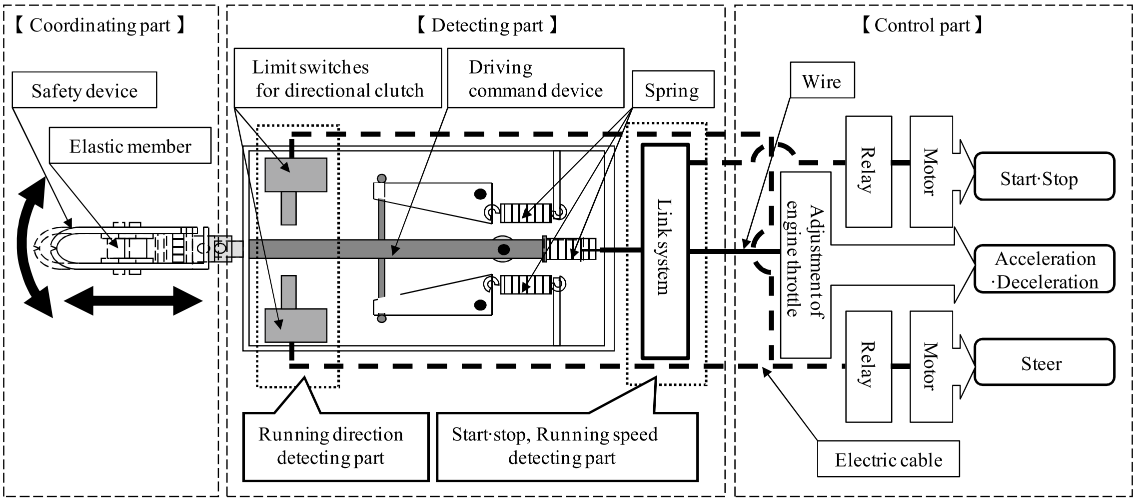

Fig. 2. Outline of following system

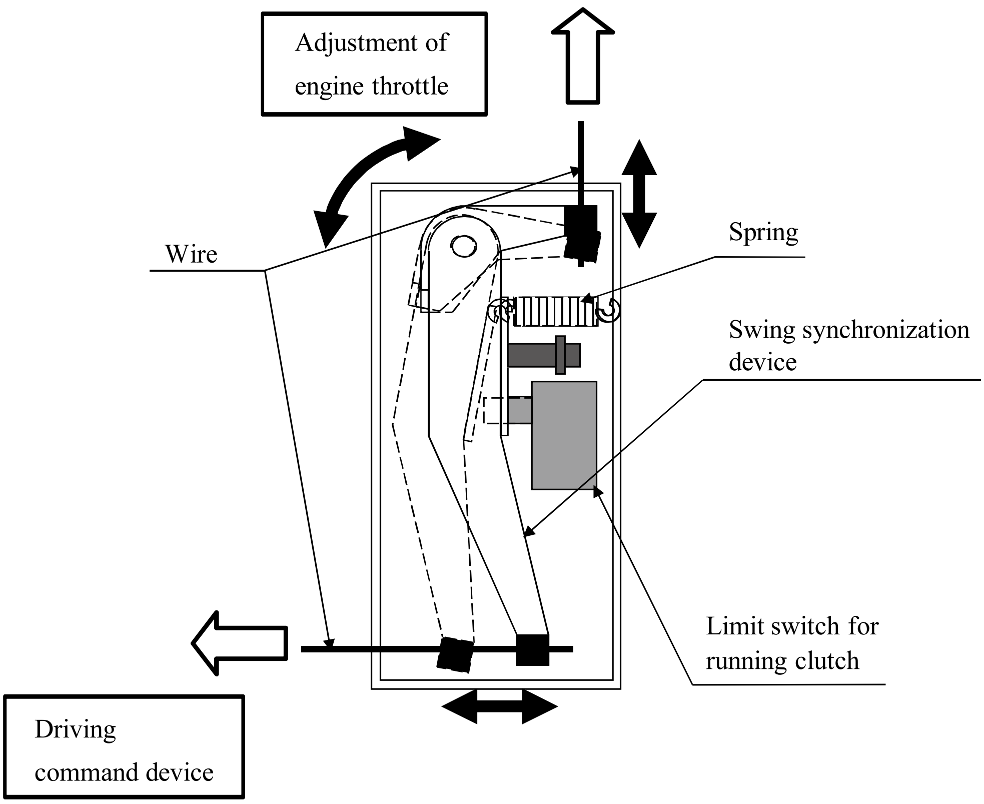

Fig. 3. Outline of link system

moves in the traveling direction, together with the driving command device of the detecting part, pulling a wire installed on the edge of the driving command device. The wire is connected with a link system to adjust the engine throttle, and the movement of the driving command device is transmitted to a swing synchronization device in the link system. When the swing synchronization device moves, the limit switch for the running clutch detects the movement, the motor begins operating, and the running clutch is engaged. As a result, power is transmitted to the traveling part, and the carrier starts. Moreover, when no tension joins the coordinating part and the swing synchronization device does not move in conjunction with the stopping of a harvester, the running clutch is disengaged, and the power transmission to the traveling part stops. Movement in the traveling direction of the coordinating part is transmitted from the detecting part to the engine throttle via a wire through a link system. The moving distance of the coordinating part is adjusted within an appropriate range for the engine throttle adjustment in the link system. As a result, the traveling speed is adjusted in proportion to the moving distance of the coordinating part, and the carrier is accelerated or decelerated. The driving command device of the detecting part can swing to the right and left. The coordinating angle of the coordinating part changes if changes take place in the direction where the harvester and the carrier coordinate. When one of the limit switches for a directional clutch detects a change of coordinating angle, the motor operates, the directional clutch in the corresponding direction is operated, and a crawler travel device is steered. Because the following system has a simple mechanism using limit switches and DC motors, it can be produced cheaply. Moreover, it is also easy to lay out the detecting part freely by wiring for electricity and to install it in two or more places because operation is detected with limit switches.

2. Performance Experiments

(1) Following performance tests

First, the carrier was made to follow a vegetable carrier in order to determine its following performance. The running speed of the vegetable carrier was set to 0.09, 0.17, and 0.21 m/s, and the following speed of the carrier was investigated. This experiment was conducted on an asphalt road with a maximum load of 500 kg in the carrier. At the beginning of the experiment, the engine speed of the carrier was set to 900 rpm in first gear. A rotary encoder with a roller was installed on the side of the carrier and was grounded using a vice. It was used to measure rotational speed. Data were recorded using a data recorder, and the running speed was calculated from the collected data (Fig. 4).

Next, the carrier was made to follow a cabbage harvester in order to determine its following performance. The running speed of the harvester was gradually increased from the halt condition, and the following speed of the carrier was investigated. This experiment was conducted on an asphalt road with 500 kg in the carrier, as in the above-mentioned experiment. At the beginning of the experiment, the engine speed of the carrier was set to 900 rpm in second gear. As with the previous experiment, the rotational speed was measured with rotary encoders installed on the cabbage harvester and the carrier, and the running speed was calculated from the collected data.

(2) Field tests

We conducted a field performance trial using a Welsh onion harvester and the carrier in combination (Fig. 5). A worker bound the harvest dug up by harvester and loaded it on the loading platform of the carrier. When the loading platform reached capacity, a worker took out the harvest from the field by the carrier and transfers the harvest to the truck. First, the trial was conducted by one to two workers in a field with a ridge length of 50 to 61 m and a ridge width of 0.83 to 0.95 m. The running speed of the harvester was set to 0.02 to 0.04 m/s. This trial was

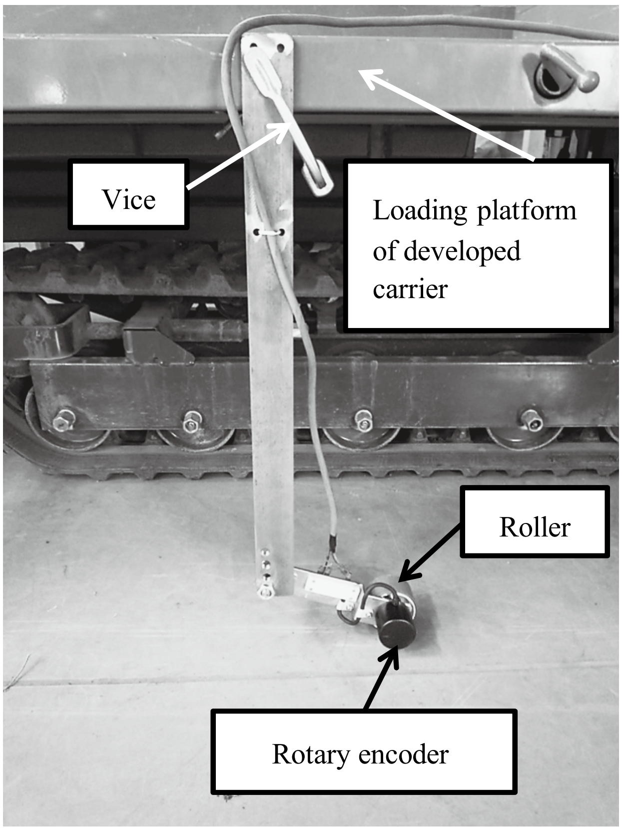

Fig. 4. Measurement device

conducted in a field in Ibaragi and Saitama prefectures. An attachment device was set up under the harvester's loading platform to connect the coordinating part of the carrier with the harvester (Fig. 6). We also conducted a trial comparing field performance using the carrier with that of conventional work. For the conventional work, a commercialized carrier that did not have the following system was used in combination with a harvester. A worker transferred the carrier close to the harvester, and then transferred the harvest from the harvester to the carrier when the loading platform of the harvester reached capacity. This trial was conducted in a field in Gunma Prefecture. The ridge length was 54 m, and the ridge width was 0.81 m. One person did the work.

Next, we measured the number of times the workers transferred the harvest, the number of times the workers moved, and the distance the workers moved in order to compare the field performance using the carrier with that of conventional work using a commercialized carrier that did not have the following system. This trial was conducted in a field in Ibaragi Prefecture. The ridge length was 57 m, the ridge width was 0.9 m, and two persons did the work. The running speed of the harvester was set to 0.04 m/s. The harvester and the carrier were connected as described above.

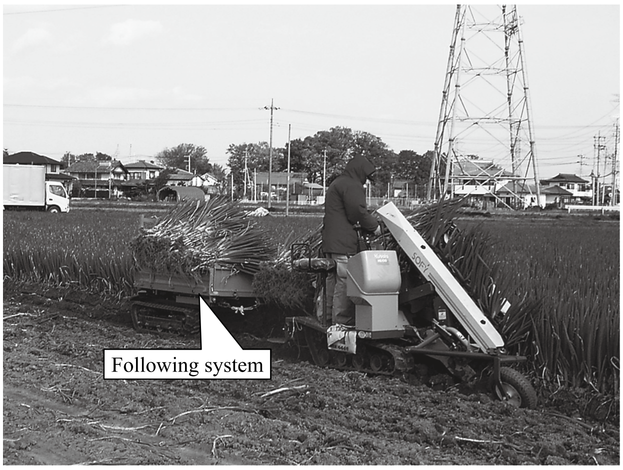

Fig. 5. Welsh onion harvest test

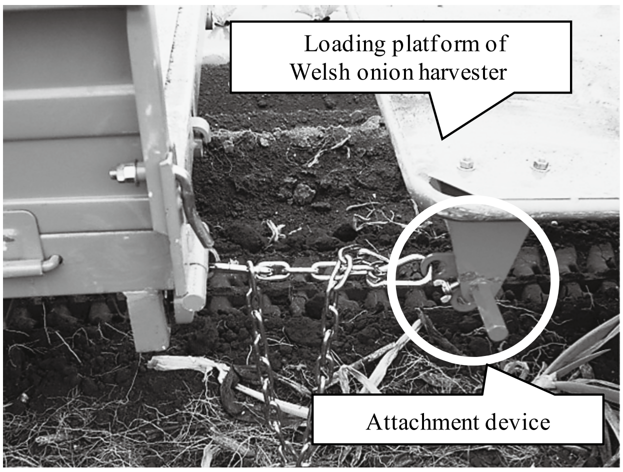

Fig. 6. Example of connection

Results and discussion

1. Basic performance of the following carrier

The speed change of the carrier following the vegetable carrier is indicated in Fig. 7. Three seconds after it started running, the carrier ran steadily at ±0.03 m/s or less of the speed of the vegetable carrier. The coefficient of variation of the running speed of the carrier in stable footing (for 3 to 50 seconds after it started running) was 9% at the vegetable carrier's running speed of 0.09 m/s, 3% at the carrier's running speed of 0.17 m/s, and 2% at the carrier's running speed of 0.21 m/s. Thus, lower running speeds tended to produce larger coefficients of variation (Table 2). It is thought that the running clutch engaged and disengaged frequently because the lowest running speed of the carrier was faster than that of the vegetable carrier at lower speed.

The running speed change of the carrier following the cabbage harvester is indicated in Fig. 8. The carrier was able to follow up to about 0.4 m/s according to the running speed of the cabbage harvester, though some speed increases and decreases were observed at starting. Moreover, the carrier followed the cabbage harvester at an average of 0.4 m/s with the cabbage harvester running at almost constant speed, and the coefficient of variation at that speed was 1% (Table 3). Thus, the carrier controlled its running speed according to changes in speed and steadily followed the harvester.

2. Field performance

The effective field capacity was 0.4 to 0.6 a/person·h, and the work efficiency was 55 to 75% using a Welsh onion harvester and the carrier in combination (Table 4). The carrier smoothly followed the Welsh onion harvester in the field, as well as in the experiment described above. Moreover, the carrier's effective field capacity was equal to that of conventional work, but required 20% fewer working hours (e.g., transferring and taking out the harvest). Use of the carrier decreased labor intensity (Table 5), with a decrease in the number of times workers moved and the distance the workers moved, thus improving harvest work (Table 6). The worker could transfer the harvest by moving it sidewise from the harvester to the carrier, rather than lifting it because the carrier closely followed the harvester. Moreover, the number of times

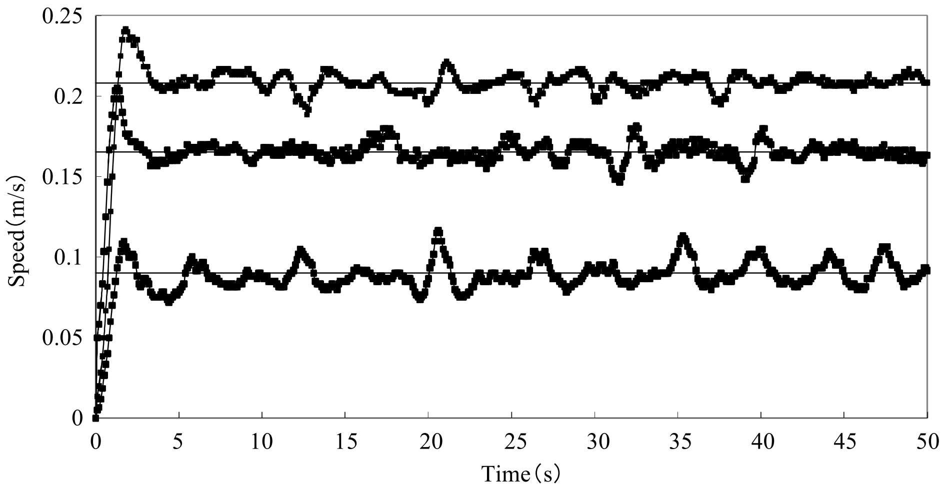

Fig. 7. Speed change (following vegetable carrier)
——— : Setup speed of vegetable carrier
—■— : Developed carrier

Table 2. Following performance (following vegetable carrier)

Vegetable carrier	Developed carrier				
Setup speed (m/s)	Running speed (m/s)			S.D. (m/s)	C.V. (%)
	Ave.	Max.	Min.		
0.09	0.09	0.12	0.07	0.008	9
0.17	0.17	0.18	0.15	0.005	3
0.21	0.21	0.22	0.19	0.005	2

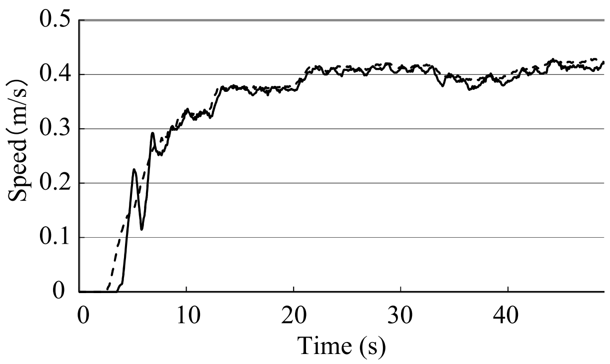

Fig. 8. Speed change (following cabbage harvester)
------ : Cabbage harvester
——— : Developed carrier

Table 3. Following performance (following cabbage harvester)

	Running speed (m/s)			S.D. (m/s)	C.V. (%)
	Ave.	Max.	Min.		
Cabbage harvester	0.41	0.42	0.40	0.004	1
Developed carrier	0.41	0.42	0.39	0.005	1

Table 4. Results of Welsh onion harvest test (field performance)

Experiment plot		I*	II**	III**
Experiment condition	Ridge length (m)	57	50	61
	Ridge width (m)	0.90	0.83	0.95
	Number of workers	2	1	1
	Harvester speed (m/s)	0.04	0.03	0.02
Effective field capacity (a/person•h)		0.4	0.6	0.6
Work efficiency (%)		55	60	75

* : In Ibaraki prefecture.
** : In Saitama prefecture.

workers moved in the field decreased by 70%, and the distance the workers moved decreased by 30%, compared with those using a carrier that did not have the following system. The workers who used the carrier did not have to move the carrier near the harvester, whereas those using a conventional carrier had to move the carrier near the harvester.

Conclusion

The findings of the experiments obtained for the

Table 5. Results of Welsh onion harvest test (comparison of field performance)

			Developed carrier	Conventional work
Experiment conditions	Ridge length (m)		54	
	Ridge width (m)		0.81	
	Number of Workers		1	
	Work speed of harvester (m/s)		0.05	0.06
Work time (h/10a)		Harvesting	7.0	5.7
		Transferring, Taking out	6.0	7.5
Effective field capacity (a/person•h)			0.8	0.8
Work efficiency (%)			54	43

Table 6. Results of Welsh onion harvest test (number of work processes)

Number of work processes (times)		Developed carrier***	Conventional work
Transferring	Moving sidewise*	17.5	10
	Lifting**	0	10
Moving (Distance [m])		5 (169)	15 (247)

* : "Moving sidewise" is a transferring work by moving sidewise.
** : "Lifting" is a transferring work by lifting.
*** : Processes of developed carrier is an average of two repetitions.

carrier that was developed to transport the harvest by automatically following a vegetable harvester are as follows:

1) The following mechanism of the carrier is simple, and is functional enough to follow the harvester smoothly.
2) The carrier could follow the cabbage harvester up to a running speed of 0.4 m/s on asphalt.
3) The carrier could follow the Welsh onion harvester at a speed of 0.02 to 0.04 m/s, with an effective field capacity of 0.4 to 0.6 a/person·h and work efficiency of 55 to 75% in the field.
4) In comparison with conventional work, the carrier had equally effective field capacity, but required 20% fewer working hours (e.g., transferring and taking out the harvest), thus decreasing labor intensity.
5) The worker who used the carrier did not need to lift the harvest and could transfer it by moving it sidewise because the carrier closely followed the Welsh onion harvester.
6) Compared with a normal carrier without a following system, the carrier decreased the number of times workers moved in the field by 70% and the distance they moved by 30%.

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