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S-shaped Multipurpose Monorail for Hillside Orchards

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Abstract

The Bio-oriented Technology Research Advancement Institution (BRAIN) developed a multipurpose monorail system for hillside orchards, with the cooperation of several manufacturers, as part of the project called "Urgent Development of Agricultural Machinery" promoted by the Ministry of Agriculture, Forestry and Fisheries of Japan. This monorail saves an enormous amount of energy and labor for various tasks in hillside orchards with slopes of up to 30º, such as transporting harvest, spraying agricultural chemicals, spreading fertilizer, weed control, and processing of pruned branches. The system consists of two independent monorails: the main monorail, which runs uphill along the edge of the orchard, and the sub-monorail, which runs between every two or three rows of trees all around the orchard along the contour lines in an "S" shape. The main monorail is used for carrying goods in and out of the orchard by conveying them to and collecting them from the sub-monorail. The sub-monorail can be connected to various devices such as freight cars, an air blast sprayer, a fertilizer spreader, an herbicide sprayer, and a branch shredder. The monorail's effectiveness for reducing labor was proved in a year of testing and evaluation at two citrus orchards.

Discipline: Agricultural engineering
Additional key words: citrus production, unmanned sprayer

Introduction

The annual production of mandarin oranges in Japan is about 1.15 million tons, and accounts for 30% of total domestic fruit production[6], making the mandarin one of the most important fruit crops in Japan. However, the quantity of production is decreasing because of a chronic labor shortage, which is caused by the aging of the workforce and insufficient replacements. The difficult working environment in steeply sloping orchards is considered to be the main reason for the lack of replacements[7].

Despite the difficult working environment, the major production areas are concentrated in the steep hillsides of the warm, southwestern districts of Japan, because these areas offer good conditions for producing high-quality fruits with high sugar content and good color. Forty-two percent of the mandarin-growing area in Japan covers steep areas where the slope is 15º or more[7]. In Ehime Prefecture, one of the major growing areas, 67% of mandarin orchards lie in steep areas where the slope is 15º or more[7].

Monorails are used in such steep orchards to facilitate conveyance up and down slopes, where infrastructure improvement such as slope modification and road construction is difficult[8]. However, work along the contour lines is still unimproved. Some projects have tried to introduce advanced systems to sloping orchards, but some of them need changes to growing methods, and others do not offer transportability as good as that provided by a monorail[1–5].

We at the Bio-oriented Technology Research Advancement Institution (BRAIN) have developed an S-shaped multipurpose monorail for hillside orchards, with the cooperation of several manufacturers. The work was conducted from 1998 to 2001, partly within the project called "Urgent Development of Agricultural Machinery" promoted by the Ministry of Agriculture, Forestry and Fisheries of Japan. Here we describe the system and report the results of a year's testing and evaluation at two citrus orchards in Ehime Prefecture.

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Specifications and function

The specifications are shown in Table 1, and a diagram is shown in Fig. 1. The main rail is constructed along the edge of the orchard running uphill. The main monorail system consists of a commercial tractor, a riding cart, and a freight car that can carry up to 200 kg. For spraying agricultural chemicals, the tractor hauls a tank car instead of a freight car.

The rail of the sub-monorail system is laid in an S shape in and out of the fruit tree rows. The straight part of the rail is almost horizontal along the contour line, but the curved part slopes. The tractor of the sub-monorail system can haul an air blast sprayer, a fertilizer spreader, or a freight car, which can also carry up to 200 kg. Two small freight cars with a carrying capacity of 100 kg each are available for some operations. The tractor can alternatively haul a commercial shredder for processing pruned branches or an herbicide distributor for weed control. The air blast sprayer (Fig. 2) can spray both sides of fruit trees in two passes. This device can be switched on and off by projections fixed to the rail at the turning points, the angle of the blow head can be automatically adjusted by the electric motor according to the inclination of the orchard, and therefore automatic operation is possible. The fertilizer spreader (Fig. 3) can spread both manure and chemical fertilizers at a width of 3 to 6 m. The amount of fertilizer can be adjusted in 18 steps independent of the running speed of the tractor, and the amount of fertilizer can be maintained in the range of 500 to 1,500 kg/ha.

Operation

Harvesting: The operator of the sub-monorail collects bins of fruit that have been placed beside the rail and loads them into the freight car (Fig. 4). When the freight car is full, the operator drives the sub-monorail tractor to the nearest point to the main monorail and transfers the bins to the freight car of the main monorail. While the operator on the main monorail carries the goods down the hill, the operator of the sub-monorail continues to collect the harvest.

Spraying agricultural chemicals: The air blast sprayer can be operated automatically, thus freeing the operator. The sprayer can be resupplied from the tank car of the main monorail or from taps on a pipe running beside the main monorail.

Applying fertilizer: The width and amount of fertilizer are manually adjustable, and resupply is available from the freight car.

Weed control and processing of pruned branches are shown in Figs. 5 and 6.

Table 1. Specifications of components of main monorail system and sub-monorail system

Applicable slope angle	< 30º
Main monorail system	Rail (rack & pinion), Tractor (engine output: 4.4 kW, velocity: 0.75 m/s), Riding cart, Freight car (maximum load: 200 kg), Chemical supplying device (tank capacity: 500 L)
Sub-monorail system	Rail (square steel pipe, curvature > 3.0 m), Tractor (engine output: 2.9 kW, velocity: low 0.30 m/s, high 0.61 m/s), Freight car (maximum load: 200 kg or 100 kg), Air blast sprayer (engine output: 5.5 kW, air capacity: 200 m^3/min, pumping rate: 24 L/min, tank capacity: 150 L), Fertilizer spreader (engine output: 2.1 kW, broadcast width 3–6 m, feed rate: 16–17 kg/min, hopper capacity: 80 L), Shredder (engine output: 2.4 kW, processing quantity: 300–400 kg/h)

Table 2. Dimensions of sample trees

Sample tree	A	B	C
X1: Distance between the sample tree and the rail on downhill (m)	3.1	4.2	4.3
X2: Distance between the sample tree and the rail on uphill (m)	3.7	3.7	4.1
Y: Difference in altitude of the two rails (m)	2.7	3.9	3.7
L: Length of the tree crown (m)	2.3	3.1	3.1
W: Width of the tree crown (m)	2.2	2.8	2.5
H: Height of the tree (m)	1.8	2.0	2.0
Number of tree rows	2	3	3
Position of the sample tree	Downhill side	Center of rows	Center of rows
Number of tests	2	2	2

Materials and methods

1. Coverage of agricultural chemicals

To evaluate the performance of the air blast sprayer, we tested the coverage with water-sensitive papers at a commercial orchard in Ehime Prefecture. As shown in Fig. 7, we set 20 measurement points consisting of four heights, 0.5, 1.0, 1.5, and 2.0 m, at five points, the four cardinal directions and the center, on sample trees (Table 2). At each measurement point, four water-sensitive papers were set. Two of them were set vertically, one facing uphill and the other downhill, and two were set hori-

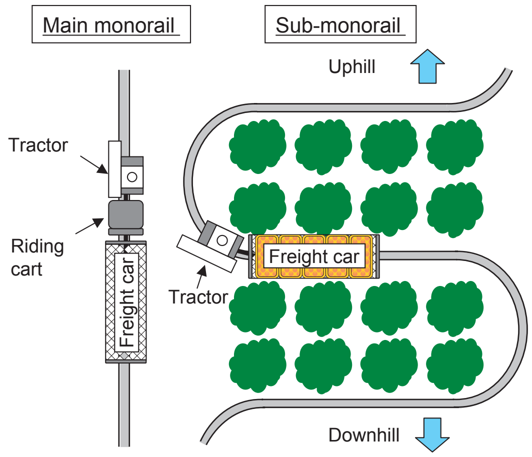

Fig. 1. Outline of the S-shaped multipurpose monorail during harvesting

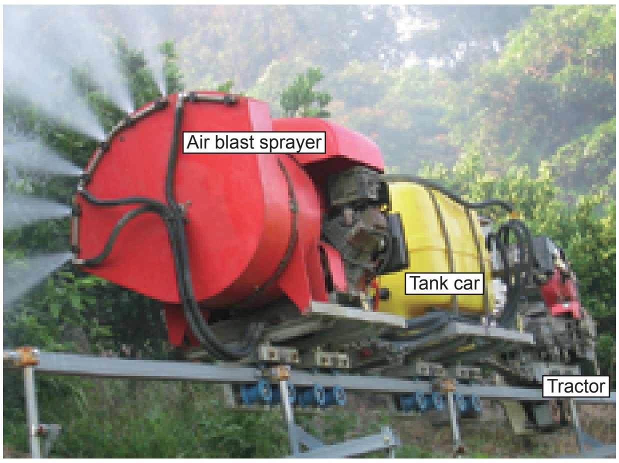

Fig. 2. Air blast sprayer, tank car and tractor

Fig. 3. Fertilizer spreader

Fig. 4. Freight car with harvest

Fig. 5. Weed control

Fig. 6. Shredding of pruned branches

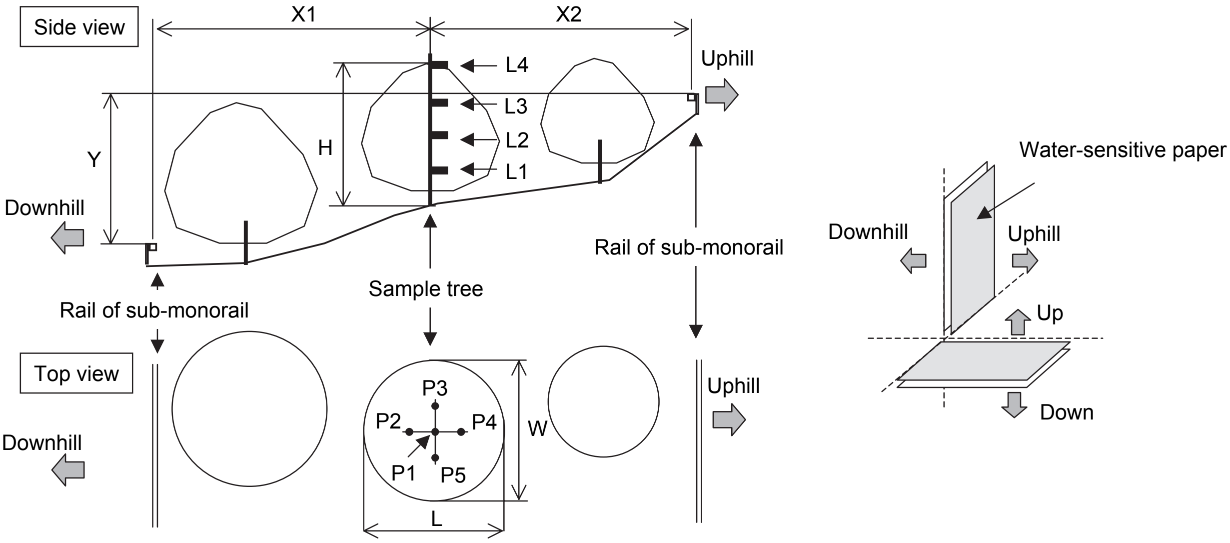

Fig. 7. Sample tree and arrangement of water-sensitive papers

zontally, one pointing up and the other down. Coverage was classified as 'ineffective', 'half-effective', or 'effective'. If two papers were 'half-effective', they were counted as one effective paper.

We also compared the air blast sprayer with the sprinkler system that is used for irrigation in some major growing areas.

2. Work efficiency

S-shaped multipurpose monorails were installed in two citrus orchards in Ehime Prefecture. Their specifications are shown in Table 3. The annual working hours for spraying, fertilizer spreading, and harvesting were recorded.

Results

1. Coverage of agricultural chemicals

The results are shown in Table 4. In the case of tree A, which faced the rail on the downhill side, the coverage with the air blast sprayer was approximately 94%, but in the case of trees B and C, which were behind other trees, the coverage was approximately 75%. The coverages with the sprinkler were 61% for tree A, 49% for tree B, and 41% for C. Thus, the coverage of the air blast sprayer was superior to that of the sprinkler on all trees.

The new system has further advantages; the amount of spray is about half the amount used with a sprinkler system and coverage is effective on the leaves at the bottom of the trees.

Table 3. Specifications of monorails in the orchards

Location	Matsuyama, Ehime Prefecture	Iyo, Ehime Prefecture
Area (ha)	0.30	0.44
Maximum slope	30º	35º
Slope of rails	main monorail: 8º–30º curved part of sub-monorail: 12º–23º	main monorail: 10º–30º curved part of sub-monorail: 10º–24º
Length of rails (m)	main monorail: 110 sub-monorail: 471 (straight 318, curved 153)	main monorail: 120 sub-monorail: 561 (straight 390, curved 171)
Distance between straight rails of sub-monorail (m)	5.5–9.1	1.9–12.2

2. Work efficiency

Spraying: Trees were sprayed seven times in Matsuyama and six times in Iyo. The efficiency, the gross area treated in an hour, ranged from 0.18 to 0.27 ha/h (Table 5). From the travel speed of the air blast sprayer and the lengths of the sub-monorails, the ideal amount of work was calculated to be 0.36 ha/h in Matsuyama and 0.43 ha/h in Iyo. According to these data, the work efficiency in Matsuyama, ranging from 50% to 72% of the ideal, was higher than that in Iyo, ranging from 51% to 62%. The greater work efficiency in Matsuyama was made possible by pre-existing piping for spraying in Matsuyama, whereas the operator in Iyo had to move the main monorail to supply the chemicals to the sub-monorail. The wide range of work hours in Matsuyama was due to cavitation. The operator often had to stop supplying chemicals because of the generation of bubbles caused by cavitation. This problem was solved with the introduction of a high performance pump. In Iyo, two operators had to resupply the chemicals from outside of the orchard. It took two or three trips to supply the chemicals to the main monorail and 11 or 12 from the main monorail to the sub-monorail. The working efficiency in both orchards was much better than the conventional method (manual operation, 0.097 ha/h)[7], but less than the sprinkler system, which took only 10 min to spray 0.44 ha in Matsuyama. However, the accuracy of the monorail sprayer was superior.

Fertilizer application: The efficiency of fertilizer application was 0.20 to 0.27 ha/h (Table 6), much larger than that by the conventional method (0.02 ha/h). Although the operator had to walk with the device to control the angle of the fertilizer ejection pipe, the operator did not have to carry the 20 kg bags of fertilizer.

Harvesting: The efficiency of harvest ranged from 68 to 144 kg/h per operator (Table 7). The work intensity was improved because the operator did not have to carry the full bins around. It took 18 min 30 s for a worker to carry six 20 kg bins within a distance of 25 m to 30 m; 24% of this time was spent carrying the full bins, and 76% walking back for the next bins. With the monorail, it took approximately 6 min 4 s to carry 11 bins for the same dis-

Table 4. Results of coverage tests

	Air blast sprayer			Sprinkler		
Sample tree*	A	B	C	A	B	C
Average coverage rate (%)	94.0	74.7	75.8	60.6	49.4	40.6
Average number of papers with ineffective coverage	2	14	11	21	28	39
Average number of papers with half-effective coverage	7	13	17	21	25	17
Average number of papers with effective coverage	71	53	52	38	27	24

*: Table 2.

Table 5. Results of work efficiency for spraying

Location	Area (ha)	Chemicals (L)	Working time (h:min)	Amount of work (ha/h)	Work efficiency* (%)
Matsuyama	0.30	1,200	1:30	0.20	56
	0.30	1,200	1:22	0.22	61
	0.30	1,300	1:15	0.24	67
	0.30	1,250	1:35	0.19	53
	0.30	1,200	1:10	0.26	72
	0.30	1,200	1:20	0.23	64
	0.30	1,200	1:40	0.18	50
Iyo	0.44	1,400	2:00	0.22	51
	0.44	1,500	2:00	0.22	51
	0.44	1,500	2:00	0.22	51
	0.40	1,200	1:30	0.27	63
	0.44	1,400	2:00	0.22	51
	0.44	1,500	2:00	0.22	51

*: Work efficiency is the ratio of amount of work to the ideal amount of work (0.36 ha/h in Matsuyama and 0.43 ha/h in Iyo).

Table 6. Results of work efficiency for fertilization

Location	Area (ha)	Fertilizer (kg)	Working time (h:min)	Amount of work (ha/h)	Work efficiency* (%)
Matsuyama	0.30	280	1:30	0.20	56
	0.30	300	1:10	0.26	71
Iyo	0.40	400	1:30	0.27	62
	0.20	140	1:00	0.20	47

*: Work efficiency is the ratio of amount of work to the ideal amount of work (0.36 ha/h in Matsuyama and 0.43 ha/h in Iyo).

Table 7. Results of work efficiency for harvesting

Location	Area (ha)	Number of Operators	Working time (h:min)	Total Harvests per day (kg)	Harvests per hour per operator (kg/h/operator)
Matsuyama	0.10	6	5:30	2,880	87
	0.08	3	6:50	1,800	88
	0.06	3	7:10	1,458	68
	0.05	3	3:50	900	78
	0.08	3	2:00	864	144

tance; 44% of this time was spent loading the bins on the freight cars of the sub-monorail, 23% carrying them on the sub-monorail, and 33% transferring them to the main monorail. The time required to carry a bin was 185 s by hand and 33 s by monorail. This is a 460% increase in efficiency.

Conclusions

The S-shaped multipurpose monorail can greatly improve the labor efficiency and reduce the amount of spray chemicals needed through improved accuracy. It can also spread fertilizer and transport the harvest with high efficiency and much less labor.

The monorail system was commercialized in 2004. It has proved too expensive for small-scale farmers to introduce into their narrow orchards, so we have developed equipment to transfer the sub-monorail system among orchards. The monorail is economical for orchards of more than 1 ha and can help overcome the labor shortage in steep fruit production areas in Japan.

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