JARQ 34(4), 239 – 245 (2000) http://ss.jircas.affrc.go.jp

Mechanized Production System for Orchards on Sloping Land in Japan

Masahiro MIYAZAKI1*
Department of Hilly Land Agriculture, Shikoku National Agricultural Experiment Station
(Zentsuji, Kagawa, 765-0053 Japan)

Abstract
In Japan, most of the farm operations in orchards on sloping land in the past had been carried out manually, since no suitable machinery was available. However presently, the problem of aging farmers and shortage of young successors, especially for citrus orchards on steep hillsides must be solved. Therefore, a mechanized production system (MPS) for orchards on sloping land was developed involving the construction of farm paths and the use of machines behind which the operator walks, such as airblast sprayer, raised bed transporter, and fertilizer spreader. The benefits of MPS were confirmed by comparison with a conventional production system (CPS) in an actual farmer's orchard at Yoshida town, Ehime prefecture, which is one of the leading citrus-production districts in Japan. The use of this system enabled to reduce the total working hours by 35% as well as improve the working conditions without yield decrease and decline of the quality of fruits.

Discipline: Agricultural machinery
Additional key words: Farm path, pest control, transportation, fertilizer application

Introduction

As in most Asian countries, the area of arable land in Japan is very small. Therefore, hilly areas have been cultivated since ancient times. After World War II, many orchards on sloping land in Southwest Japan were brought under cultivation for satsuma mandarin, the most popular citrus variety with the highest fruit production. Since orchards on sloping land are well-drained, exposed to sunshine and well ventilated, farmers can grow sweet citrus fruits that fetch a high price.

However, the mechanization of such orchards has been lagging behind that of lowlands in Japan because the use of machinery is difficult, and sometimes even dangerous due to the steep gradients and high-density planting. As a result, farmers have tended their orchards by hand, spending long hours stooped over their trees. Statistics showed that the yearly labor requirement for citrus crops per unit area was 4 times higher than that for rice production using a tractor, a rice transplanter, and a head-feeding combine. Moreover, farming in Japan is facing serious problems due to the shortage of efficient farmers associated with the increase of the average age of the farmers and decrease of the number of young people. Therefore the number of abandoned orchards is increasing.

To address these problems, a mechanized production system (MPS) was developed to reduce hours as well as improve the working conditions in citrus orchards on steep slope. This system involves the construction of farm paths and the use of small walking-type machinery behind which the operator walks.

Construction of farm paths[5)]

The mechanization of orchards on sloping land with steep gradients depends on the construction of paths for agricultural machinery. The construction of wide farm roads or paths to allow the passage of large machines is not suitable on steep slopes because the construction costs are high and there is a risk of landslide. Furthermore, the total yield from the orchard decreases because many trees must be cut to make room for the machinery.

Present address:
[1]Department of Tea Agronomy, National Research Institute of Vegetables, Ornamental Plants and Tea (2769 Kanaya, Haibara, Shizuoka, 428–8501 Japan).
*Corresponding author: fax +81–547–46–2169, e-mail miyamasa@tea.affrc.go.jp
Received 15 November 1999, accepted 19 January 2000.

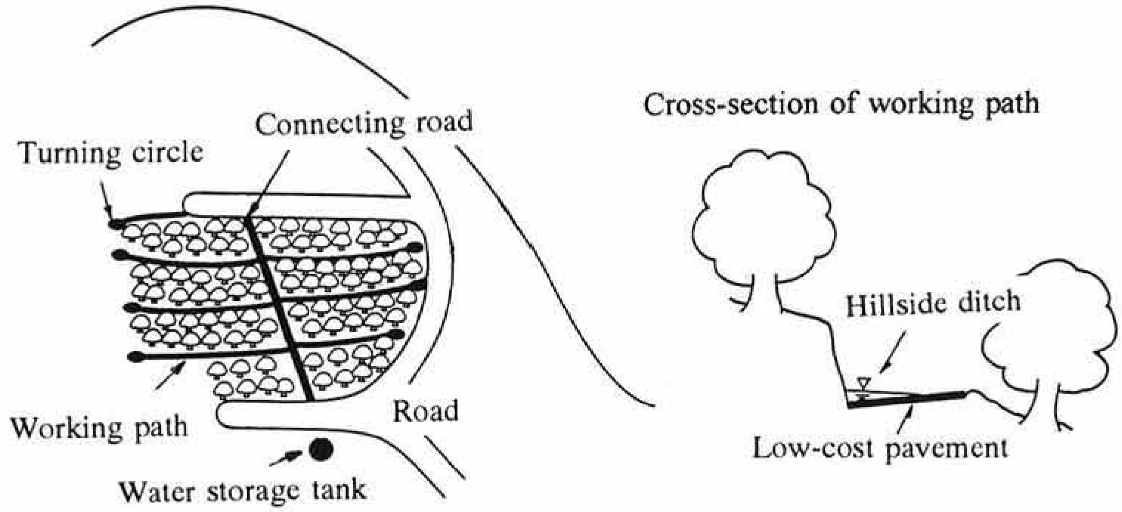


Fig. 1. Layout of farm path system

Instead, a new farm path system was developed for MPS.

The layout of the farm path system is shown in Fig. 1. It includes 2 kinds of paths, a working path which is 1.0 m wide, and a connecting road more than 1.3 m wide. The connecting road acts as a backbone, while working paths are located laterally to the road. To ensure that the machines can travel safely along the paths, the gradient of the connecting road should be less than 15°. The path should have a turning circle where the machines can turn around, with a diameter of 2 m.

The working paths also function as hillside ditches, intercepting run-off water. It is important to pave them, to prevent erosion and to allow machines to travel smoothly. We have developed a low-cost cement aggregate pavement, using soil from the orchards rather than gravel and sand brought in from outside. The cement is mixed with a coagulant powder and water, and hardens into smooth, durable pavement. Such a pavement is easy to construct, and the total cost is comparatively low.

Construction process of farm paths is carried out as follows (Fig. 2): (1) The path is dug out using a small back hoe. (2) Cement is mixed together with the coagulant and spread over the soil surface. (3) It is mixed together with soil, using a rotary-tiller. (4) Water is sprinkled onto the mixture, using a power sprayer. (5) A rotary-tiller is used to mix all the ingredients thoroughly together, and level out the surface.

The ratio of soil, cement, and coagulant in the pavement materials is 100 : 13 : 0.3, respectively. The water is sprinkled at a rate of 20 L/m^2. Pavement depth is 7–10 cm. The farm path is constructed at a rate of 100 m^2/h with a team of 5 workers.

It is also important to install a water supply system. Usually a water storage tank is constructed at the lower end of the connecting road, for collecting the water running down the farm paths. The water is used for irrigation, or for mixing pesticide sprays.

Development of small machines[1,2]

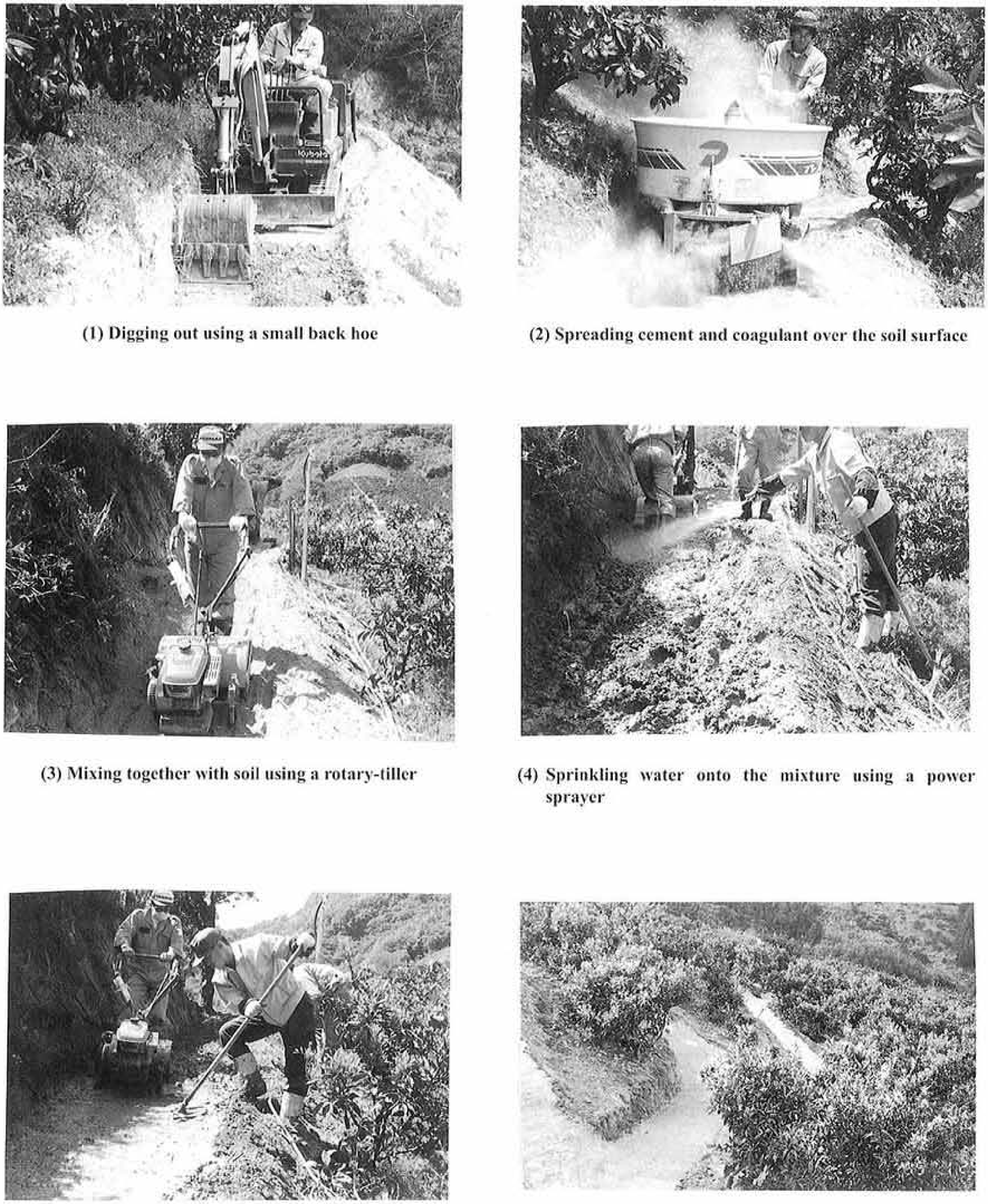
Because the farm paths in orchards on sloping land are steep and narrow, large farm machinery cannot be used. Instead, we designed specialized small machines with the following basic specifications: (1) Use of crawler treads, rather than wheels. (2) The operator does not ride on the machine, but walks behind it. (3) The machine has a very small turning circle.

1) Mechanization of pest control

In fruit culture, chemical sprays are necessary for pest control. In Japan, they need to be applied about 10 times per year. At present, power sprayers with long hoses are widely used, but they require a large amount of labor. Farmers need a kind of sprayer with a lower labor requirement and higher efficiency.

Therefore, we designed an air-blast sprayer (Fig. 3). The operator walks behind the sprayer along a farm path. The sprayer is equipped with an axial fan, and emits a fine and dense chemical mist. The operator can direct the spray precisely onto the target by controlling the direction of a fan drum, that can be adjusted freely between 35° upward and 20° downward. Air turbulence associated with the fan drum swinging automatically shakes the leaves of trees, so that chemical spray adheres to both sides of the leaves.

This sprayer is equipped with a liquid chemical tank with a capacity of 300 L. It can apply pesticides at a rate of 3,000 to 5,000 L/ha with a working efficiency of 0.15



(1) Digging out using a small back hoe

(2) Spreading cement and coagulant over the soil surface

(3) Mixing together with soil using a rotary-tiller

(4) Sprinkling water onto the mixture using a power sprayer

(5) Mixing all the ingredients and leveling out the surface

Paved farm path

Fig. 2. Construction process of farm path

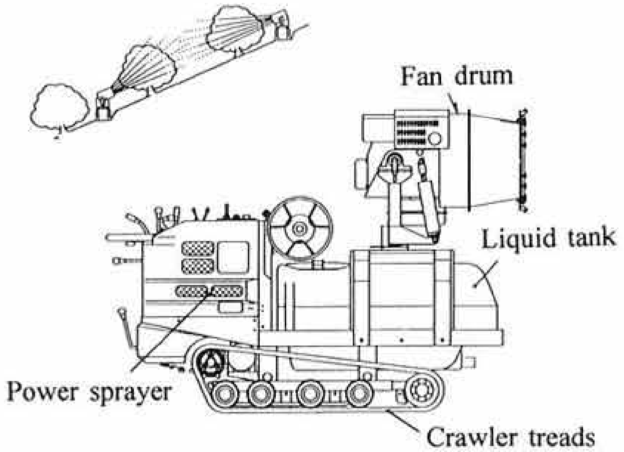


Fig. 3. Walking-type air-blast sprayer
Length: 2,600 mm, Height: 1,410 mm, Width: 960 mm, Weight: 510 kg, Spray capacity: 13–27 L/min, Air flow rate: 180 m^3/min.

ha/h. Since the machine is operated by only one operator without any co-workers, the application can be conducted at suitable times for fruit trees.

2) Mechanized transportation

At present, the transportation of loads involving a container for harvested fruits and a bag of fertilizer weighing 20 kg has been conducted manually with a high labor intensity. However, a transporter with crawler treads could be used to carry heavy loads. With a good network of farm paths, the use of such a transporter may lead to a significant improvement in efficiency and comfort of farm work.

The transporter we developed has an adjustable elevated bed measuring 45 to 118 cm, with outriggers to give stability (Fig. 4). Its loading capacity is suitable for 10 containers (a 200 kg load). By raising the bed, it is possible to reduce the labor required for loading harvested fruits from the transporter to a truck. In addition, the raised bed can be used as a platform for the farmer who carries out operations in the tree canopy, such as pruning, thinning and harvesting.

3) Mechanized fertilizer application

The application of fertilizer 3 times each year (in spring, summer, autumn) does not require many working

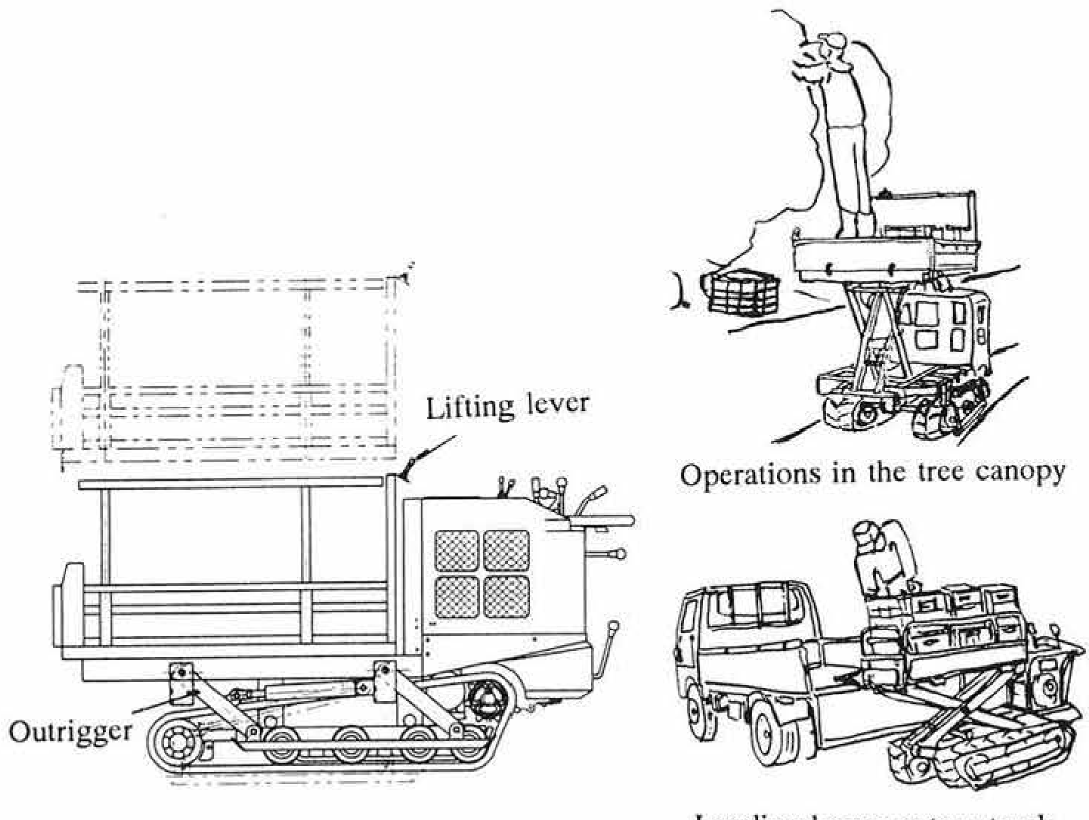


Fig. 4. Walking-type raised bed transporter
Length: 2,090 mm, Height: 1,080 mm, Width: 1,110 mm, Weight: 530 kg, Lifting height: 1,180 mm, Loading capacity: 500 kg.

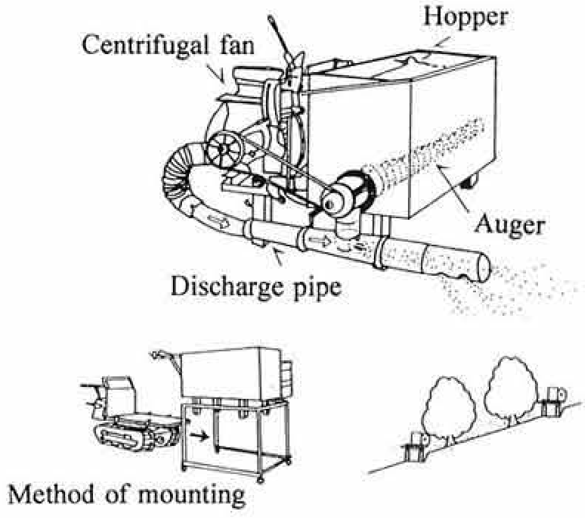


Fig. 5. Fertilizer unit mounted on transporter
Length: 1,930 mm, Height: 1,350 mm,
Width: 900 mm, Weight: 355 kg,
Discharge capacity: 14–25 kg/min,
Air flow rate: 11 m^3/min.

hours for fruit production in Japan, but the work of spreading fertilizer over an orchard is rather hard.

We developed a fertilizer unit mounted on the bed of the transporter (Fig. 5). The capacity of the hopper of the fertilizer is about 100 L. Granular or pellet type fertilizer metered through an auger attached to the bottom of the hopper is led to a discharge pipe, and blown out with air from a centrifugal fan. Mounting and unmounting the unit on the bed of the transporter are easy operations, because of the transporter's hydraulic lift system.

Fertilizer can be applied in a band up to 4.6 m wide, at a rate of 14–25 kg/min. Fertilizer can be applied at a rate of 1.0 to 1.5 t/ha with a working efficiency of 0.45 ha/h.

Advantages of mechanized production system[3,4]

1) Methods

To confirm the advantages of MPS, we set up a model orchard in an actual farmer's orchard with a mean slope gradient of 25° at Yoshida town, Ehime Prefecture. The model orchard was improved by adopting the developed farm path system from 1994 to 1995. The working path was placed at an interval of every 2 tree rows, with a path density of 1.2 km/ha. The rate of removed trees for the construction of the farm path was only 8%.

Field experiments were conducted to determine the labor intensity of each operation and the yearly working hours by comparison with a conventional production system (CPS) for 2 years. The labor intensity level of each operation was classified based on the increase of worker's heart rate. Fig. 6 shows the difference between MPS and CPS for pest control, transportation of harvested fruits, and methods of fertilizer application. The other operations such as pruning, thinning, and mowing were also improved. Investigations of yield and selling price for the model orchard were performed to evaluate the productivity compared with the area average.

2) Labor intensity and working hours

Table 1 shows the labor intensity and yearly working hours for MPS and CPS. The labor intensity required for pest control, fertilizer application, harvesting in the case of MPS was obviously reduced by the use of small machines. In addition, the labor intensity for mowing weeds using a bush cutter was also reduced because the worker could perform the operation on the working path and not on a slope. As a result, the labor intensity of the operations was reduced to less than the average level.

The working hours of each operation in the case of MPS were also reduced, and the application of fertilizer using the fertilizer spreader was more uniform than that

Table 1. Labor intensity and working hours in MPS and CPS

Work	Mechanized production system (MPS)			Conventional production system (CPS)			Rate of working hours MPS/CPS(%)
	Method	Labor intensity[a)]	Working hours (h/ha)	Method	Labor intensity[a)]	Working hours (h/ha)	
Pruning	Manual work	Moderate	81[b)]	Manual work	Moderate	140	58
Fertilizer application	Fertilizer unit	Moderate[b)]	22	Hand-spread	Hard	20	110
Mowing	Bush cutter	Moderate[b)]	83[b)]	Bush cutter	Hard	115	72
Pest control	Air-blast sprayer	Moderate[b)]	84[b)]	Power-sprayer	Hard	159	53
Thinning	Manual work	Light	313[b)]	Manual work	Light	442	71
Harvesting	Transporter	Light[b)]	258[b)]	Hand-carry	Moderate	414	62
Total			841[b)]			1,290	65

a): Labor intensity level is classified based on the increase of worker's heart rate. Light: 0–30%, Moderate: 30–50%, Hard: 50–90%.
b): Effects of MPS.

Pest control

Transportation of harvested fruits

Spreading fertilizer

Mechanized production system (MPS) **Conventional production system (CPS)**

Fig. 6. Pest control, transportation, and fertilizer application in MPS and CPS

Table 2. Yield and selling price of citrus fruits in model orchard compared with area average

Year	Yield			Price[c]		
	Model orchard (M t/ha)	Area average[a] (A t/ha)	Rate of yield (M/A %)	Model orchard (M yen/kg)	Area average[a] (A yen/kg)	Rate of price (M/A %)
1994[b]	20.6	19.5	105	233	207	113
1995[b]	30.1	22.3	135	153	152	101
1996	26.3	17.3	152	272	241	113
1997	45.7	28.9	158	70	50	140

a): Area around model orchard at Yoshida town site.
b): Model orchard was improved by the construction of farm paths for MPS from 1994 to 1995.
c): Yen rate, about 0.01 US$.

with the hand-spreader. Especially the transporter in the case of MPS led to a significant reduction of the labor required for the transport of fruits during harvest so that the output of harvested fruits per worker could be increased. Tests showed a 38% reduction in the working hours required for harvesting. As a result, the yearly working hours were reduced by 35%.

3) Effect of introduction of MPS on citrus production

Table 2 shows the yield and selling price of fruits in the model orchard where farm paths were constructed from 1994 to 1995. The yield and selling price of citrus fruits varied with the years because fruit-bearing occurred in alternate years. Compared to the area average, the yield in 1994 and 1995 was slightly higher than in case of thinning of citrus trees. The yield after the introduction of MPS was more than 150% higher, indicating that the improvement of orchards by this system did not cause a yield reduction in spite of some thinning of citrus trees.

The selling price also was higher than that of the area average. Considering that this district is one of the leading citrus production centers in Japan, MPS enabled to produce high-quality citrus fruits. In addition, the owner who introduced MPS stated that this system enabled to reduce the labor intensity and working hours and also to enhance the quality of fruits due to the improvement of the light conditions in lower and inner portions of the tree canopy.

Conclusion

In citrus orchards on sloping land, the shortage of labor has become a serious problem in Japan. Therefore, we developed a mechanized production system (MPS) involving the construction of farm paths, and the use of small machines behind which the operator walks, including an air-blast sprayer, raised bed transporter, and fertilizer spreader.

The advantages of MPS were tested in an actual farmer's orchard by comparing it with the conventional production system (CPS). The tests showed that the MPS enabled to reduce yearly working hours by 35% as well as improve the working conditions without a decline of the quality of fruits and yield. These results indicate that the introduction of this system enabled farmers to avoid hard manual labor required for the maintenance of orchards on sloping land and extended the scale of farm operations. Consequently, the MPS for orchards on sloping land should contribute to the development of stable orchard management.

References

1) Miyazaki, M. (1998): Mechanized farming for slopeland orchards I Japan. *Food Fert. Technol. Cent. (FFTC), Ext. Bull.*, **452**, 1–8.
2) Miyazaki, M. et al. (1999): Improvement of pesticide and fertilizer application works on steep sloping citrus orchards. *Jpn. J. Farm Work Res.*, **34** (2), 85–94 [In Japanese with English summary].
3) Miyazaki, M. & Ishizuka, N. (1999): Analyzing the process of selecting an operation system for citrus production by the developed decision support system. *Jpn. J. Farm Work Res.*, **34**(3), 191–201 [In Japanese with English summary].
4) Miyazaki, M. et al. (1999): Reducing hours and hardness of works in steep sloping citrus orchards by construction of farm path and a small machinery system. *Jpn. J. Farm Work Res.*, **34**(3), 203–210 [In Japanese with English summary].
5) Okazaki, K. et al. (1998): Simple construction technique of orchards path in slope land. *Jpn. J. Farm Work Res.*, **33**(4), 213–219 [In Japanese with English summary].