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BARD

FINAL REPORT

PROJECT NO. US-770-84

Engineering Systems for Production and Harvest of Fruit Grown in High Density Dwarf-Tree Orchards

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Title of Research Project:

Engineering Systems for Production and Harvest of Fruits Grown in High-Density Dwarf Tree Orchards

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Summary:

Results of recent studies have shown that high-density orchards of dwarf trees can produce a much higher yield per unit area and give a product much earlier than standard orchards. However, the success of this new fruit production method depends on the availability and proper utilization of suitable equipment.

A joint project between Israeli and U. S. researchers was initiated in 1985 to develop an engineering system for harvesting and cultural operations in such high-density dwarf-tree orchards. The general concept was to develop a multi-use system consisting of an over-the-row machine (a carrier) and detachable equipment modules for various cultural and harvesting operations.

The Israeli team has developed a fruit handling system for hand harvest operation. The system consists of a self-propelled power frame and a fruit handling module equipped with elevators and over-the-row conveyors for transporting fruits from the pickers to the receiving bin under the power frame. The power frame is also equipped with a mechanism for retrieving and lifting the empty containers from the ground, positioning them below the discharge elevator, and subsequently placing the filled containers on the ground.

The U. S. team has developed an over-the-row self-propelled carrier and equipment modules for spraying, hedging, pruning, and cultivating operations in high-density peach orchards. This machine is uniquely designed so that its inside clearance can be easily adjusted from 1.8 m wide by 1.2 m high to 2.8 m by 2.6 m. The adjustment is accomplished through hydraulically powered parallel four-bar linkages and can be done within 17 minutes.

Test results indicated that the concept of using an over-the row carrier and detachable equipment modules worked well in high-density dwarf-tree orchards. The results also provided useful information for further improvements of some of the equipment modules.

Objectives of the original research proposal

1. To determine engineering requirements for various cultural and harvesting operations.
2. To develop equipment to meet these engineering requirements.

Final Report for BARD Project US 770-84R

AN ENGINEERING SYSTEM FOR PRODUCTION AND HARVEST OF FRUITS GROWN IN HIGH DENSITY DWARF TREE ORCHARDS

by

P. Chen, Y. Sarig, F. Grosz

Introduction

In recent years the possibility of increasing yield through tree spacing closer than that in current use has been explored in several places with encouraging results. Carry (1981) cites experiments in Australia, California, Florida, Japan and other areas where early yields were more or less proportional to number of trees. Although few long-term experiments have been carried out to completion, the trend to higher planting density will continue, driven by economic forces and a potential yield in an ideal orchard that might approach (in citrus, for example) 100 MT/ha (Wheaton et al., 1978).

There is evidence (Passos and Boswell, 1979) that high quality fruit can be produced on closely spaced trees, provided that excessive crowding is avoided.

Although increasing yield is a valid goal by itself, the major thrust for the intensification of orchards is due to rising costs of land, energy, chemicals and primarily, labor. An inadequate seasonal labor force, especially in Israel and other countries with similar labor shortage situation, make it almost mandatory to change from the traditional orchard to dwarf trees grown in more intensive systems.

Extensive field research in Australia on citrus has shown that a bud-transmissible dwarfing factor, when inoculated into orange growing on specific rootstocks, offers potential to reduce normal tree size while maintaining tree health, early cropping and fruit quality.

An alternative method, currently under extensive experimentation in Israel, also with citrus, is dwarfing through root restriction by drip irrigation, supported by other growth restriction elements (Golomb, 1988).

Another example of the intensive dwarf orchard is the peach meadow-orchard concept which has been developed and explored extensively in Israel (Erez, 1976).

While orchard dwarfing and intensification show significant advantages in terms of convenience of tree-care, plant protection operations and harvesting, they also present new engineering problems (Chen and Studer, 1984). Because the trees are small and planted at high density, existing machines are now suitable for such orchards. Success of this fruit production method depends, therefore, on the availability and proper utilization of suitable equipment for cultural, harvesting and fruit handling operations.

Objectives

The aim of this research was to develop an experimental machine with equipment modules for various cultural operations in high-density dwarf orchards. The specific objectives were to (a) determine the desired tree density and planting configuration based on economic and horticultural considerations; (b) develop proper equipment for all cultural operations in a high-density orchard and specifically to develop a fruit handling system for harvesting operations.

The research is a joint project of Israel and U.S. researchers attempting to develop a multi-use system for all high-density dwarf-tree fruit orchards.

While the original objectives were aimed only for genetically dwarf deciduous trees, the concept of high-density dwarf orchard applies, in principle, to all fruit trees.

Economic and Horticultural Considerations

An analysis was made to evaluate the influence of distance between rows in a high-density simulated orchard on production costs (Pasternak et al., 1988). This is essential for the determination of the mode of operation of the machine, as it has a direct influence on the final design.

The analysis assumed a constant in-row spacing of 2 m, and compared production costs of two orchards with row spacings of 2.5 m and 3.0 m, respectively. Increasing the distance between the rows has resulted in fewer rows per unit area and thereby reduced the total yield per unit area. On the other hand, increasing row spacing provides for better radiation and hence increased yield per row.

Although most orchard activities and inputs are row-dependent (in a drip irrigation-fertilization orchard), the reduction in production costs resulting from increasing row spacing is outweighed by the loss in yield due to the decrease in the foliage volume. To pursue the objective of minimizing production costs, we should aim for the maximum number of rows possible, providing that the row spacing is still acceptable from the horticultural and operational points of view.

Although the system is aimed to be applicable to a variety of fruits, horticultural requirements may differ. While for an apple orchard, for example, alternating planting of two species of trees is needed to provide for optimum pollination which will result in high yield and high quality fruits, such a requirement does not apply for citrus. The limiting factor in this case may be, primarily, a functional one and determined on the basis of the optimal size of the picking crew on the one hand, and engineering design on the other.

A proposed orchard configuration, shown in Fig. 1, provides for simultaneous operation in four consecutive rows. This configuration is not mandatory, but its advantage is that it lends itself also to an apple orchard where harvesting of two different varieties is required at different dates without mixing the two. If there is a single variety of trees in the grove, the number of tree rows between access ways can be increased to five rows as shown in Fig. 2.

Description of the Experimental Systems

Harvesting and handling system

An experimental system was designed for harvesting and handling both deciduous and citrus fruits in high-density dwarf orchards. The system is a modified and more versatile version of the IMAG system (van Lookeren Campagne and van de Werken, 1984) which consists of a self-propelled power-frame, (an existing 'UPRIGHT' Co. prime-mover was utilized after modifications as the power frame in our experiments) which moves along the access way where the fruit containers have been distributed prior to harvesting.

The power frame is equipped with a fruit handling system comprised of a conveying system, a controlled fruit-discharge system and a system for lifting empty containers from the ground. The proposed system is shown in Fig. 3.

The conveying system

Over-the-row cross conveyor. Two over-the-row cross conveyors are mounted on the two sides of the prime mover (due to lack of funds, actually only one side has been constructed). The conveyors are provided with hydraulic cylinders to adjust their inclination up to ±15° from ground level to conform with differences in the orchard terrain and topography. The over-the-row conveyors can be hydraulically folded into transporting position parallel to the prime-mover. Two rails are provided on the side of the conveyors on which the elevators can move along the length of the conveyors.

Elevators. There are three elevator conveyors on each side of the machine for lifting fruits from the pickers to the over-the-row conveyor. The elevators are pin suspended as a pendulum on a carriage which can move along the rails on the over-the-row conveyor. The system enables adjusting to the ground slope and the row spacing. The elevators are provided with a conveying belt with rubber fingers for a gentle handling and elevating the harvested fruit to the cross conveyor. The elevators are electrically driven for flexibility and noise suppression. An electric power generator on the prime mover provides power for the elevators through flexible cables.

Each elevator can serve one to two workers. Thus, a harvesting team may consist of 6 to 12 pickers plus one driver.

Central conveyor. The central conveyor receives the fruit from the cross conveyors and transfers them to the bin filler conveyor.

Fruit-discharge system

Bin filler conveyor. A vertical belt conveyor is provided with rubber fingers to hold the fruits and handle them gently onto the bin. An electro-hydraulic sensor system provides for the lifting of the conveyor according to the fruit level in the bin. Hence, during its work the conveyor rises up to the maximum possible level where it stops automatically.

Rotating table. The rotating table ensures an even filling of the bin (uniform fruit distribution). The table is provided with a hydraulic system and a fork mechanism to ensure the lowering of the table and to transfer the filled bin to the forks on which it will slide down onto the ground. Hence, the forks could be unloaded by simply moving forward.

As soon as the full bin is left on the ground, the table will rise back to the normal position. The bin table is hydraulically driven and is also equipped with a positioning system to stop it in the designated position for unloading. The rotating table can accommodate a standard bin and rotates at about 10 r.p.m.

Technical data corresponding to the various components of the conveying system are given in Table 1.

Construction of the Experimental System

Due to budget restrictions only one side of the fruit handling system was built. The over-the-row conveyor and the elevators were built only for one side. For the other side, a counter-weight was provided to compensate for the temporary absence of the complementing section. For the same reasons, the system for lifting empty containers from the ground was not constructed. Figure 4 shows the experimental harvesting system being tested in a high-density citrus orchard.

Equipment for Cultural Operations

The U. S. team has designed and built an over-the-row self-propelled carrier for carrying different equipment modules in high-density orchards. The machine has four-wheel drive and four-wheel steering capabilities and is powered hydraulically. This machine is uniquely designed so that its inside clearance can be easily adjusted from 1.8 m wide by 1.2 m high to 2.8 m by 2.6 m . The adjustment is accomplished through hydraulically powered parallel four-bar linkages.

The following equipment modules have been designed and built: a spraying unit, a tree hedging unit, a mechanical aid for hand pruning, and a cultivating unit. The general design criteria for these equipment modules are as follows: 1) the module should be easily fabricated, and commercially available components should be used whenever possible; 2) the module should be easily attached to, or detached from, the carrier; and 3) each unit should perform its function well.

The spraying unit consists of six 40-cm Span Spray fan-type spraying heads, capable of uniformly delivering 935 L/ha, mounted on a frame under the carrier. The spray heads can be positioned around the tree so that they blow the spray into the tree from all directions (top and two sides). The high-speed air from different fans shakes the branches and helps improve penetration of the spray into the dense foliage.

The hedging module consists of two 1.2-m Chisholm-Ryder vineyard trimmer cutter bars vertically attached to a frame which is mounted in front of the carrier . The horizontal distance between the two cutter bars and their vertical position are adjustable. One of the cutter bars can be rotated 90° into horizontal configuration for trimming the tops of the trees.

The pruning unit is a worker's aid. It consists of a frame suspended under the over-the-row carrier. The frame has four seats, two on each side of the row, for the manual pruners to sit on while pruning the trees with hydraulically powered pruning shears.

A one-meter wide Howard rotavator is used for cultivating. The rotavator is mounted on a vertical frame suspended under the over-the-row carrier. A hydraulically powered, spatial, parallel-bar linkage between the vertical 3-point frame of the rotavator and the vertical mounting frame on the carrier provides both powered up and down and free horizontal motions.

Figure 5 shows the Over-the-row machine, equipped with the hedging module, in operation in an orchard of genetically dwarfed peach trees. More detailed descriptions of the machine and equipment modules have been presented by Chen et al., 1988.

Experimental testing

Experimental harvesting work was carried out in two places: in the experimental plot for peach meadow-orchard at the Volcani Center, Bet-Dagan, and at the Dwarf Grapefruit plot, Kibbutz 'Gadot'. The existing plots were not planted for machine harvesting, thus, the full advantage of the proposed system was not manifested.

The cultural operation modules were tested (in California) in an experimental orchard of genetically dwarfed peach trees planted at 4 feet spacing within the row and 11 feet between rows. The trees were planted in 1981 and had not been hedged or pruned previously.

A chemical thinning test was conducted in an experimental orchard of 6-year-old genetically dwarfed peach trees planted at a density of 2500 trees/ha. A total of 32 trees were selected. Three equally spaced branches from each tree were tagged on April 1, 1987, and the number of young fruits (the seed length was approximately 8 mm) on each branch were counted. The trees were divided into four groups of eight trees each. The four groups were sprayed on April 10 with ethephon solutions of four different concentrations: 0, 30, 60, and 90 ppm. In addition to the 32 tagged trees, a separate group of ten trees with very heavy fruit set was sprayed with a highly concentrated (200 ppm) ethephon solution.

In mid June, the fruits remaining on the tagged branches were counted and the number was recorded. Whole-tree fruit counts were made on three trees that were sprayed with 200 ppm ethephon solution and on three untreated trees of comparable size. The dimensions and weights of 30 fruits from the treated trees (200 ppm) and 30 fruits from the untreated trees were measured and recorded.

Results and Discussion

Harvesting operation

Grapefruit harvesting. Only partial time studies were made with a crew of 3 workers (excluding the driver). The measured field capacity was one container (holding approx. 300 kg) in 5 minutes. Fruit quality was the same as that obtained by conventional methods. While the results do not show an advantage over the conventional manual method, the expected potential advantage should be viewed in light of the overall advantages of the system. Thus, while the results of the rate of picking reflect the actual time studies' measurements, the daily average output would, conceivably, be higher. The mechanical system provides for better picking environment, thus eliminating the need to carry the picking bag and walking long distances for dumping onto the containers. In addition, the system should not be evaluated on the basis of its contribution to the picking operation only, but as a comprehensive, integrated system, which is capable of performing all orchard operations.

Peach harvesting. Since only an experimental peach meadow-orchard was available for our experimentation and not the truly genetically dwarf orchards, no time studies were made.

Extrapolation from the citrus orchards' experiments show, however, that rate of picking would be similar or slightly higher than that obtained with conventional manual picking. Nevertheless, the less experienced the pickers - which is typical of labor storage conditions - the more significant is the advantage of using the mechanical system. Peaches are more sensitive to mechanical damage, and especially that which shows up at a later date after harvesting.

Results of mechanical damage incurred during harvesting of peaches are given in Table 2. While the results show a significant reduction in fruit quality due to light and severe marks of pressure, a subsequent close observation has traced its origin to the intersection between the fruit elevators and the over-the-row belt. This can be easily changed and hence fruit quality should be comparable to that obtained from conventional methods.

Other cultural operations

Hedging. A hedging test was conducted in April, 1986. The cutter-bars were set 4 feet apart for vertical cuts. Both sides of the trees were cut at the same time. Then one of the cutter bars was rotated and set in a horizontal position 5 feet from the ground, and the trees were topped off at 5 feet. The cutter-bars worked well with branches under 2 cm in diameter. The blades were frequently stopped by larger branches, especially those which were oriented in such a way that the angle between the branch and the cutter-bar was less than 45 degrees. After the hedging operation the trees remained in good hedged rows for the entire year.

Cultivating. A cultivating test was conducted in the spring of 1987. A 1.2-m wide strip of ground extending laterally from the center of the tree row was cultivated. The cultivator performed well in chopping up the weeds under the dwarf trees. When the cultivator came in contact with the tree trunk, it automatically swung away from the tree. However, the force created by the rototilling action was not strong enough to pull the cultivator back into the original position. This problem can be alleviated by using a spring or a hydraulic cylinder to assist the return swing of the cultivator. We plan to make modifications to correct this problem.

Spraying. The over-the-row machine equipped with the spraying module was tested in the spring of 1983. A preliminary test with water indicated that the spray droplets could penetrate the extremely dense foliage of genetically dwarfed trees. The spraying system was used successfully to control mites on three-year-old dwarfed peach seedlings in the summer of 1983.

Height and width adjustment test. A test was made to determine the time required to change the clearance width and height of the carrier. Height change from high to low or vice versa took only 2 minutes. Width change from the smallest dimension of 1.8 m to the largest dimension of 2.8 m required about 15 minutes. The total time required to change from the smallest inside clearance of 1.8 m wide by 1.2 m high to the largest clearance of 2.8 m wide by 2.6 m high was only 17 minutes.

Chemical Thinning

The results of fruit counts on a total of 96 branches (24 branches per treatment) are shown in Table 3. The average fruit count on April 1 (before spraying treatment) was about 160 fruits per branch. Foliage spraying of ethephon solutions at 30, 60, and 90 ppm concentrations had a significant effect on fruit thinning. Fruit thinning increased as the concentration of the ethephon solution increased. Fruit counts on June 12 indicated that the average percent of fruit remaining on each branch for 0, 30, 60, and 90 ppm treatments were 29.0, 22.5, 17.5, and 13.5%, respectively. The differences between the controlled (0 ppm ethephon) and the other three treatments are significant at the 5% level. The difference between the 30 ppm and 60 ppm treatments is not statistically significant, but that between 30 ppm and 90 ppm treatments is significant.

The effect of spraying with 200 ppm ethephon was conspicuous. While most of the branches on the untreated trees were loaded to the ground, and some were broken, the branches of treated trees were all upright and had visibly fewer and larger fruits. The results of whole-tree fruit count of three treated and three untreated trees are presented in Table 4. Untreated trees averaged 589 fruits/tree, whereas treated trees averaged only 225 fruits/tree. The average weight and dimensions of the fruits on the treated trees were significantly greater than those of fruits on the untreated trees.

Conclusions

The production costs of high-density orchards can be minimized by maximizing the number of tree rows, providing that the row spacing is still acceptable from the horticultural and operational points of view. Specially designed machines needed for harvesting and cultural operations in high-density orchards have been built and tested. The concept of using an over-the-row carrier and detachable equipment modules worked well in high-density dwarf-tree orchards.

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2. Chen, P. and H. E. Studer. 1984. High-density culture of dwarf-tree orchards -- engineering problems and challenges. Proc. Int. Symposium of Fruit, Nut, and Vegetable Harvesting Mechanization. ASAE Publication 5-84. St. Joseph, MI 49085, pp 382-388.
3. Hansche, P. E. and W. Beres. 1980. Genetic remodeling of fruit and nut trees to facilitate cultivar improvement. HortScience 15(6):710-715.
4. Van Lookeren Campagne, P. and J: van de Werken. 1984. Onderqoek van het plukbanden-systeem voor de oogst van appels en peren in volveldsbeplantingen. Rapport 64. Instituut voor Mechanisatie, Arbeid en Geobiwen (IMAG, the Netherlands).

Table 1. Conveyor system's technical data

	Elevator	Over-the-row conveyor	Central conveyor	Bin filler conveyor
Length (m)	2.7	7.6	0.9	1.65
Width (m)	0.23	0.35	0.38	0.38
Belting	Belt with fingers	Belt with carriers & V-shape centering	Belt with carriers & V-shape centering	Belt with fingers
Driving	Electric motorized drum	Hydraulic motor	Hydraulic motor	Electric motorized drum
Belt velocity (m/min)	15.6	~22	~22	21.6

Table 2. Mechanical damages of peaches ('Texas' variety) incurred during harvesting with the proposed system.

Fruit Quality (%)				
Pressure marks	With cuts	With light pressure marks	Without damages	
5	-	-	95	Manual harvesting
21	1	23	55	Fruit from the central conveyor
24.5	1.5	28	46	Fruit from the container

The damages were examined 48 hours after harvesting.

Table 3 Effect of spraying with ethephon solution on fruit thinning

Ethephon concentration	Number of branches	Number of fruits/branch (mean ± standard deviation)	
		April 1, 1987 (before spraying)	June 12, 1987
0 ppm	24	164.8 ± 25.8	47.3 ± 11.5 a*
30 ppm	24	159.6 ± 24.4	35.9 ± 11.9 b
60 ppm	24	159.1 ± 10.7	27.8 ± 12.3 b c
90 ppm	24	161.9 ± 13.5	22.0 ± 8.9 c

*Numbers followed by the same letter are not significantly different at the 5% level.

Table 4 Result obtained with spraying the trees with high concentration (200 ppm) ethephon solution

Treatment	No. of Fruits per tree	Fruit weight g	Fruit dimensions, mm		
			Length	Width	Thickness
Untreated	589 ± 46	47.3 ± 9.1	46.2 ± 3.8	40.6 ± 4.3	44.8 ± 3.5
200 ppm	225 ± 38	76.6 ± 13.3	53.7 ± 3.7	49.7 ± 6.2	53.6 ± 3.6

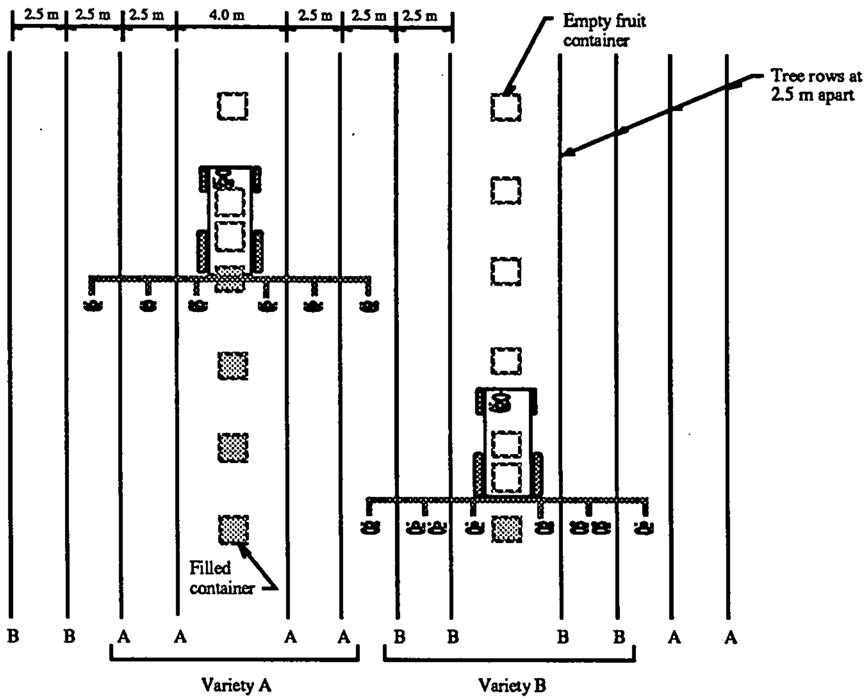

Figure 1 Proposed configuration and working team for a two-variety orchard

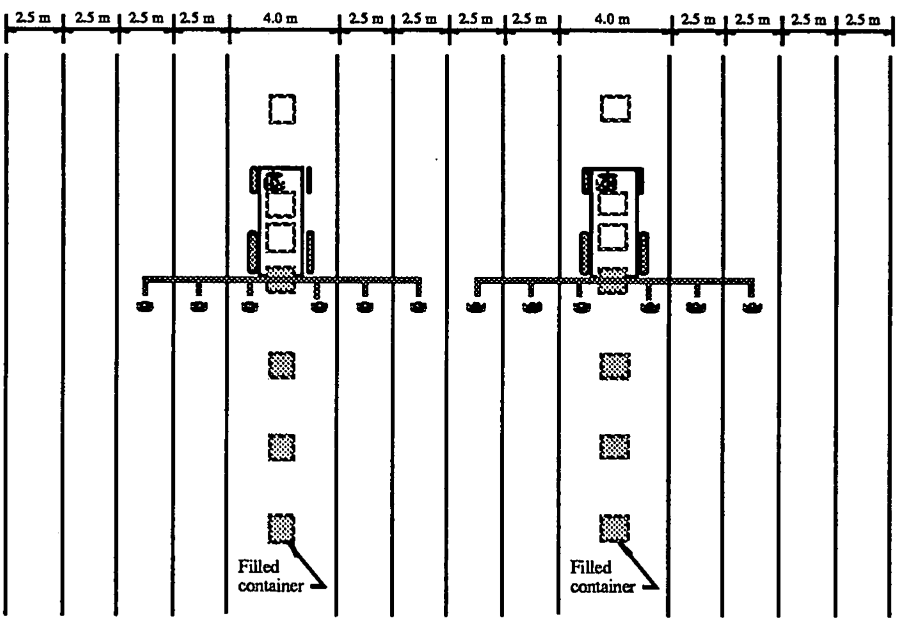

Figure 2 Proposed configuration for a single-variety orchard

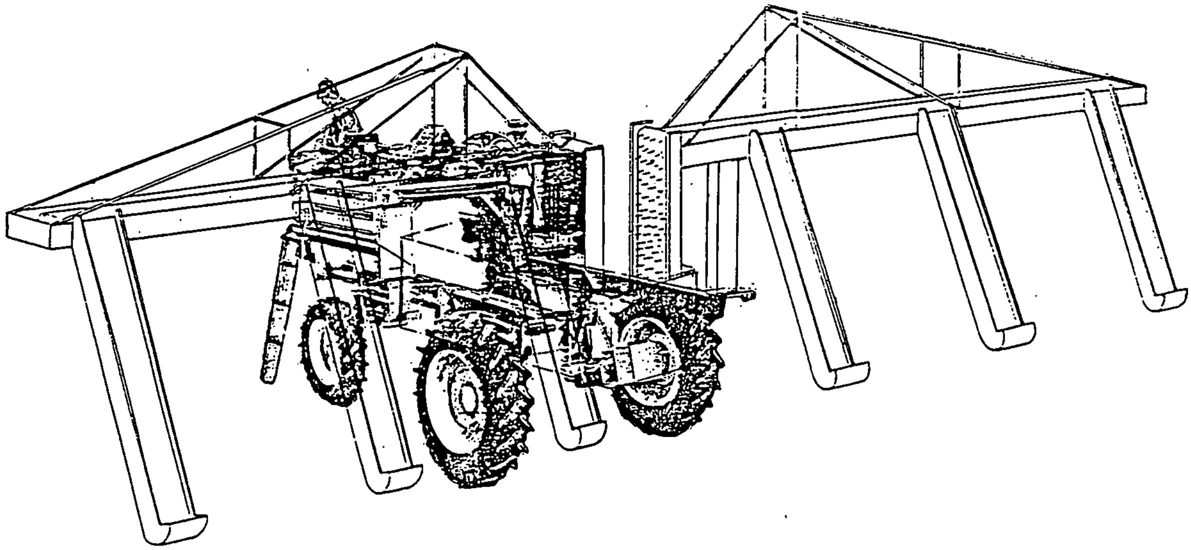

Figure 3 The proposed fruit handling system showing two cross conveyors, one on each side of the machine, and six elevators.

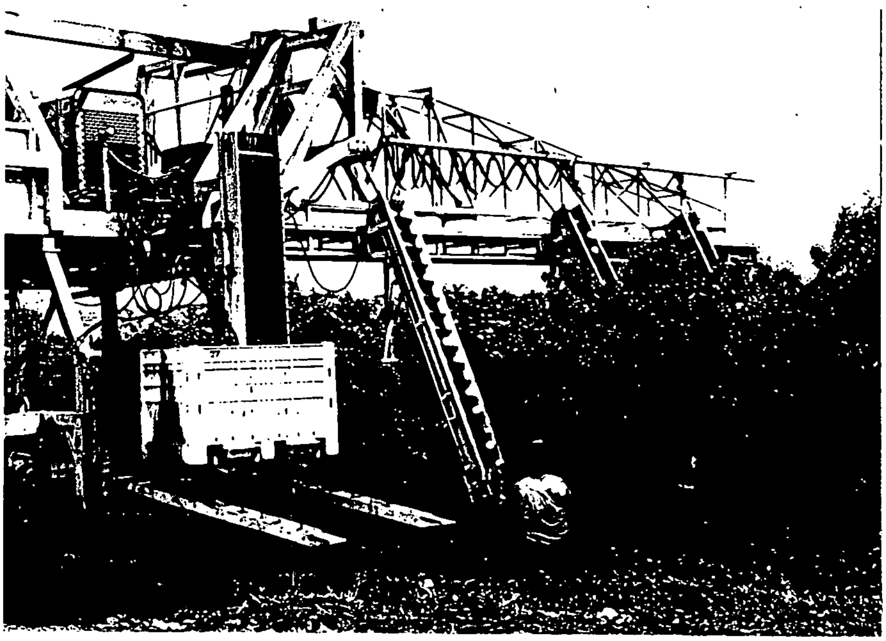

Figure 4 The experimental fruit handling system being tested in a high-density citrus orchard

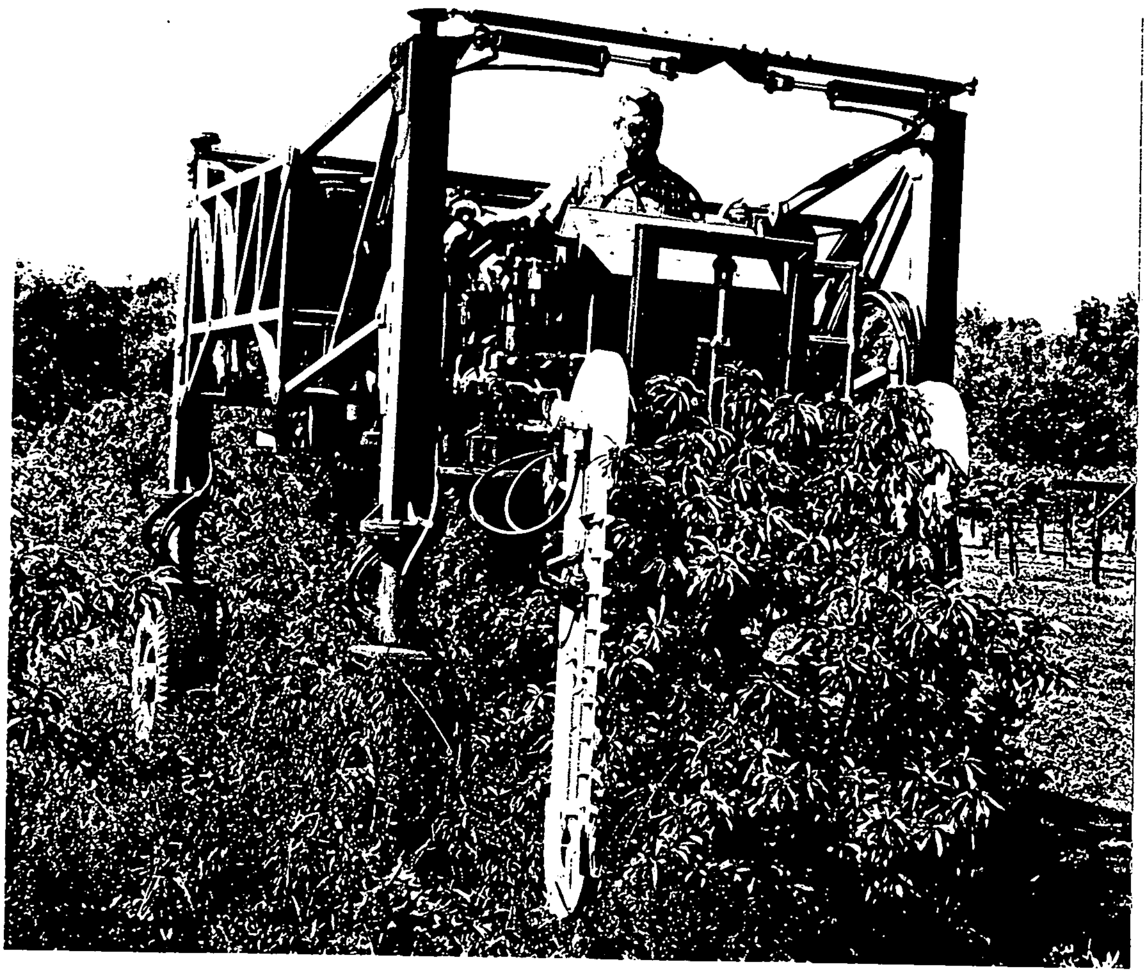

Figure 5 The over-the-row machine, equipped with the hedging module, is being tested in a high-density orchard of genetically dwarfed peach trees.

Description and Results of Cooperation

Activities of the Israeli team focussed on the economic evaluation, design, and construction of a semi-mechanized integrated system for harvesting fruits in dwarf intensive orchards. The U. S. team directed research efforts toward developing and testing various equipment modules for cultural operations in high-density dwarf-tree orchards and investigating methods for thinning fruits on genetically dwarfed peach trees.

The Israeli team leader, Dr. Yoav Sarig, made a trip to the U.S. in the summer of 1987 to discuss research plans of both teams. Plans were made for both teams to complement each other's research and to avoid unnecessary overlapping of work. Dr. Sarig spent his sabbatical leave in Davis, California, from September, 1988 to September, 1989. During this year, additional field testing of the Israeli harvesting system were planned, and extramural funding was obtained for evaluating the application of the machines developed by this project to commercial high-density peach orchards in California.

The final project report was written jointly by researchers from both teams.

Evaluation of the Research Achievements

This research project resulted in the development of an experimental fruit harvesting and handling system and an over-the-row machine and equipment modules for various cultural operations in high-density dwarf-tree orchards. The Israeli team has established design requirements for a fruit harvesting and handling system based on economic and horticultural studies of high-density dwarf-tree orchards. The proposed system has been designed, and one half of the system has been built and tested.

The U.S. team has designed and built an over-the-row machine with detachable equipment modules for spraying, hedging, pruning, and cultivating operations. The machine and different equipment modules were tested in a genetically dwarfed-peach orchard. The U.S. team also conducted chemical thinning tests on genetically dwarfed-peach trees, and obtained promising results.

This research provided useful information for developing equipment for high-density orchards. Although the use of the harvesting system may not increase the picking rate nor improve the quality of the fruits, the system does provide a fruit handling method needed for harvesting fruits in high-density orchards. The common problem of excessive cost of single-purpose machines can be alleviated by using a multi-purpose power frame and detachable equipment modules.

The row spacings of many existing high-density fruit orchards are limited by the available machines. The availability of over-the-row equipments would enable growers to increase tree density (within horticultural limit) and further improve the efficiency of fruit production.

List of Publications

1. Chen, P., J. J. Mehlschau, G. Huang, and Y. Sarig. 1987. An over-the-row machine for high-density dwarf-tree orchards. ASAE Paper No. 87-1034. For presentation at the 1987 Summer Meeting, American Society of Agricultural Engineers, Baltimore, MD, June 28-July 1, 1987. (Published in Applied Engineering in Agriculture 4(2):111-117. 1988)
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4. Sarig, Y., Grosz, F., Chen, P., Kendel, R., Pasternak, H. 1988. Preliminary evaluation of an engineering system for production and harvest of citrus fruit grown in high density dwarf tree groves. Proc. 6th Int. Citrus Congress Middle East, Tel Aviv, Israel 4:1811-1817.

Reprints of Publications

An Over-The-Row Machine for High-Density Dwarf-Tree Orchards

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ABSTRACT

An over-the-row, self-propelled carrier and equipment modules for cultural operations have been designed and constructed for use in high-density dwarf-tree orchards. The four-wheel drive, four-wheel steering machine is powered hydraulically and can be adjusted to straddle dwarf trees of different sizes. The inside clearance of the machine can be easily changed from 1.8 m x 1.2 m to 2.8 m x 2.6 m in 17 min. The concept of using an over-the-row carrier and detachable equipment modules worked well in high-density dwarf-tree orchards.

INTRODUCTION

High-density culture of dwarf tree orchards has been the subject of an ever-increasing number of studies in recent years. Results of recent studies indicate that a high-density peach orchard of genetically dwarfed trees can produce earlier and yield much more fruit per unit area than does a standard orchard. Hansche and Beres (1980) found that four-year-old genetically dwarf peach trees planted at 3750 trees/ha can produce more than 25 t/ha the second year after planting. In the fourth year, the yield of high-density dwarf peach orchards can be triple that of standard peach orchards of the same age planted at 270 trees/ha and can be double that of mature standard clingstone peach orchards grown in California. However, this high-density cultural method also presents new engineering problems (Chen and Studer, 1984). Because the trees are small and planted at high density, existing machines are not suitable for such orchards. Moreover, genetically dwarfed trees have certain characteristics—such as extremely dense foliage, heavy fruit set, and bushy tree structure—that may require new techniques for various phases of cultural and harvesting operations. Success of this new fruit production method depends on the availability and proper utilization of suitable equipment for cultural, harvesting, and fruit handling operations.

Tennes et al. (1976) suggested concepts for mechanizing high-density orchard fruit culture by using multipurpose machines designed to incorporate several functions into a complete fruit-cultural equipment system. Although Tennes and Brown (1981) subsequently built an over-the-row machine and a sway-bar shaker for harvesting operation, they did not report the development of equipment for other operations. Several groups of researchers have worked on the development of mechanical harvesting systems for high-density orchards (Allshouse and Morrow, 1972; Berlage and Langmo, 1974; Monroe, 1982; Peterson, 1984; and Webb et al., 1973). All these machines were designed for semi-dwarf trees and were not suitable for smaller genetically dwarfed trees.

OBJECTIVES

The objective of this research was to develop an experimental machine with equipment modules for various cultural operations in high-density orchards of genetically dwarfed peach trees. This report describes the design of an over-the-row carrier and different equipment modules.

MACHINE DESCRIPTION AND DESIGN CONSIDERATIONS

General Requirements of the Experimental Machine

A common problem related to any type of orchard machinery is the lack of operation space in the orchard. For high density orchards the space between trees within the row is eliminated, and space between rows is so limited that it is practically impossible to use conventional orchard equipment between tree rows. Thus, a machine for high density orchards should be designed to fit in the narrow row spacing. This criterion is met by the over-the-row concept which is commonly used in vineyards and berry fields and has been used experimentally for harvesting dwarf fruit trees (Allshouse and Morrow, 1972; Berlage and Langmo, 1974; Monroe, 1982; and Peterson, 1984). Additionally, the inside clearance of an experimental machine should be easily adjustable in height and width to fit dwarf trees of different sizes and different row spacings. The machine should be reduceable to 2.4 m overall width and 3.2 m height for transportation. Other important design criteria include high maneuverability, good visibility, ease in attaching equipment modules, and an adaptable, ample power supply.

Description of the Over-the-Row Carrier

An over-the-row self-propelled carrier has been designed and constructed as a prime mover for carrying different equipment modules in high-density orchards. The machine has four-wheel drive and four-wheel

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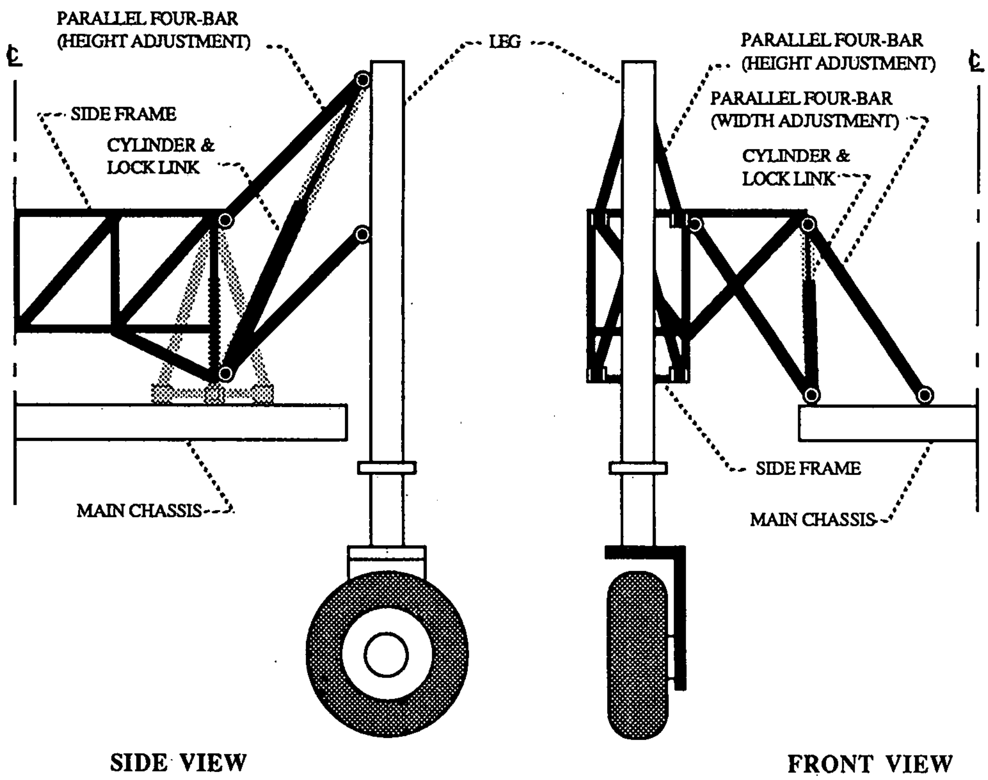

Fig. 1—Schematic drawing of the over-the-row carrier showing the main chassis, side frames, legs, and parallel four-bar linkages for width and height adjustments.

steering capabilities and is powered hydraulically. This machine is uniquely designed so that its inside clearance can be easily adjusted from 1.8 m wide by 1.2 m high to 2.8 m by 2.6 m. The adjustment is accomplished through hydraulically powered parallel four-bar linkages. Each set of these four-bar linkages is powered by a diagonally mounted cylinder and can be locked in discrete positions by a telescopic lock-link mounted parallel to the cylinder.

The machine consists of three major components: main chassis, two side frames, and four legs. The main chassis is attached to the side frames through four identical sets of parallel four-bar linkages, hydraulic cylinders, and lock-links—one set at each corner for width adjustment (Fig. 1, front view). Each side frame is in turn attached to two legs (front and rear) through two identical sets of parallel four-bar linkages, hydraulic cylinders, and lock-links for height adjustment (Fig. 1, side view). The operator station, engine, hydraulic pumps, and most of the hydraulic components are mounted on the main chassis. The 130-L fuel tank and 150-L hydraulic oil reservoir are mounted in the side frames. The machine without any equipment module weighs about 4.5 tons.

Hydraulic Power Supply

A 60-kW water-cooled gasoline engine supplies power through a dual pump drive to the hydraulic system. Hydraulic oil from the reservoir supplies pumps for four separate circuits. One is the charge pump of the closed-circuit hydrostatic ground drive (Fig. 2). The other three are sections of a stack pump that provide constant flows of 34, 34, and 45 L/min (Fig. 3). The flow of one of the 34 L/min sections is divided between a stack of four-way valves for controlling height and width adjustment (10.2 L/min) and power steering (23.8 L/min). The return from the power steering is again divided with a 4-L/min flow sent through the wheel motor cases and hydrostatic pump case. A four-way valve is used in the steering circuit to direct flow to the rear steering cylinders for four wheel and crab steering modes. Relief valves, which limit operating pressure at 13,800 kPa, are located at the pumps for all three sections. Quick disconnects with manually operated two-way dump valves tee'd into the line are attached directly to two of the pumps following the relief valve. The returns form power steering and the stack valve are also fitted with quick disconnects and dump valves. This arrangement gives flows of 6, 24, 34, and 45 L/min. When the various modules are attached, they are equipped with their own control valving and are plugged into the appropriate quick disconnects. The tree hedging unit requires approximately 30 L/min for the cutter bar motors and 7.5 L/min for a lift cylinder. The spraying unit requires 34 L/min for the solution pump and 23 L/min for each spray fan. The cultivating unit requires 80 L/min for the drive motor and 7.5 L/min for a lift cylinder. Required flows were achieved by combining various pump section outputs and using flow dividers.

A cross-over relief valve limits loop pressure of the ground drive circuit to 24,000 kPa which, with the 38-mL displacement motors, 30:1 planetary drives, and size 9.00-16 tires, produces up to 38.5 kN of drawbar pull. For higher road speed, series/parallel valving is used between the front and rear wheel motors to achieve a two-speed hydrostatic drive of 3 and 6 km/h (Fig. 2).

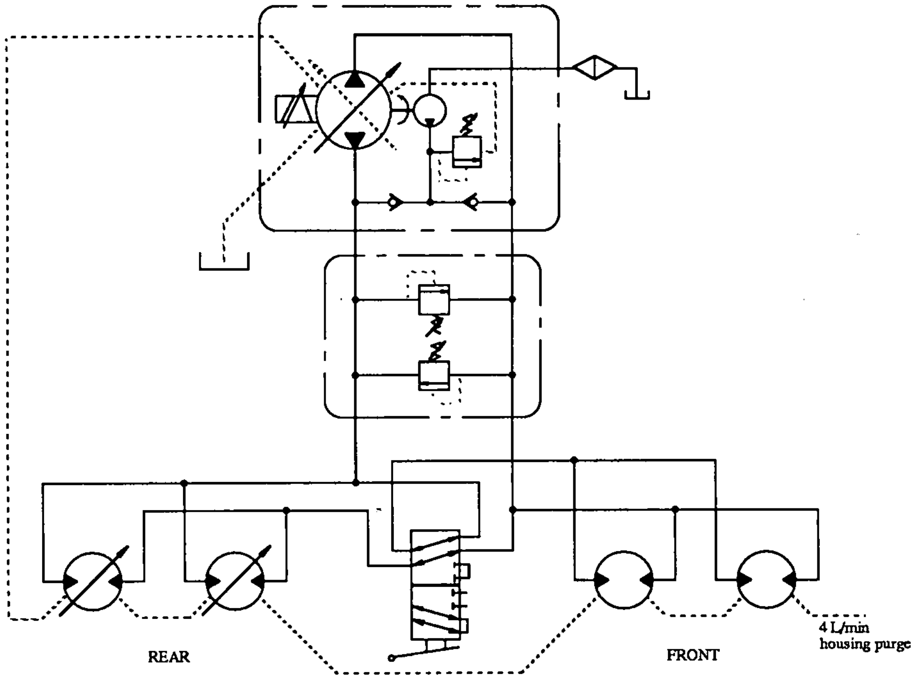

Fig. 2—Hydraulic circuit for hydrostatic ground drive.

Procedure for Changing Width and Height of Machine Clearance

To change the height of the machine clearance, the main chassis and side frames are raised/lowered relative to the legs. This is done by first removing the lock pins from the telescopic links at the two front legs, powering the cylinders until the front of the machine reaches the desired height, and then placing the lock pins in new holes corresponding to the new height. Needle valves at the stack of four-way control valves limit the rate of lowering. The same process is then repeated for the rear end of the machine.

The procedure for changing the width of the machine follows a similar unlocking and hydraulic cylinder powering sequence. However, the presence of a steering tie rod and the fact that tires do not slide well sideways add steps to the width-change process. Either of two procedures can solve the tire problem. For the first method, place a supporting frame (structure from pruning aid module) between the right side of the main chassis and the ground. Then, follow these steps: (a) loosen telescopic section of front and rear steering linkages, (b) remove lock pins from the two width adjusting linkages on the right side of the machine, (c)

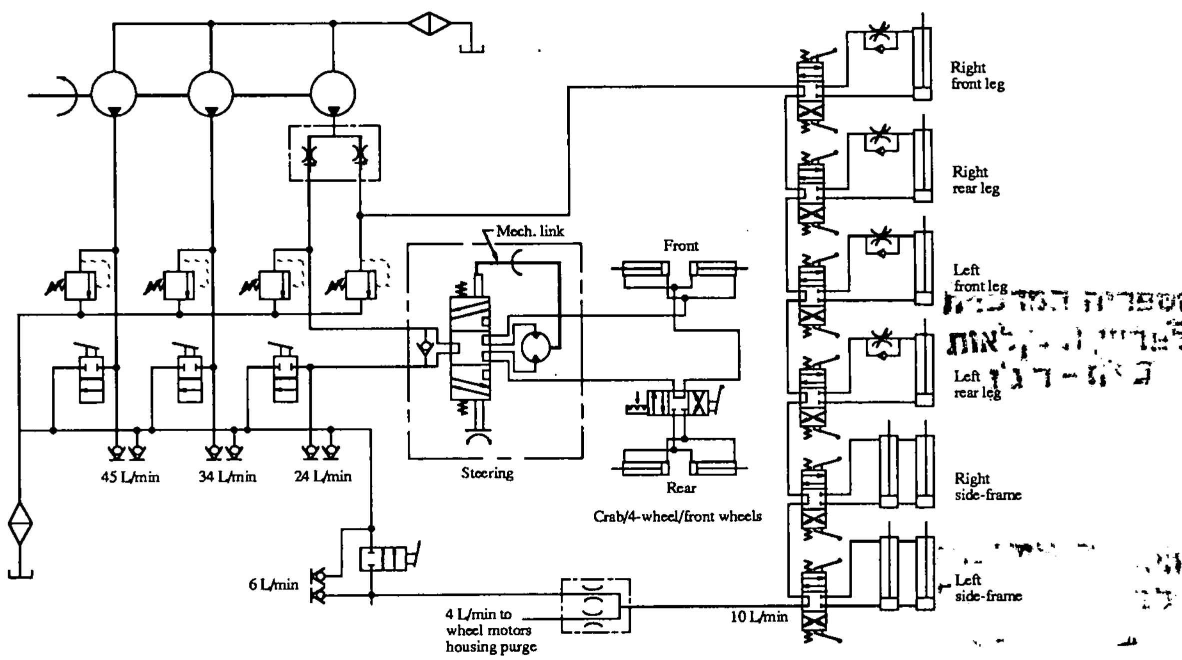

Fig. 3—Hydraulic circuit for the power supply to power steering, height and width adjusting cylinders, and equipment modules.

remove the lock pins from the two height adjusting linkages at the right front and right rear legs, (d) power the cylinders to lift the two right legs off the ground (the right side of the machine is now resting on the supporting frame), (e) power the cylinders at the two width-adjusting linkages to move the right side-frame and legs assembly out to the desired width, (f) replace the lock pins in the telescopic width-adjusting linkages, (g) lower the two right legs to the desired height and lock the linkages in place, (h) move the supporting frame to the left side of the main frame and repeat steps (b) through (g) for the left side of the machine, (i) adjust the steering linkages and tighten the lock bolts. A second, quicker procedure is to follow the steps for releasing the steering links and width locking links (one side at a time) and then to advance the machine while activating the hydraulic control for the cylinders at the two width adjusting linkages. This procedure allows the side frames to change position as the wheels are gradually skidded sideways. This method is very fast, but it has the risk of the wheels steering in a counter-productive direction either because of the terrain or friction in the telescopic portion of the steering tie rod.

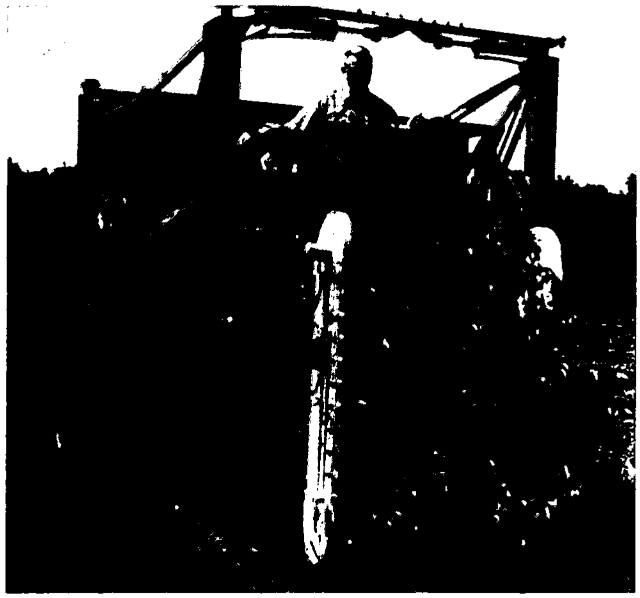

Fig. 5—Hedging module with the two cutter bars mounted in vertical position.

Description of Equipment Modules

The following equipment modules have been designed and built: a spraying unit, a tree hedging unit, a mechanical aid for hand pruning, and a cultivating unit. The general design criteria for these equipment modules are as follows: (a) the module should be easily fabricated, and commercially available components should be used whenever possible; (b) the module should be easily attached to or detached from the carrier, and (c) each unit should perform its function well.

The spraying unit consists of six 40-cm Span Spray fan-type spraying heads, capable of uniformly delivering 935 L/ha, mounted on a frame under the carrier (Fig. 4). The spraying heads and portions of the support frame are clamped in place tool-bar fashion to allow reconfiguration from two rows of small trees to a single row of large trees with up to six fans per row. The spray heads can be positioned around the tree so that they blow the spray into the tree from all directions (top and two sides). The high speed air from different fans shakes the branches and helps improve penetration of the spray into the dense foliage.

The hedging module consists of two 1.2-m Chisholm-Ryder vineyard trimmer cutter bars vertically mounted on a frame which is mounted in front of the carrier (Fig. 5). The cutter bar has a set of moveable cutting blades attached to a moving belt and a set of stationary blades fixed on the cutting bar. Continuous cutting action is produced by moving the movable blades along side the fixed blades. The horizontal distance between the two cutter bars and their vertical position are adjustable. One of the cutter bars can be rotated 90 deg into horizontal configuration for trimming the top of the trees (Fig. 6).

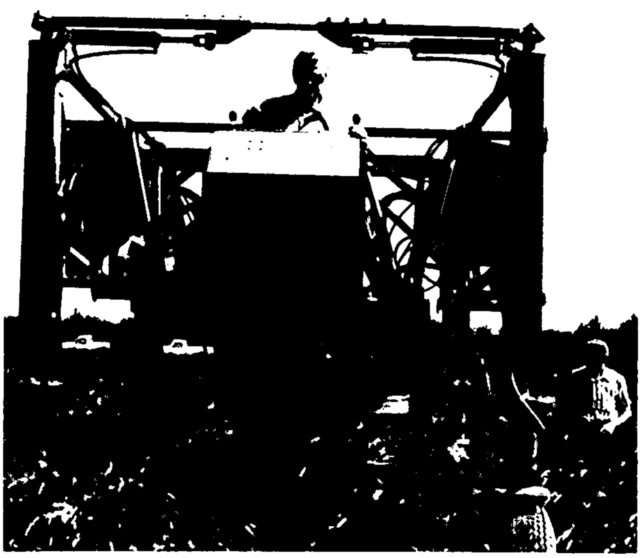

Fig. 4—Spraying module with six fan-type spraying heads mounted on a frame under the carrier. The machine is being used to spray three-year-old dwarf peach seedlings.

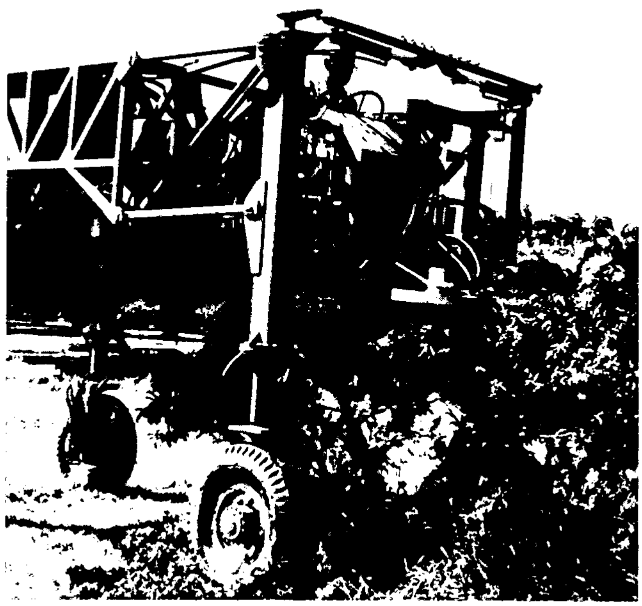

Fig. 6—Hedging module with one cutter bar rotated 90 deg for topping the trees.

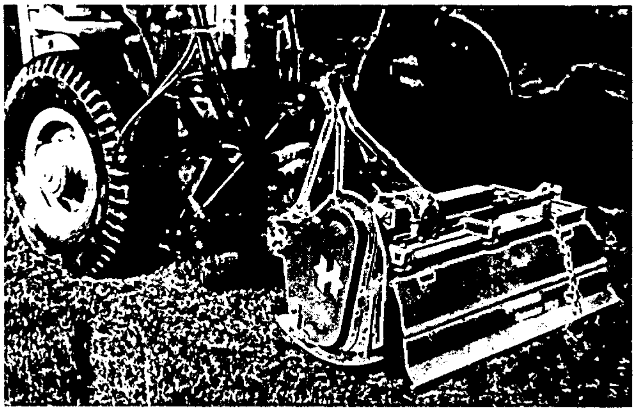

Fig. 7—The cultivating module mounted on a vertical frame suspended under the carrier.

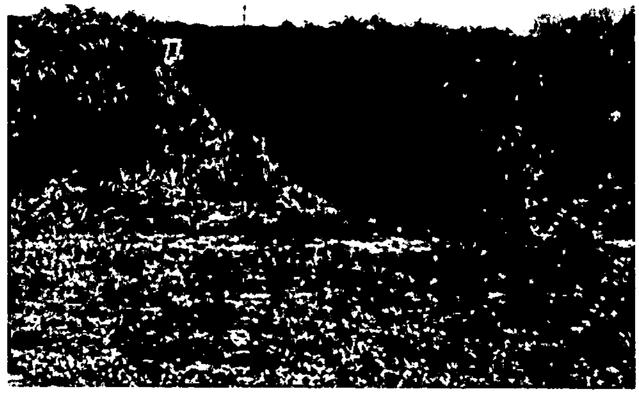

Fig. 9—Five-year-old genetically dwarfed peach trees after hedging.

The pruning unit is a worker's aid. It consists of a frame suspended under the over-the-row carrier. The frame has four seats, two on each side of the row, for the manual pruners to sit on while pruning the trees with hydraulically powered pruning shears.

A 1-m wide Howard rotavator is used for cultivating. The rotavator is mounted on a vertical frame suspended under the over-the-row carrier (Fig. 7). A hydraulically powered, spatial, parallel-bar linkage between the vertical 3-point frame of the rotavator and the vertical mounting frame on the carrier provides both powered up and down and free horizontal motions. Engagement of the rotating blades and the soil results in a forwarding force which, when combined with the constraint of the linkage, tends to swing the rotovator diagonally forward into the tree row. Subsequent contact with a tree causes the rotavator to swing away from the tree row.

PRELIMINARY TESTS

The machine was tested in an experimental orchard of genetically dwarfed peach trees planted at 1.2 m spacing within the row and 3.3 m between rows. The trees were planted in 1981 and had not been hedged or pruned previously.

Hedging

A hedging test was conducted in April, 1986. The cutter-bars were set 1.2 m apart for vertical cuts. Both sides of the trees were cut at the same time. Then one of the cutter bars was rotated and set in a horizontal position 1.5 m from the ground, and the trees were topped off at 1.5 m. The cutter-bars worked well with branches under 2 cm in diameter. The blades were frequently stopped by larger branches, especially those which were oriented in such a way that the angle between the branch and the cutter-bar was less than 45 deg. Figs. 8 and 9 show the tree rows before and after hedging, respectively. After the hedging operation the trees remained in good hedged rows for the entire year. Figs. 10 and 11 show the hedged trees in the following summer and early spring of the next year.

Cultivating

A cultivating test was conducted in the spring of 1987. A 1.2-m wide strip of ground extending laterally from the center of the tree row was cultivated. The cultivator performed well in chopping up the weeds under the dwarf trees as shown in Fig. 12. When the cultivator

Fig. 8—Five-year-old genetically dwarfed peach trees before hedging.

Fig. 10—Five-year-old genetically dwarfed peach trees 3 months after hedging.

Fig. 11—Hedged genetically dwarfed peach trees in early spring (11 months after hedging).

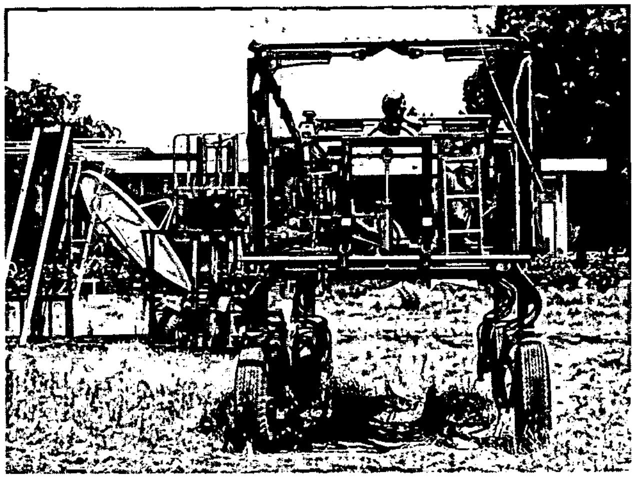

Fig. 13—Over-the-row carrier adjusted to minimum inside clearance (1.8 m wide x 1.2 m high).

came in contact with the tree trunk, it automatically swung away from the tree. However, the force created by the rototilling action was not strong enough to pull the cultivator back into the original position. This problem can be alleviated by using a spring or a hydraulic cylinder to assist the return swing of the cultivator. We plan to make modifications to correct this problem.

Spraying

The over-the-row machine equipped with the spraying module was tested in the spring of 1983. A preliminary test with water indicated that the spray droplets could penetrate the extremely dense foliage of genetically dwarfed trees. The spraying system was used successfully to control mites on three-year-old dwarfed peach seedlings in the summer of 1983. Additional tests will be made to determine spray droplet distribution in mature dwarf trees.

Height and Width Adjustment Test

A test was made to determine the time required to change the clearance width and height of the carrier. Height change from high to low or vice versa took only 2 min. Width change from the smallest dimension of 1.8 m to the largest dimension of 2.8 m required about 15 min. The total time required to change from the smallest inside clearance of 1.8 m wide by 1.2 m high (Fig. 13) to the largest clearance of 2.8 m wide by 2.6 m high (Fig. 14) was only 17 min.

General Performance of the Over-the-Row Carrier

The machine performed quite well in general. Machine height was easily changed for transport each time the unit went to the field. The four-wheel drive and four-wheel steering features greatly aided the mobility and maneuverability of the machine. Visibility was good during hedging and spraying operations. Although the operator could not see the cultivator well during cultivating operation the poor visibility was not a significant problem because the cultivator was designed to go around the tree trunk automatically. The main problems were low traction and soil compaction due to the narrow 9.00-16 size, 8-ply truck tires which came with the wheel-drive assemblies salvaged from an old melon-pickup machine. These problems can be

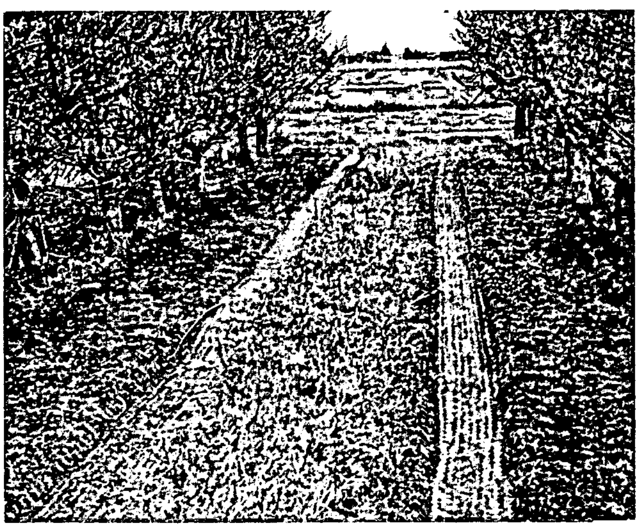

Fig. 12—Cultivated ground under the dwarf-tree rows.

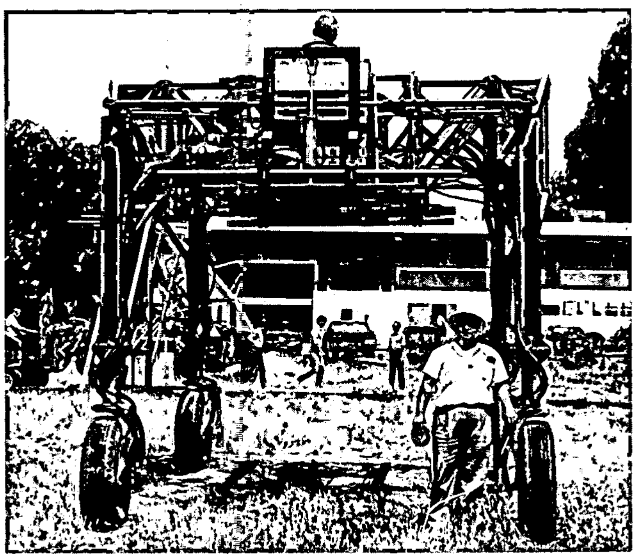

Fig. 14—Over-the-row carrier adjusted to maximum inside clearance (2.8 m wide x 2.6 m high).

corrected by replacing the existing tires with high floatation tires. This change may require the redesigning of the wheel-drive assembly.

CONCLUSIONS

An over-the-row, self-propelled carrier has been designed and constructed for use in high-density dwarf-tree orchards. The four-wheel drive, four-wheel steering machine is powered hydraulically and can be adjusted to straddle dwarf trees of different sizes. The inside clearance of the machine can be easily changed from 1.8 m x 1.2 m to 2.8 m x 2.6 m in 17 min. Equipment modules for spraying, hedging, pruning, and cultivation have been built and preliminary tested in an experimental high-density orchard of genetically dwarfed peach trees. Although the equipment modules still require additional modifications to improve their performance, the concept of using an over-the-row carrier and detachable equipment modules for cultural operations in high-density dwarf-tree orchards worked well.

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