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ARTIGO TÉCNICO

HARVESTING FRUITS USING A MOBILE PLATFORM: A CASE STUDY APPLIED TO CITRUS

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KEYWORDS

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ABSTRACT

Harvesting fruits and vegetables has been a challenge. Mobile platforms for harvesting vegetables and fruits have been used, but with some limitations, such as their applicability for a certain time of the year and for a specific crop. A mobile platform was initially developed for harvesting fresh market tomatoes, mainly staked in Brazil. However, after field trials, many problems were identified, such as crop use limitation and machine structure problems. Therefore, the initial project was reformulated to assume different functions, with a retractable and smaller frame and the possibility of adding on other devices, expanding crop harvest and farm use. The concept of a hybrid vehicle with one electric power generator to drive all four wheels with electric motors was kept. The main goal of this article is to describe the development of the mobile platform machine structural details and integration of electrical, hydraulic, and mechanical project and field tests performed in a commercial orange orchard, comparing harvest types, evaluating yield and machine performance. Tests with the mobile laboratory prototype show its potential application to assist harvest and to other farm operations, especially due to its mobility. Harvest productivity through machine was higher, though not significantly different from manual harvest.

INTRODUCTION

Harvesting Fruits and Vegetables

Worldwide, in recent years, it has been a challenge to harvest fruits and vegetables for the fresh market and processing industry. Sarig (2012) considers that mechanical harvest has not increased for many horticultural crops mainly because in the past, harvest labor was available at low cost. Manual harvest may also have a number of advantages compared to mechanical harvest. Trained pickers can easily detect and select appropriate fruits for harvesting (Prussia, 1985). However, manual harvest is a very intensive labor activity and exposes workers to health risk factors. There are number of studies pointing to the hazards and physical damage that occurs during manual harvest of vegetables (Chapman et al., 2004; Fathallah, 2010) and fruits (Earle-Richardson et al., 2006; Fathallah, 2010). Human performance can be enhanced by modifications in three areas: physical factors, organismic factors, and adaptive factors (Prussia, 1985). Mechanical equipment to assist harvest can especially

improve physical factors, providing better work conditions, compared to only manual activity (Prussia, 1985). Picking platforms can greatly improve harvesting conditions for workers and, due to reduced physical demands, can include many previously excluded workers. Picking platforms can therefore also be an important aid in decreasing musculoskeletal disorders – MSD (Fathallah, 2010).

Harvest aid machines can be a valuable alternative for improving labor conditions in the field and increasing harvest yield (Sarig, 2012; Elkins, 2012). Picking aids have been studied for a number of crops, but applied to few. Seamount & Opitz (1973) described a mobile platform for orange harvesting. Whitney et al. (2012) reported that mobile platforms had been used to replace ladders in citrus harvest in the 1950s, but even with a 30-40% gain in productivity, growers did not adopt them, preferring to invest in mechanical harvest. A similar situation was found for pears. Elkins (2012) reported that mobile platforms were largely used on pears on the 1970s, with many advances - inexperienced workers could harvest

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and improve their productivity from 5-50% (average 25%) through a broad range of canopy access. Those platforms are no longer in use, and the main reasons indicated are related to labor availability and that the platforms are not an advantage for experienced crews whose members are paid individually. However, according to the same author, this situation is now changing, due to shortage of labor availability. Sanders (2005) noted that harvest efficiency evaluation is limited to the individual; for the use of harvest aid equipment, harvest as a group must be considered, and that could be a limitation. Costa & Camarotto (2012) reported a similar situation on the use of a mobile platform for citrus harvest. However, trained pickers showed a 60% increase in productivity. On the other hand, Cubero et al. (2014) and Vidal et al. (2013) described a mobile hand picking platform that sorting were efficiently done using a computer vision system, showing an improvement of this system.

Citrus harvesting

Brazil has become a large scale orange producer in recent decades, with 16,197,828 t of an area of approximately 688,248 ha in 2015 (Agriannual, 2017), and in 2014 employed about 138,000 people (RAIS & CAGED, 2014), mostly in harvesting operations. The main part of this production is for juice exportation, 70%, and 30% is to internal market (Neves et al., 2013).

Therefore, citrus fruits are economically important for Brazil; yet challenges arise in harvesting, with increased costs in harvesting from 30 to 44% on recent years (Neves et al., 2013). Sanders (2005) estimates about 35-45% of total citrus production costs are related to harvest. Agriannual (2017) reports similar values, depending on the crop system, reaching up 47%. Citrus harvest has been widely studied, especially looking at mechanized harvest. Whitney & Harrel (1989) gave a historical overview of citrus harvest, starting in the early 1960s, showing an increase in harvesting costs and dependence on hand labor. Basically, the same principles of the mechanical harvest system used at that time are still in use today, with application of shake-catch systems. There are four main mechanical harvesting techniques for citrus: (a) air shaking, (b) trunk shaking, (c) limb shaking, and (d) canopy shaking (Sanders, 2005; Torregrosa et al., 2009). Some of these are used not only for citrus, but also for other crops. The shaking modality is used for olives

(Sessiz & Ozcan, 2006), pistachio nuts (Polat et al., 2007), and apricots (Erdogan et al., 2003). However, Roka & Hyman (2012) reported that mechanical citrus harvest has been decreasing in the state of Florida, USA, in recent years mainly due to tree damage, recovery time for the next crop season, and the increase in greening disease. Sanders (2005) stated that, for citrus, none of the current mechanical harvesting systems are efficient, and an alternative is to improve manual harvest, increasing productivity. Li et al. (2011) reported in an extensive review about mechanization applied to citrus, that none of the current systems are able to replace efficiently humans on the ability of fruit selection. However, Miranda et al. (2015) observed that there are different impacts levels on manual harvest, especially when using fruit detachment instead of hand harvest. Therefore, there is a clear indication for improvement on citrus harvest.

MATERIAL AND METHODS

Previous Studies. Mobile platform for harvesting fresh market tomatoes

Initially, prior to designing and constructing the first platform, field tests were held with prototypes to determine operating parameters. Sanchez et al. (2006) simulated different harvest situations to choose the ideal travel speed for each fruit density per plant in different picker positions, testing pickers seated, standing, and walking behind the harvest aid machine. Results of initial tests showed that the best potential configuration to be applied to the harvesting platform would be pickers standing behind the machine. The parameters measured in those tests were used in the first harvest aid platform design, allowing harvest of 3 to 4 crop rows. Subsequently, this harvest aid unit was developed to enable multiple harvests, sorting and packing fresh market tomatoes, and the machine had an estimated capacity of two metric tons per working hour based on average field production for table tomatoes, which is dependent on harvest yield and crew training.

The mobile platform operated with ten people as follows: three for harvesting, three for sorting, three for packing, and one for driving. Platform measurements were 6,650 m width, 7,635 m length, and 3,715 m height (Figures 1 and 2). Harvest speed was usually low at 0.044m/s, but the machine could reach over 0.28 m/s.

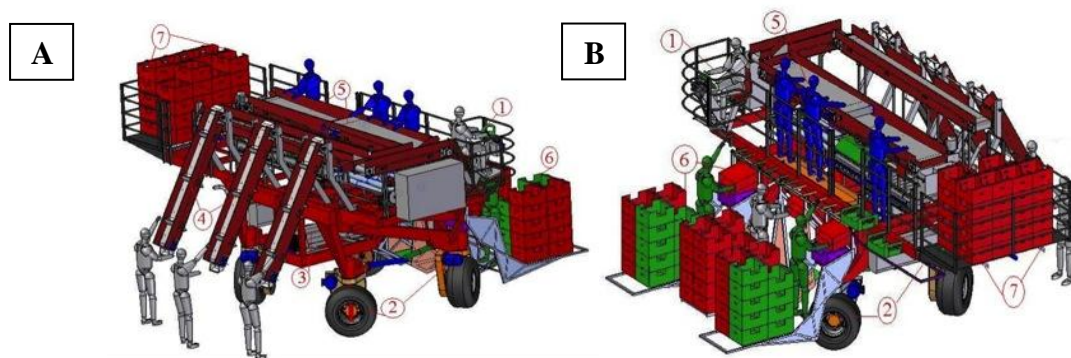


FIGURE 1. View of the machine. (A) View of the harvesting system with a detailed view of the fruit supply module including three supply conveyors and showing three pickers. (B) Back view of the machine. The machine has the following components: 1) steering control system 2) 4-wheel steering control system; 3) power supply module 25-kva motorized; 4) fruit supply module, with three supply conveyors; 5) sorting and classification module; 6) three packing modules and 7) compartment for empty boxes. Total of ten operators.



FIGURE 2. Clockwise: Front and back view of the equipment, to tomato field and mobile platform in operation.

Mobile Platform for multiple uses

Initial tests were performed with the first prototype (Figures 1 and 2) and problems were identified such as: (1) excessive length, making transport and maneuvers in the field difficult; (2) gaps too narrow for the passage of fresh market to mato plants; (3) lack of adjustment in the frame, restraining use only to crops with previously planned spacing; (4) mechanical structural problems in the chassis with cracking, leading to calculation of new structural component; (5) equipment restrictions for other uses on a farm. The platform was therefore modified to include a retractable chassis containing lateral drilling for adding attachments (Figures 3 and 4).

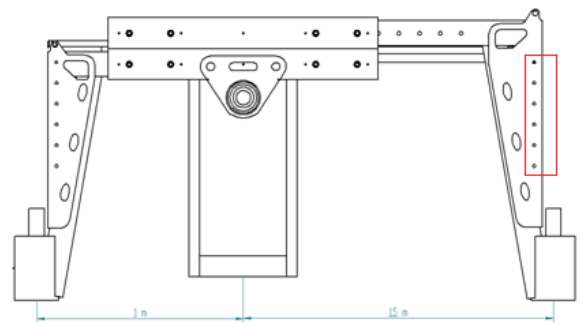


FIGURE 4. Retractable chassis with lateral drilling for adding attachments.

Description of Physical Structure

The new modified machine consists of an agricultural vehicle with a mobile platform with the following measurements: 2.0 m width, 4.0 m length, and 3.6 m height (Figure 5), with smaller dimensions than the previous format, allowing the machine to operate in plant rows from 2 meters (fully retracted gauge) to 3 meters (completely open gauge), with the possibility of variation at 20 centimeter intervals (Figure 5). The upper deck of the machine was completely redesigned to permit adjustments of its transverse position, allowing adaptation to perennial crops such as citrus and apple, with a wide range of variance in row width. The adjustment control of these decks is performed through hydraulic pistons, allowing quick and easy adjustment by the operator, even with the vehicle in movement. An important additional advantage is related to retractability of the chassis for transport, since it was very complicated to move the previous mobile platform from one place to another due to size. After those alterations, the machine fits in a common truck body, with significant reduction in transport cost.

The prototype machine has transmission and steering systems, directly controlled by an operator, which allow performing maneuvers in tight spaces and turning on its own axis, as well as a four wheel drive system, impelled by electric motors powered by an electric



FIGURE 3. (A) Former mobile unit showing fixed gauge and a narrow gap for plant rows (on blue lines). (B) New prototype with retractable gauge and showing expanded space for plant rows (on red line).

generation module located in the central region of the machine. This module consists of a diesel power generator (35 kva) for power supply (220V three-phase system) for all drives on the machine. The frame support for the electric power supply module for the entire machine was refurbished, improving weight distribution and becoming narrower for better use in harvesting the tomato crop, freeing space for plant rows. This module has become a detachable part of the machine by the simple removal of four screws, making maintenance easier and allowing its use as a motor-generator or other source of mechanical energy when the platform is not in use.

The mobile platform has the following accessories: Ladders in front and back to access the top of the machine; a narrow platform placed on the back for disposal of plastic boxes for fruit packaging; an picking station with a 0.5 m circular base and 1.2 m height. In all sides of the chassis holes, it is possible to attach distinct accessories for use in different crops and for specific farm demands, providing versatility to the machine (Figure 5).



A



B

FIGURE 5. Mobile platform in harvest position with a picking station. (A) Front view. (B) Back view, showing narrow platform for box disposal.

Electrical and hydraulic system

Although the two systems have independent activities, when the machine is in movement, it is necessary that both work together since the hydraulic system has electrically operated valves. Both systems are described below.

Electrical System

The electrical structure consists of a panel that commands the electric motors installed on the wheels. The control cabinet is located on top of the chassis, isolated through cushions, thus minimizing the effects of vibration. This panel contains: four frequency inverters, model 001 CFW 11 6T2SZ (WEG brand); motor load contactors; fuses; circuit breakers; supply sources; and auxiliary contactors that will determine the direction of rotation. This electric system has the function of directing the machine logic control that drives the machine (forward, reverse, and turns), hydraulic brake valves, and monitoring lights.

Hydraulic System

The hydraulic system in this machine is used to: steer the wheels, drive the mobile side decks, and brake the vehicle. Basically, the system consists of an oil reservoir that feeds a gear pump driven by pulleys and a multichannel belt directly on the main shaft of the power generator. The pilot operation valves used were double solenoid, 24V. Substitution of these valves solved locking problems in the first prototype platform observed during maneuvers, improving the functioning of the entire hydraulic system. Two new valves were added, creating an alternative for the passage of oil, preventing locking of the booster oil cylinder. For this new system, hydraulic pistons that drive the retractable deck were installed.

Control System

The control panel is positioned on the main operator station on the right front of the machine. It contains a Programmable Logical Controller (PLC) that monitors the frequency inverters, controlling speed and wheel motor rotation. The control panel has two selector switches (brake switch and function selector switch that operate the machine). The fully operation system is described below.

Operating System

For operation of the wheels, the hydraulic circuit releases the cylinder brakes, freeing hydraulic oil circulation, leaving the wheel free to spin. There are three movement positions, described below: (1) Transport: This position is used for internal displacement on the farm. The wheels are placed at a 90° angle to the chassis and speed can be modified every 1 second. (2) Harvest: For harvesting operations, the wheels are placed at a 180° angle to the chassis. (3) Spinning on its own axis: in this position, the machine turns around its own axis, an action that allows change in direction and maneuvering in narrow spaces. Wheels are placed at angles from 45° to 155°. In each column of the machine, wheel potentiometers are positioned for reading analog signals. Depending on wheel position, the potentiometer will send a regulated voltage in the 0 to 10 V range. According to the voltage, the PLC will convert and control motor speed to produce the differential effect for rotation, as the inner wheels must rotate at a speed below that of the outer wheels. Therefore, this mobile platform has the ability to move in both directions, transversally and longitudinally, for harvesting operations and transport. In situations where maneuvering room is reduced, the machine also has the ability to spin around its own axis.

Field Trials on Citrus Orchards

Trials for evaluating harvest productivity using the mobile platform were performed on a farm located in a citrus-growing area in the state of São Paulo, Brazil, in a ten-year-old orange orchard of the Valencia cultivar, with a row spacing of 7 meters and between-plant spacing of 4 meters, and average tree height of 3.5 meters. To conduct the trials, the orchard was divided in plots, one for manual harvesting and another for the platform machine. Trials were performed by the same harvesting team, 4 men, ranging in age from 47 to 52, with 5 years of experience in orange harvesting. For both methods, time spent in harvest was measured with a precision chronometer. Fruits were harvested at a standard commercial stage, yellow color and average diameter size of 60 mm. Green and inferior-sized fruits were maintained on the tree. After harvest, all boxes (net weight of 26 kg), with outer dimensions of 0.55 m (length), 0.30 m (height), and 0.35 m (width) were counted.

Manual Harvesting

For manual harvest, the traditional method was used, with pickers walking through the rows using canvas bags with neck support, which were completely filled (average weight 25 kg) and then transferred to individual plastic boxes (net weight 26 kg), until full. For the higher parts of the tree canopy, ladders were used, one for each collector, and the fruits were placed in the bag and then dumped in a plastic harvesting box. In this case, five plants were harvested individually in four replicates.

Harvesting with the prototype

Machine-aided harvest was performed with the mobile platform, with and without use of an accessory, a lateral harvest enclosure – a picking station (Figure 6). Initially, trials were performed without this accessory to verify machine mobility and, following that, one was attached. In both situations (with and without the picking station), three pickers walked behind the machine, and a fourth one was placed on the upper part. Pickers on the ground used the canvas bag, and after it was filled, dumped it in the plastic boxes. The picker on the upper part did not use canvas bags and fruits were put directly in the plastic boxes. Harvesting was done on one side of the row that consisted of 10 plants, with a spacing of 4 meters between plants, for a total of 39 meters (including 1.5 meters of canopy). After harvesting with use of the mobile platform, a second harvest was performed to pick the left over fruit. Two harvest trials were performed without the picking station accessory, and one with it. Four replications were made for each trial.

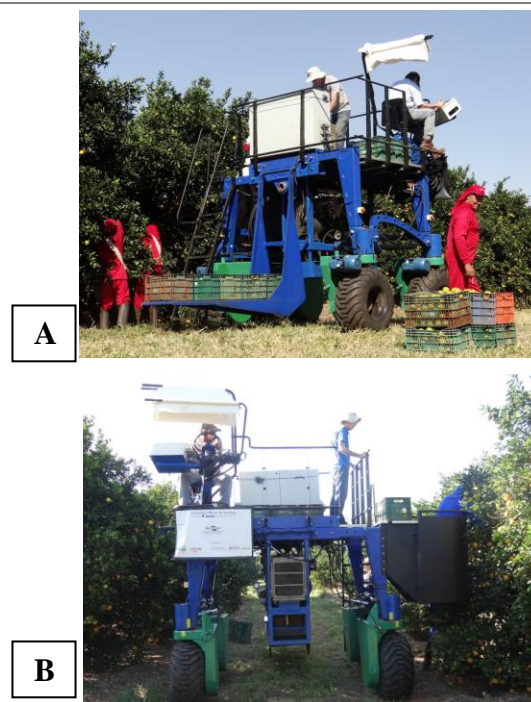


FIGURE 6. Harvesting with the mobile platform. (A) Pickers behind machine (3 pickers on ground, 1 on the top and 1 driver). (B) Front of machine with detail of picker at the picking station. Men with white hat, giving technical support on field trials.

Field Analyses

Productivity (kg s^{-1})

With the mass of the harvested fruits and the time spent harvesting, it was possible to estimate the productivity per hour of each picker in each treatment.

Average harvest speed (m s^{-1})

Harvest speed was calculated as an average of the time spent by the group of pickers to harvest the defined plots. In the case of the mobile platform, the time used harvesting with the mobile platform and the time of the second harvest for the fruits left on the tree were separated.

Statistical Analyses

Analysis of variance was used to compare the average worker productivity of the three methods of harvesting (manual, mobile platform with and without use of an accessory, a lateral harvest enclosure – a picking station). The software used in analysis was Statistica 8.0, and the significance level for all analyses was 5%.

RESULTS AND DISCUSSION

Productivity

On figure 7, is possible to observe productivity per hour of each picker (mean value) on manual, mobile platform with and without use of accessory – a picking station.

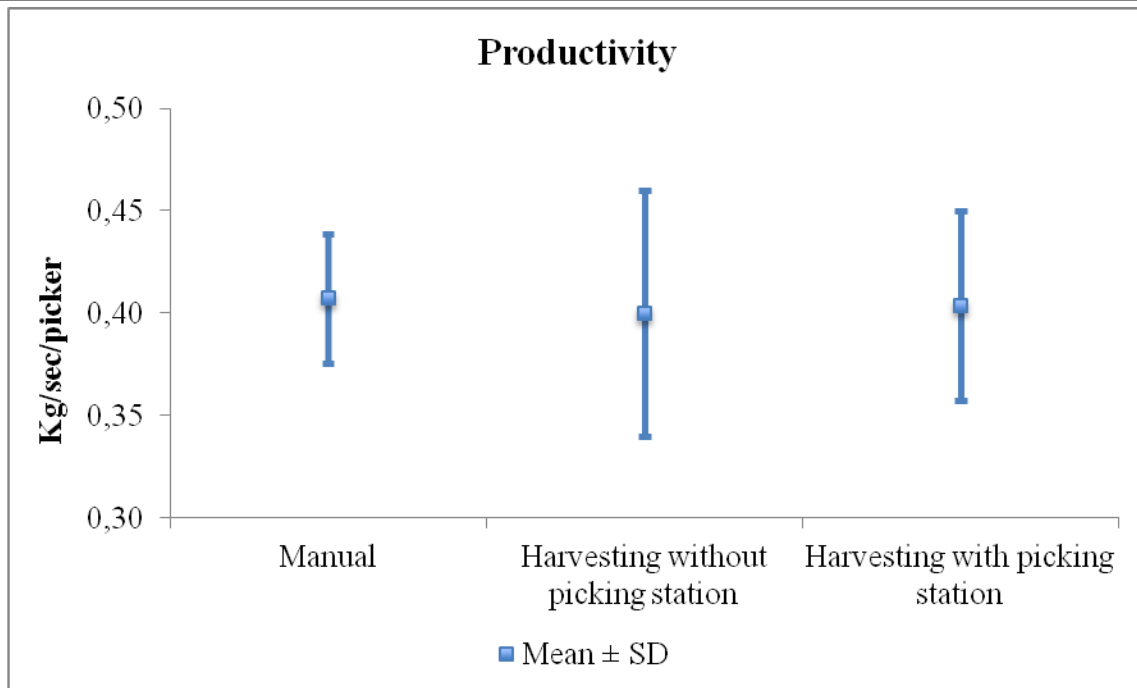


FIGURE 7. Productivity trial results

Through analysis of variance, it was observed that there were not significant differences among the average productivity from manual harvest (0.41 kg/s), machine harvest without the picking station (0.40 kg/s), and machine harvest with the picking station, (0.40 kg/s), $p = 0.972$ (Figure 7). These results were not in agreement with those of Costa & Camarotto (2012), that used 12 pickers, and observed a 60% increase in productivity. However, on this platform, pickers were in inferior number and not trained, and only one picking station was used. Sanders (2005) reported that harvest is usually considered individually, and moving to a group can be a challenge. Therefore, it may be possible to enhance the harvest aid system by adding devices and complements and training pickers. It should be kept in mind that harvest aid equipment improves harvesting conditions for pickers. Pranav & Patel (2016) reported results on agreement on those findings.

Average Harvest Speed

The average speed of pickers on the harvest aid machine ranged from 0.39 to 0.48 m/s, higher than traditional manual harvest speed (0.11 m/s) and lower than the machine working speed (0.56 m/s), due to some machine stops during harvesting. The driver can adjust machine speed according to crop conditions. However, for internal farm movement, 3.5 m/s was achieved. This platform speed higher than manual speed can be considered an advance, because can improve harvesting efficiency on picking more rapidly, especially if the devices added can help harvesting in the middle and upper part of the tree. High speed on this machine can also contribute on other farm operations, such as roughing.

CONCLUSIONS

The mobile platform was able to carry out harvesting with productivity similar to manual harvesting. The mobile platform has potential for use in farm harvesting by avoiding ladders, therefore improving picker

labor conditions. The retractable frame and independent wheel movement, associated with a hybrid vehicle, provide mobility and broad use for other farm activities and crops, expanding its application throughout the year.

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