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# Design, building and testing of a transplanting mechanism for strawberry plants of bare root on mulched soil

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## Abstract

In order to reduce costs of hand-transplanting of strawberry crop, a transplanting mechanism (module) was designed, built and tested, as a main component of the transplanter for bare root plants on mulched soils, which design is carried on. The transplanter should be used with an existing irrigation system, that must be able to supply water by sections and allows to irrigate as soon as the transplanting operation finishes. The principle of operation of proposed machine is based on the transplanting module, which remains in a short contact with the ground and comprises mechanisms such as a cutter, a hook and a clamp to make automatically operations of cutting the plastic, hide the cut plastic and insert the plant in the ground. Relative movement between module and main frame of the transplanter is used as a sequential actuation source for its mechanisms. A prototype of the transplanting module and a testing device were built to evaluate the performance of the module main components in laboratory conditions. A 100% of plastic cuts made by the cutter were correct. Plastic hiding activity was satisfactory in 95% of repetitions. Placement of the plants by clamp, was satisfactory in 95% of the tests, that means a good plant insertion (crown covered by soil), and 85% of transplanted plants were correctly oriented. The module showed a satisfactory general performance, which allowed to prove the technical feasibility of the proposed concept as a principle of design of the transplanter for bare-root strawberry plants on mulch soil.

**Additional key words**: agricultural machines, *Fragaria vesca,* planters, planting operations.

## Resumen

**Diseño, construcción y pruebas de un mecanismo de trasplante para plántulas de fresa de raíz desnuda, sobre suelo acolchado**

Para reducir los costos del trasplante manual de la fresa, se diseña, construye y ensaya un mecanismo de trasplante (módulo) como componente principal de una trasplantadora de plantas a raíz desnuda sobre suelos acolchados, en fase de diseño. La trasplantadora se utilizaría en suelos con un sistema de riego sectorizado, que permita irrigar de forma inmediata al concluir el trasplante. El principio de funcionamiento de la máquina se basa en el módulo, que permanece en contacto con el suelo un tiempo determinado y que cuenta con los mecanismos, que de manera automática cortan y ocultan el plástico cortado e insertan la planta en el suelo. El movimiento relativo entre el módulo y el bastidor de la máquina se emplea como fuente de accionamiento secuencial de sus mecanismos. Se construyó un prototipo de módulo de trasplante y un dispositivo para ensayarlo, evaluándose el desempeño del los componentes principales del módulo. El 100% de los cortes de plástico realizados fueron correctos. La actividad de ocultar el plástico fue satisfactoria en 95% de los casos. La colocación de la planta por la pinza resultó correcta en 95% de los ensayos en cuanto a la posición de la planta en el suelo (enterrado de la corona), y en 85% en cuanto a la verticalidad de la misma. El módulo presenta un comportamiento satisfactorio en términos generales, comprobando la viabilidad técnica del concepto propuesto, como solución técnica para la construcción de la trasplantadora de plantas de fresa a raíz desnuda sobre suelo acolchado.

**Palabras clave adicionales**: *Fragaria vesca,* maquinaria agrícola, plantadoras, trasplante.

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## Introduction

One of the crops, which mechanization has been experiencing a slow progress, is strawberry (*Fragaria vesca*) and this is not due to its marginal importance. In fact, world production reached 3.6 million tons that represents an annual value greater than 30,000 million euros. Strawberry is the horticultural species that has experienced the greatest increment of total world production for the last two decades. At the same time, the technological development of the crop has been evidenced by recent emergence of systems of forced production (www.faostat.fao.org).

While in many other crops, seeding and transplanting operations have been mechanized successfully, strawberry vegetative propagation system has been imposed over the propagation *in vitro* and *ex vitro* growing methods (López-Aranda, 2003), so that majority of cultivated strawberry in the world is transplanted by hand, with daughter plants of mother plants, that have been developed for this purpose in nurseries. Guarella (1992) has mentioned about the progressive replacement of the production system of bare-root plants for the root-ball plants. However, there is not a viable solution for implementing such a system for strawberry crop, which could be transferred easily to the farmers. O'Dell (1998) indicated that is more viable to growth root-ball strawberry plants than build a transplanter able to operate in forced production systems (mulched soils with polyethylene). However, nowadays traditional spread by stolons system prevails, including hand transplanting of bare root plants, also including its particularity of soil mulched to enhance crop growing. Transplanting one hectare of strawberry requires at least a group of 20 persons working a whole day (Sanz, 2002). The cost of this labor raises dramatically production costs of crop, so that mechanization seems to be en effective solution.

There are several transplanters in the market with several models, as well as non-commercial patents, with very ingenious operational ways but reduced technical feasibility. Also, its applications tend to be broader in terms of the type of plant that handle and they are not specific for strawberry with its particular requirements. Transplanters more suitable for transplanting bare root plants make use of flexible discs or pressing clamps (Wayne, 1983). But in both of them, operation principle is based on the furrow opener, that can not be used in mulched soils. Transplanting alternatives for mulched soils have been developed only for root-ball plants, with mechanisms that after cutting the plastic mulch, release the plant in the soil (Loris, 1989).

In traditional production systems (not mulched soil) strawberry plants should be vertically placed and the crown must be completely covered by soil just below the surface. In mulched soils it is also necessary to cut the plastic mulch where the plant is placed, this must leave a portion of soil exposed out to allow an adequate growing of plants. Therefore, the object of this work is to develop and test a new concept of transplanting mechanism, capable to satisfy requirements listed above. Such a mechanism is the transplanting module of a transplanting machine, currently being designed.

## Material and methods

### Conceptual design of proposed transplanter

Traditional strawberry cultivation, adopted for mulched soils, utilizes rows 1 m apart from each other. Plants are placed in zig-zag, it means in two lines along the row, separated 30 cm, and the distance between two plants along the line is 30 cm as well, with phase difference of 15 cm between plants of both lines. Such a system requires a thoroughly prepared soil, that allows conform the rows without damaging the plastic mulch or drip irrigation pipe, which must be placed at the same time.

The operational concept that incorporates the use of the proposed transplanter, consists of two steps: plastic mulch and drip irrigation pipe must be placed in the soil in state of permanent wilting point (PWP); thus there must be a hydraulic system with valves around the field in order to activate the irrigation by sections, preferably one valve for each row. In a second step, the plastic cut must be done and plants must be transplanted according to agronomic indications. Once transplantation finishes in that row, watering should be done immediately.

Gutiérrez *et al.* (2006) conducted a study with strawberry plants, transplanted into mulched soil at PWP, to determine the maximum time elapsed before applying the first irrigation, without compromising the integrity of the plant; the results showed that irrigation can be implemented until six hours after transplanting, with no significant effects in plant germination.

The field speed of the transplanter, which is pulled by a tractor, is supposed to be 15 cm $s^{-1}$ (0.6 km $h^{-1}$), which allows to place one plant every 2 s that is the time for an operator to feed a plant continuously in the distribution mechanism, recommended by Guarella and Perellano (1990). The economic viability of the transplanter is mainly depending to the number of plants that can be transplanted by the machine per unit of time, compared to the efficiency achieved by hand transplanting.

The operation principle of the machine is based on a plant distributor mechanism (transplanting module) that remains in contact with ground (zero relative speed) for a specified time; the modules have a movement similar to that of the links in a caterpillar traction system. The module comprises mechanisms that automatically carry out the following operations: cut the plastic mulch, place the plant, compress soil around the plant leaving the crown embraced and covered by soil. Figure 1 shows a conceptual scheme of the transplanter in stage of design. Modules are linked together (articulated) forming an endless chain-link, with 15 cm step; this chain is guided in the main frame of the implement and actuated by the chain gear, connected to the implement wheels, due to the movement of machine along the row. Displacement speed of the transplanter and the module must be equal in magnitude but opposite in direction to eliminate relative movement between the module unit and the ground. In addition, the relative motion between module and transplanter main frame is used as a source of sequential action of module mechanisms; the module movement through a fixed tracks system, attached to the main frame of machine, causes pressures on bearings, generating movement of individual mechanisms of the transplanting module.

Considering all functions described above, size of plants, depth of placement in the ground, that determines geometry of the transplanting module and feeding conditions of plants, the minimum number of module units resulted to be 14. The width that occupies one chain of modules is considerably smaller than the plants line separation; that allows to employ two parallel module chains per row of soil. The chain step which is equal to half of the distance between plants in the same line allows the zig-zag plantation, as described before.

## Design of transplanting module

The system that meets the requirements of the transplanting operation, described above, consists of three mechanisms and its support structure, as a unit called transplanting module (Fig. 2). These mechanisms and their functions are: i) a cutter, to cut the mulched plastic on soil; ii) a hook, to hide the cut plastic; iii) a clamp, to insert the plant in the soil

### *Cutter*

The cutter adopted the shape shown in Figure 3, that consist of three vertical walls, right angles, with sharp borders of jagged lower edge, making it convenient to interact with the hook and clamp. The area of plastic to be cut is related with the minimum area of soil which should be exposed to ensure an adequate plant growing.

Gutiérrez *et al*. (2007) studied cutters with different jagged edge geometry, which penetrated the plastic film in perpendicular direction. They determined, that cutters with teeth geometry of equilateral triangle with 1 cm side, performed a good plastic cut and required less energy than other similar jagged geometries, thus

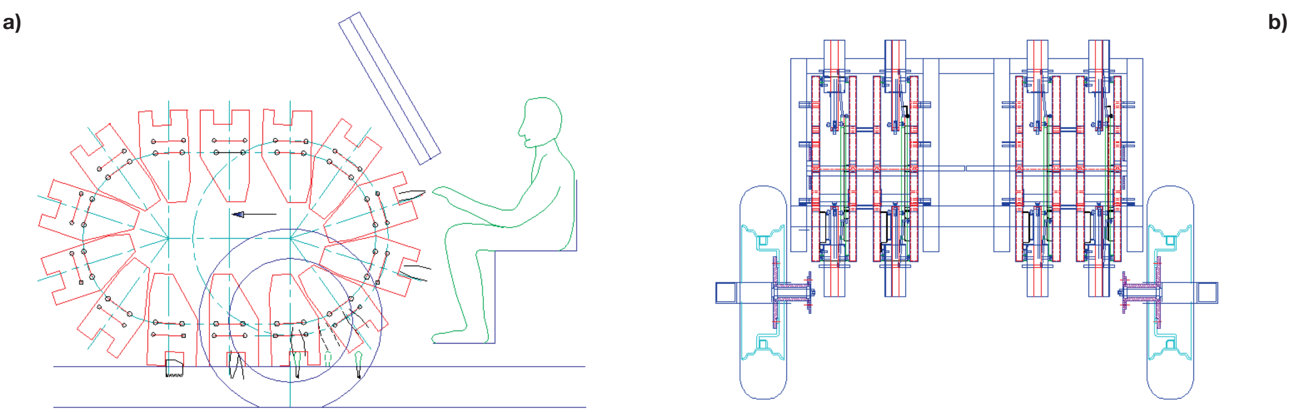


**Figure 1.** Functional scheme of the transplanter: a) lateral view, b) rear view.

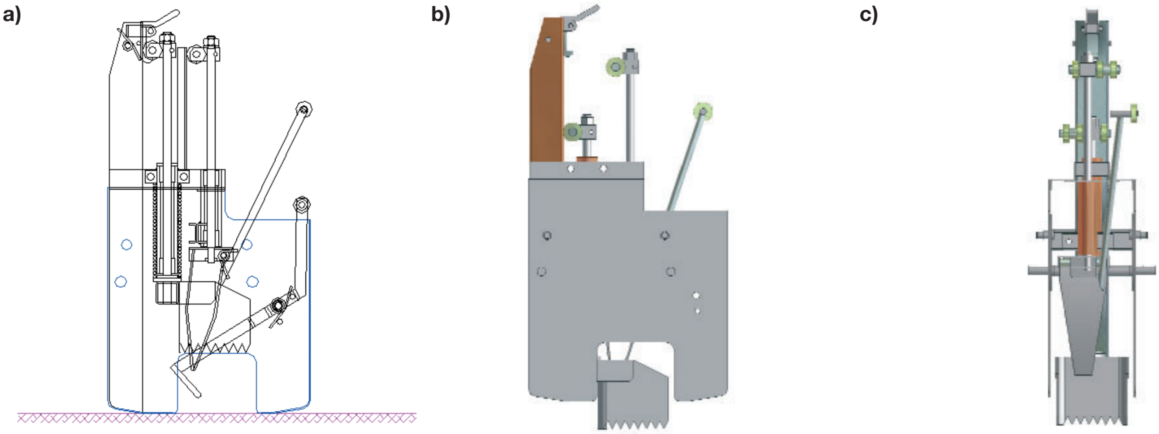


**Figure 2.** Transplanting module: a) internal schematic view, b) side view, c) rear view.

this geometry was adopted for the cutter of the transplanting module.

Considering 10.5 J as the energy needed to cut the plastic mulch, determined in the work mentioned above, a spring was design as a main element for energy storing. Figure 4 shows the upper position of the cutter, where the spring has its maximum compression and the lower position at a depth slightly greater than that required for a complete cut of the film, determined experimentally for different variables of soil and cutter movement. Once the cut is done, the cutter is retracted against helical spring, due to the track and the relative movement between transplanting module and implement main frame.

*Hook*

The final geometry of the hook was given after experimenting with different shapes of mechanisms for hide the cut plastic, different trajectories of downwards movement and considering geometric restrictions, due to three mechanisms interaction, sharing the same space. The hook is a pendulant framework that ends in rounded fingers inclined in the lower end (Fig. 5b). It has a spring return rotation around its pivots, to contact and hide under the plastic mulch the piece of plastic, previously cut by the cutter. Figure 5 shows initial and working positions of a hook, moved by a track and released at the end of it, to be retracted to the initial position.

*Clamp*

The concept of plant placing due gravity force, used in root-ball plants planters, was considered inefficient in this case. The transplanting module has to provide a direct control of plant movement, along its trajectory

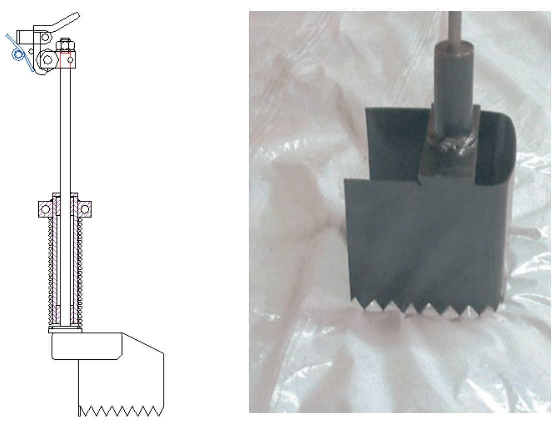

**Figure 3.** Cutting element.

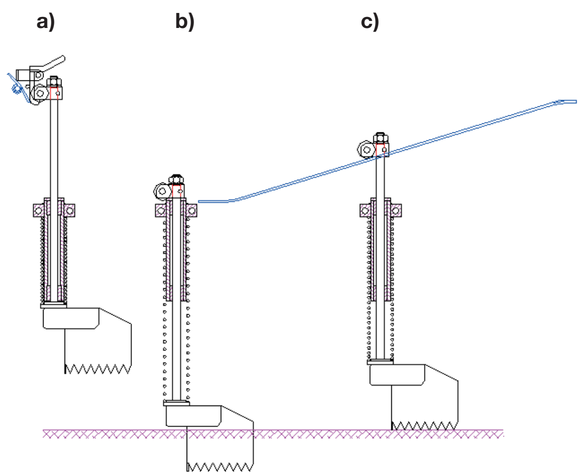


**Figure 4.** Working positions of cutter: a) upper (initial) position, b) lower position, c) intermediate return position.

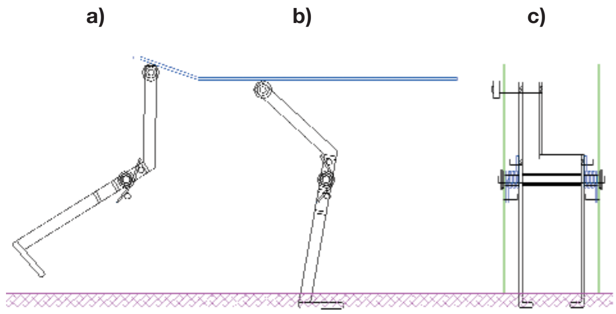


**Figure 5.** Schematic views of hook: a) side view in extreme positions, b) rear view.

through the machine, thus a system of pressing clamps is used. Furthermore, the use of clamps requires the length of plant roots to be uniform, because clamps press a plant at the root. Duval and Golden (2002) and Gutiérrez *et al.* (2006) proved in their studies, that cutting the root of strawberry plants to standardize their size does not affect its growing. Thus, plant roots can be cut to 5 cm length, measured from the crown to the root tip. In the same context, the way to insert the plant in the soil must avoid leaving the plant roots oriented towards the ground surface because it could affect its growing. Cutting roots resulted in a better introduction of the plant in the soil, without bending the root.

Bare root plants placed into the ground must be covered by soil; the root and the crown, avoiding the formation of air cavities around the roots. Thus, the clamp pliers should allow the flow of soil into them. It was resolved leaving opened the sides of the clamp, it means without side-walls (Fig. 6). Any mechanical damage to the plant due to transplanting mechanisms of the module must be avoided. The designed system meets the requirements listed above and in addition allows free interaction with the cutter and hook, as shown in Figure 6d. Figure 6a shows the clamp at the initial position of operation cycle, when a contact with track begins, in order to move down the clamp, deep enough to place the plant root in the prepared soil (Fig. 6b). At this moment the clamp actuator makes a contact with another track, opening the clamp to release the plant, then the clamp begins to ascend still opened and return to the initial position (Fig. 6c). The clamp remains in that position and then opens and extends out, before arriving to plant feeding zone, where new plants are placed by operators. Figure 6d shows the rear view of the clamp and relative location to the cutter; the hook has been omitted in this figure in order to make it more explicit.

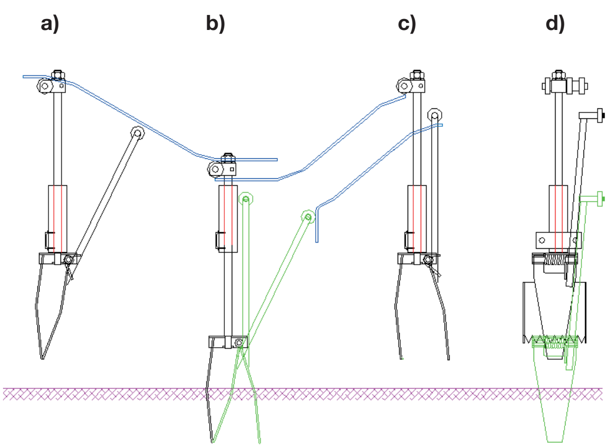


**Figure 6.** Operation sequence of the clamp: a) initial position, b) placement and elease of the plant, c) opened clamp returning, d) rear view of the clamp-cutter set.

## Laboratory test of the transplanting mechanism

Tests with the transplanting module were done in the laboratory of the Agricultural Engineering Department, which is part of Life Science Division, of University of Guanajuato, Mexico. A soil bin was used, which contained two type of soils; clay loam and sandy loam (Fig. 7). The soil humidity measured with a humidity sensor (Moisture meter HH2 Delta-T Device) was below to PWP, specifically 7% and 3.4%, respectively. Also, the level of soil compaction was recorded with a digital cone penetrometer (Rimik COP 20, manu-

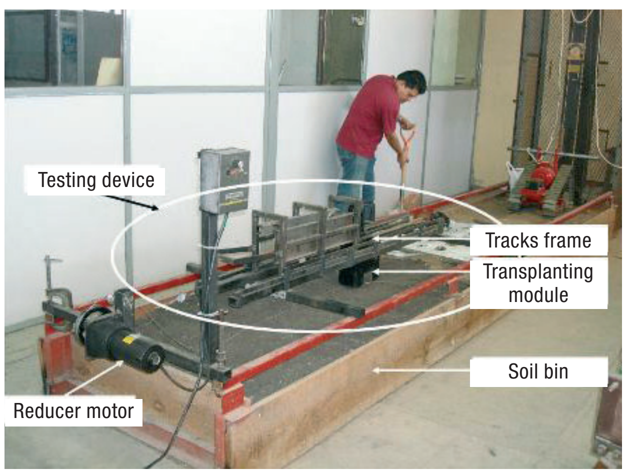


**Figure 7.** Soil bin.

a) b)

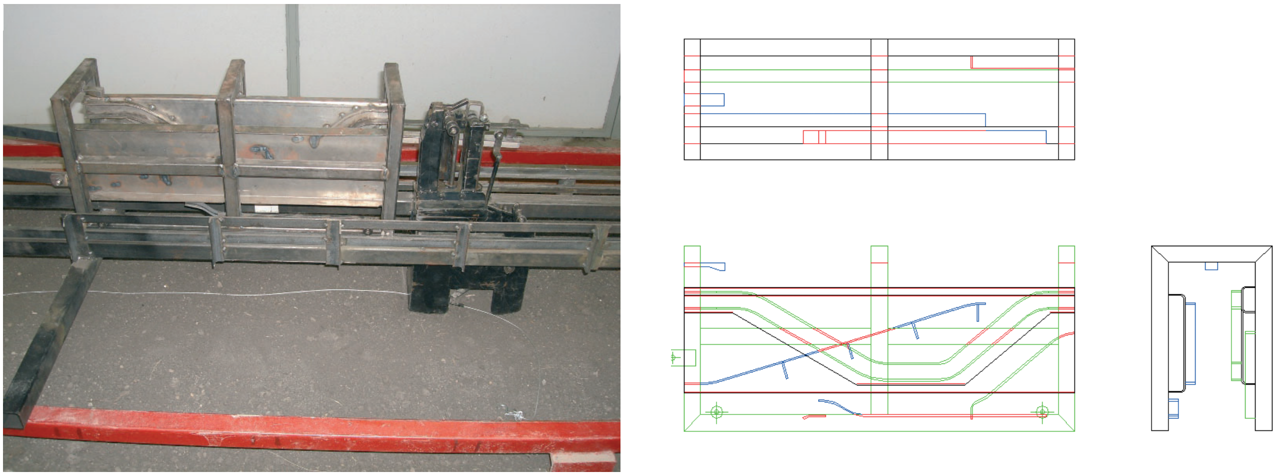

**Figure 8.** Testing device: a) general view, b) scheme of tracks frame.

factured by Agridry Rimik PTY LTD). Measurements of soil compaction were made up to 10 cm depth, as clamp and cutter are not expected to penetrate more. Maximum cone index recorded was 1 kPa, which is acceptable because does not affect plant growing (De León, 1998).

Plants used were first cycle «Festival» cultivar, acquired by the National Council for Strawberry (CONAFRE A.C.) and given to the Agricultural Engineering Department, to be refrigerated at 4°C, until tests were carried out. The plants structure did not present abnormalities at the moment of transplanting test; some of them presented sprouts, not relevant for the test.

The soil was covered with plastic attached adequately, simulating the apparent tension that is achieved in production fields. The plant was placed by hand in the clamp of the transplanting module, which was placed on the base of a testing device, constructed especially for the tests (Fig. 8). The testing device gives to the transplanting module a static position during the test, just above the mulched soil. Subsequently, the tracks frame was placed, whose function is transferring the respective movement to the transplanting module mechanisms. The tracks frame was pulled by a steel cable attached to a gear motor («Baldor», 90 VCD, variable speed, 21 rpm output, 80 N · m torque), using a pulley arrangement, where the cable is rolled to transmit 15 cm · $s^{-1}$ average speed. The displacement of the tracks frame makes the set of tracks to get in contact with actuators of the mechanisms of transplanting module and thus to generate sequential movements of the elements: cutter, hook and clamp, responsible of transplanting operation. The same relative movement will occur in the real machine, where the endless chain of transplanting modules will cross the tracks set and drive its mechanisms.

Twenty tests were made for each soil type and transplanting quality was qualitatively assessed for each test as shown in Table 1.

Five variables were assessed and maximum possible qualification for each variable was two points, thus full transplanting operation summarizes 10 points when a correct performance was reached. Less than eight points for test was considered an unsatisfactory transplanting operation; from eight to 10 points was considered a satisfactory transplanting operation, with a condition that if one of the assessed variables got zero points, the transplanting was considered unsatisfactory.

Before starting test, roots and stalks of plants were cut to 5 cm, measured from the crown to each end respectively, leaving a 10 cm plant length.

## Results and discussion

The Figures 9 and 10 show performance graphics of assessed variables of the transplanting mechanism, for each type of soil, respectively. From 40 tests carried out, 38 obtained satisfactory rating, ranged from 8 to 10 points and none of the assessed variables was evaluated as zero. Twenty one tests were considered as completely correct, obtaining a 10 rate (Fig. 11). Only two tests were considered unsatisfactory, one of them due to the clamp conflict with a plant, after it was inserted (the clamp took the plant out from soil when

**Table 1.** Pondering of performance variables, which were assessed for the transplanting module

| Cutter | | Hook | | Clamp | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Plastic cut** | **Points** | **Plastic hiding** | **Points** | **Crown covered with soil** | **Points** | **Verticality** | **Points** | **Champ-plant interaction** | **Points** |
| Complete cut: *correct* | 2 | 0-1 cm of plastic not hidden: *correct* | 2 | Full covered: *correct* | 2 | Inclined less than 30° respect to vertical axe: *correct* | 2 | Clamp does not move the plant after insertion: *correct* | 2 |
| Partially cut: *acceptable* | 1 | 1-3 cm of plastic not hidden: *acceptable* | 1 | Partially covered: *acceptable* | 1 | from 30° to 45°: *acceptable* | 1 | Clamp moves partially the plant after insertion: *acceptable* | 1 |
| With no cut: *incorrect* | 0 | > 3 cm of plastic not hidden: *incorrect* | 0 | Out of soil: *incorrect* | 0 | Greater than 45°: *incorrect* | 0 | Clamp takes plant out of soil after insertion: *incorrect* | 0 |

retracting), thus assessed variables for crown covering with soil and verticality of its position were affected; the second failed test was due to an incorrect plastic hiding operation.

A 100% of plastic cuts were correct, which indicates a satisfactory performance of cutting elements (see Figs. 9 and 10). Hiding plastic operation reached a 65% of correct tests and 30% of only acceptable tests, due to a partially plastic hiding, within the range of 1 cm to 3 cm of plastic remained (Fig. 12); the sum of both equals to 95% of successful tests.

The position of the crown, which is one of the conditions of transplanting operation for a proper plant growing, happened to be correct in 95% of tests carried out; the crowns were completely covered by soil, just below the soil surface. In 85% of tests the verticality was correct, what is an important factor for a proper plant emerging (Fig. 13). Remaining 15% of tests were acceptable, thus the plant verticality variable could be considered satisfactory.

The tests showed also, that the preparation (grading) and leveling of soil to ensure contact with the transplanting module, and the correct placement and tension of the plastic mulch, are important conditions for desired performance of all transplanting module elements.

Taken in account all of the assessed variables, nine of 10 of the tests carried out for the transplanting mechanism were satisfactory and more than five showed correct performance, according to established criteria.

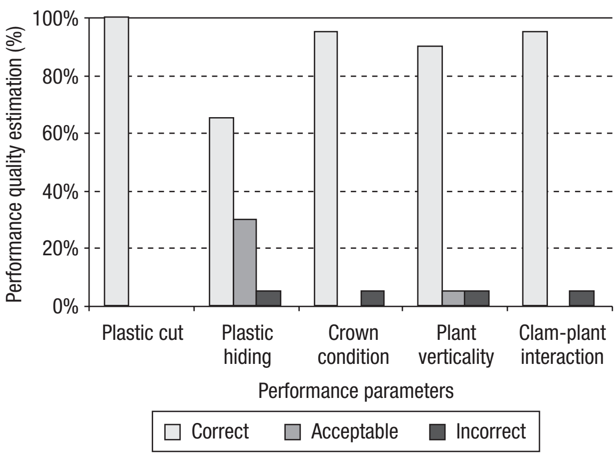


**Figure 9.** Module performance in terms of assessed quality parameters (Clay loam).

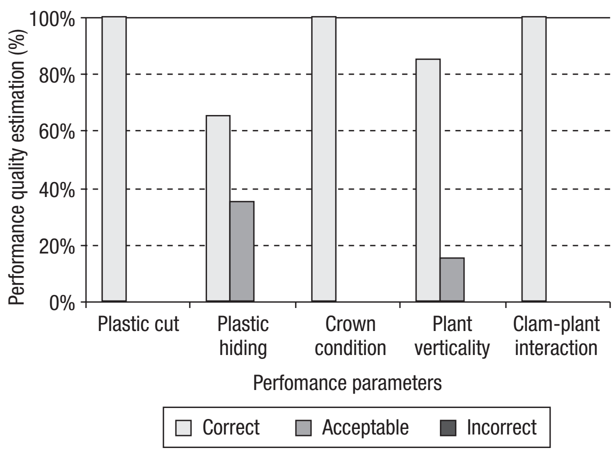


**Figure 10.** Module performance in terms of assessed quality parameters (Sandy loam).

**Figure 11.** Correct transplanted plant.

**Figure 13.** Verticality problem in a transplanted plant.

There are few bibliographic references related to transplanters performance evaluation results. Munilla and Shaw (1987) reported planting success rates of 93%, demonstrated by the prototype developed by them. Guarella and Perellano (1990) indicated the work quality value between 72 y 97%, obtained from field tests with different types of transplanters, field conditions and horticultural plants. Thus, it is justified to consider satisfactory the preliminary tests results of the described mechanism.

## Conclusions

Transplanting module, described in this paper, offers a satisfactory technical solution according to the performed laboratory tests. The transplanting module is capable to place orderly and vertically a bare root plant in mulched soil, cutting and removing the plastic mulch from the area of plantation and ensuring a proper rooting.

**Figure 12.** Acceptable plastic hiding.

It is necessary to test the transplanting module by real work conditions in the field, where an interaction with other factors, like soil stage, tension of plastic, dynamic effects, etc. might suggest adjustments and modifications of the proposed design.

## Acknowledgements

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