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DEVELOPMENT AND FIRST TESTS OF AN AUTOMATIC SYSTEM FOR COMMERCIAL VINE CUTTING TRANSPLANTERS BASED ON DGPS-RTK TECHNOLOGY

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1. Introduction

The various operations required for planting a vineyard take on significant aspects in economic terms (5-6% of the total cost, [Gubiani 1995]), and operative terms (need of an excessive number of hours – up to 20 man hours/ha – of skilled labour, [Planeta 2001]). This is why the planting of the vineyard is usually carried out by contractors using transplanting machines which not only save on costs but also assure extreme accuracy in heeling vine cuttings.

As the various steps in planting a vineyard include, in the first phase, the heeling of the vine cuttings, followed by the positioning of the posts, it is clear that the transplanting phase is of fundamental importance. In fact, the spatial evenness of the entire vineyard depends on the above. This is essential not only for aesthetic purposes, but especially for the successive mechanized operations on the canopy (pruning, lopping, leaf stripping), leading to the mechanical grape harvest.

It is well known that heeling accuracy must concern:

a) transversal longitudinal alignment among the plants and among the rows;
b) method of heeling the vine cutting.

Usually the first phase regards the lay out and the relief of the perimetric points of the field and the beginning of the rows. This is accomplished either with topographic tools or by using GPS devices and GIS software. In the first case skilled workers are needed employed for the time necessary to meet the complexity of the planting of the vineyard.

In the second case the squaring of the vineyard is automatically carried out once the perimetric points of the field and the lay out of planting [Sartori 2004]. The result is twofold: a savings in work time and the employment of transplanting machines that use digital project data for the integral or semi-integral automation of the transplant.

The wide use of DGPS, above all for navigation purposes in the fields [Bell 2000; Iida 2006; Keicher 2000], has allowed the definition of algorithms and components which have produced complete forms of automation of the planting phase, especially for some cover crops (rice [Nagasaka 2004; Nagasaka 2006], beets [Griepentrog 2005]). In spite of this, sectional literature has not fully analysed the vine cutting transplanters sector. Currently quite a bit can be done to optimise the transplant process through specific innovative solutions for these machines which, although they have a lower market share compared to other machines, they are very likely to increase their share - nationally and internationally – in the wine growing sector.

The aim of this paper is to propose and analyse performance of an innovative system for commercial transplanters, without preliminary setting out of the field allowing maximum automation in point-laying location – specified by a project digital map – using electromechanic and electro-hydraulic actuators controlled by a DGPS-RTK system. The purpose being to eliminate all preventive manual operations, which today are necessary in planting a vineyard, reducing costs without losing accuracy in the transplanting.

2. State of the art

2.1 *Constructive typologies*

Generally, a vine cutting transplanting machine is composed of a supporting frame incorporating the plant boxes and the seats for the personnel employed in setting the vine cuttings in the plant pockets, the transplanting machine set and the control devices to check the equidistance of the lay out of planting among the rows and within the row. From a mechanical point of view, the models available on the market are easily distinguishable from the typology of the transplanting set (Table 1). Currently three basic typologies are available:

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A) Disk planting unit. It is composed of a variable number of equally distant plant pockets radially mounted on a horizontal rotary axis. Distributor supply is obtained through a conveyor chain upon which the small plants are manually placed. The plant pocket opening and the following release of the vine cutting in the furrow opened by a furrow opener shoe, is regulated by a segmented profile whose position determines the point of release of the vine cutting. The plant is set in a vertical position because of the combined action of the soil (which fills the furrow as it slips) and two cover wheels converging to the centre of the furrow itself. A ridger, adjustable according to the steepness and type of soil, closes the furrow.

B) Chain distributor. It is composed of a chain that rotates in the opposite direction compared to working speed, on which equally distant plant pockets are fixed. The plant is set vertically in a furrow which has been opened by a ploughshare and kept open by two cover wheels which compress the soil. After the vine cutting has been released, two disk coverings earth up the plant.

C) Pneumatic piston distributor. It is composed of two half moon spades which dig into the soil making a hole where the vine cutting is to be set. The plant slides into the hole and a disk ridging system compresses the soil around the root system. In the meantime the two spades are raised by a pneumatic piston and repositioned in order to make the next hole.

2.2 *Control device*

2.2.1 *General considerations*

In order to obtain equal distance when heeling vine cuttings in the row and among the rows, planting machines have a built-in control device which acts on the transplanter set and on the frame respectively. In particular, it includes: a) an alignment system of the row, which has a dual purpose: to guarantee the rectilinear alignment of the vine cuttings in the row and the equal distance (according to the planting project) among the rows, and b) a synchronisation system that regulates the movement of the vine cutting distributor to guarantee equal distance among the plants in the rows.

2.2.2 *Row alignment system*

From a purely mechanical point of view, both the alignment of the vine cuttings in the row and the distance among the rows depend on the transversal movement of the transplanter frame combined with its translation in the working phase. A hydraulic piston starts the transversal movement and an oil-pressure pump is activated by the tractor's pto. A second piston, controlled by an inclinometer on two axis, keeps the transplanter unit in an horizontal position.

Automation of the process is assured using laser systems or GPS. In fact, mechanical transplanters may be equipped either with a device that receives a laser signal from a transmitter positioned next to the row adjacent to the row where the transplanter advance, or with a highly accurate GPS system (usually

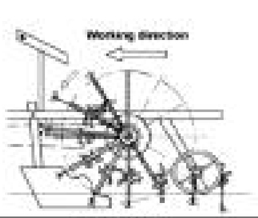
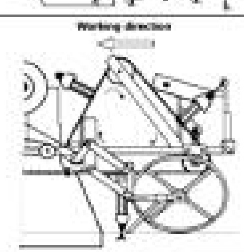
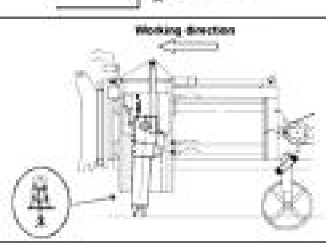
Distributor type	Diagram	Features	Producer companies
Disk		• Suitable for transplanting vine rooted cuttings bare and whole. • Suitable for not so heavy soils with optimal humidity conditions. • Difficulty in setting the vine cutting in vertical position. • Continuous distribution. • Good working speed (2-6 km/h).	Wagner (D)
Chain		• Suitable for transplanting vine rooted cuttings bare and whole. • Suitable for not so heavy soils with optimal humidity conditions. • Suitable for setting the vine cutting in vertical position. • Continuous distribution. • Good working speed (2-6 km/h).	Wagner (D) Semapoma (ES)
With pneumatic piston		• Suitable for transplanting vine cuttings without root system, or in peat pot. • Also suitable for heavy soils with no optimal humidity contitions. • Highly suitable for setting the vine cutting in vertical position. • Discontinuous distribution. • Reduced working speed (<2 km/h).	Clemens (D)

TABLE 1 - Principal constructive typologies of commercial vine cutting transplanters.

double frequency). In both cases, systems generate signals which act on the hydraulic system of the machine and control and maintain the “target” position of the frame through lateral translations, equal to the accidental route deviations as determined by driving the tractor.

2.2.3 *Synchronization system*

The purpose of the synchronization system is to guarantee the equal distance of the plants in the row. This is accomplished by keeping a constant ratio between the tractor working speed and, respectively: a) the peripheral distributor speed in the A and B typologies and b) the alternate movement of the pneumatic piston in the C typology. The functioning principle - based on a mechanism that uses a steel wire - in spite of some functional differences, is the same for the three cases mentioned.

Generally, the synchronization system is composed of two overlapping pulleys the motion of which is determined by a steel wire whose tip is fixed to the ground at the beginning of each row. The back pulley, on which the wire winds around only once, controls a hydraulic motor which determines the rotation speed of the members connected to the distributor through a combined chain-gears transmission. The speed depends on the density of the area to be planted (distance in the row), and can be controlled by correctly choosing the pinion gears. Another hydraulic motor connected to the axis of the top pulley serves two purposes: to supply moderate feedback to keep the wire tight and to allow rapid rewinding of the wire at the end of each row. Both hydraulic motors are controlled by the only pump activated by the pto.

The wire synchronizer has the advantage of ensuring the uniformity between the rotation speed of the distributor and the speed of the machine’s advancement. Nevertheless it has two significant drawbacks: a person is needed at the beginning of the row who must hook and unhook the wire, and what is worse is that in cases of across the dominant field slope (as the wire does not follow the inclination of the soil) the distance (*d*) among the plants is normally different from the projected one (*i*) (Figure 1), (*i*>*d*).

Furthermore the necessity to rewind the wire at the end of each row and the successive operation of fixing the end of the wire at the beginning of the row to be planted, cause a great loss of time and consequently a reduction in the work rate of the transplanting equipment.

From an operational point of view, the transplanters that use the wire synchronizer and/or the laser/DGPS to align the row, realize a <u>continuous</u> distribution , as the ratio between the advancement speed and peripheral speed of the members that drive the distributors is constant. In this case, working speed can vary greatly during the transplanting without affecting the final result.

3. Materials and methods

3.1 *Objective of the work*

The present work proposes an automatic vine cutting transplanting system which can eliminate the use of the wire synchronizer. In short, the entire transplanting process is regulated by the same DGPS which controls both the alignment system and the equal distance among the rows, and an electric constant speed motor started intermittently by an electromagnetic brake connected to the vine cutting distributor. In this case, the distributor no longer works in a continuous rotation but intermittently (“tripping action” advancement). In fact, the heeling position is calculated by the DGPS and depends as a consequence on its resolution (number of fixing calculated in the unit of time), and on the working speed which

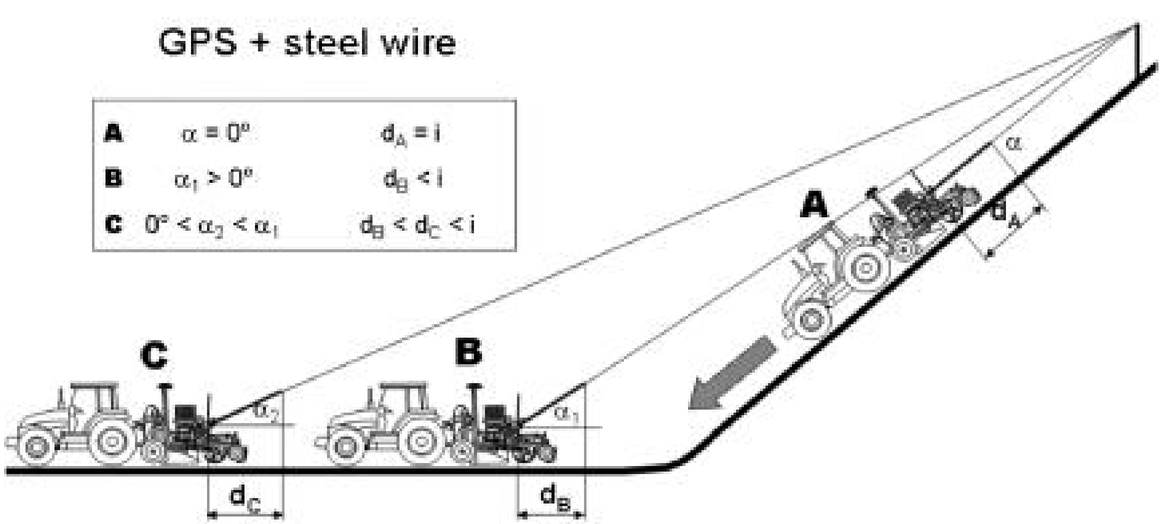


Fig. 1 - Transplanting distance variation according to slope change.

cannot be too high if setting accuracy is to be maintained.

The aim of the system is to reduce manpower while maintaining accuracy in transplanting the vineyard. The overall result is a significant reduction of auxiliary time, thereby increasing work rate and the productivity of labour.

The modified machine employed to realize integral automation in the setting phase of a vineyard, is a semi-mounted disk planting unit transplanter made by the Wagner company, originally equipped with a built-in laser to maintain equal distance among the rows and as a synchronization set a continuous wire system. Figure 2 shows a scheme of the system proposed in the present work .

The alignment system includes two double frequency GPS receivers with RTK differential correction: the first is the master station located on the field margin, and the second is the rover located on the machine. The GPS antenna is fixed to the transplanter and the differential correction message transmission is carried out using two radiomodems. A two-axis inclinometer (± 0.07° resolution) compensates both diagonally and longitudinally the antenna position in cases of slope heeling.

The wire synchronization system is replaced by an electric motor (12 V, 30 A), fixed to the frame and connected to the disk planting unit through the chain transmission. A on-board computer is located in the tractor cabin (VIA C3 1 GHz processor, touchscreen high brightness display) and it comprises the control unit which regulates both the transplanter activators and the electromagnetic brake connected to the electric motor.

With this system preliminary squaring of the field is avoided: it is enough to memorize the distance of the plant in the row, the distance among the rows, and the initial and ending points of the first row. Subsequently the software in the computer automatically squares the field and calculates the setting point for each vine cutting.

The electric motor rotates at a constant speed; therefore the electromagnetic brake must stop it before the vine cutting setting point calculated by the software and identified in real time by the GPS (hence, the “spurt” rotation of the distributor system). The smooth setting of the vineyard is thus obtained by combining the vine cutting release instant (plant pocket opening) with the working speed.

3.2 *Experimental plan*

To verify the performance of the machine, a series of transplanting tests were carried out considering a lay out of planting among the rows of 2 x 1 m (5000 plants/ha). The tractor employed was a 100 kW McCormick 4WD.

The experimental diagram of the theses tested is summarized in Table 2.

Briefly, the new system controlling the setting position using the DGPS together with an electromagnetic brake (P_i thesis) was compared to a conventional tester (DGPS + mechanical wire, T thesis). Thesis T and P1 were carried out on 4 50-metre long rows each one (for a total of 200 plants per thesis). To analyse the dependence between working speed and the accuracy of the planting, two additional tests at different

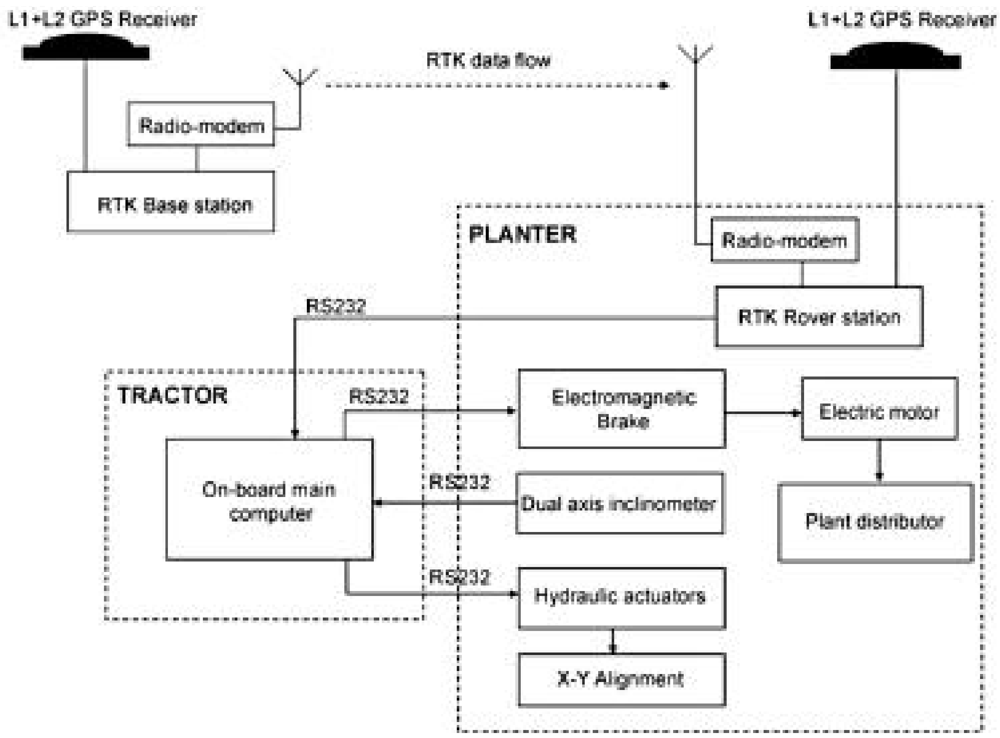


Fig. 2 - Diagram of the transplanter control system based on DGPS + electromagnetic brake.

		MACHINE CONFIGURATION	
		GPS + wire	GPS + electric motor
AVERAGE WORKING SPEED	2 km/h	T	P1
	1.8 km/h	-	P2
	2.2 km/h	-	P3

TABLE 2 - Experimental theses carried out on the transplanter equipped with two distinct control systems and different working speed.

speed were carried out (thesis P2 and P3). In order to match analysis needs with organizational problems (after each test the soil had to be completely re-tilled), P2 and P3 were performed on an half number of rows (100 plants per thesis). Anyhow this had no implications on subsequent analysis because the single factor ANOVA that has been then applied permits to manage theses with a different number of observations.

In order to keep the thesis conditions identical, we always worked in the same field, mainly clay texture soils with variable steepness between 6 and 7% along the working direction (Figure 3). After each test the plants were picked up and the field was re-ploughed after each GPS manual survey (carried out to measure the real position of the plants to the soil). Each planting was carried out following level lines and unoperating return.

The main difference between the T theses and the various P_i concerns distributor rotation modes (continuous and intermittent respectively). In fact, in the P_i, the verification of the vine cutting release (comparing the current position with the objective position), is carried out using the single fixing of the DGPS positioning system.

The greater is the F frequency (Hz) of the fixings, the better is the accuracy of the system. Obviously accuracy depends on the working speed v (m/s) of the machine. In fact, the R (m) resolution in which the system can determine the point of heeling is given by:

$$R = \frac{v}{F} \qquad (1)$$

Therefore, working at 2 km/h, the theoretical resolution is 11.1, 5.6 and 2.8 cm in cases where the frequency is equal to 5, 10 and 20 Hz respectively. Very low frequencies significantly compromise the quality of the work. On the other hand, "power calculating" problems may arise (the system software includes interface graphics which use up the computer's resources). In fact, the destabilization of the control system is possible with too high frequencies (performance DGPS receiver permitting). The affect of speed was tested by the P_i theses, which single average working speed varied from 1.8 to 2.2 km/h. It was not possible to investigate a wider test range because the optimal speed rotation of the electric motor was designed for a 2 km/h forward speed. Alternative speeds exceeding a ± 10% variation with respect to this optimal value prevent the electromagnetic brake to stop the electric motor at a position perpendicular to the soil. As a consequence, in addition to a greater number of deviations with respect to the targeted planting positions, the quality of the work carried out is even compromised by a relevant number of sloping plants.

During the tests two DGPS Geotop receivers were used, the Hiper-Pro model as master on the field and the Geotop GB-500 model as rover on the machine. Both receivers are able to trace all signals L1 + L2 GPS/GLONASS and up to 20 satellites simultaneously. For the experimental theses they were set at F = 10 Hz frequency allowing theoretical resolutions between 5 and 6 cm, depending on the speed tested.

The same DGPS receivers, with radiomodems for the transmission of the RTK correction, were successively manually used to measure absolute position in the soil of each vine cutting planted. To guarantee verification accuracy, the GPS was kept on each plant for 10 seconds. All positions were then expressed in UTM format in the WGS84 reference system.

4. Results and discussion

Table 3 shows the results of the transplanting carried out using the wire synchronizer machine and the one carried out with the electric motor.

Regarding the distance among the rows (project value: 2m), the result is suitable with the precision required of the planting even in cases of slight steepness of the field. In fact, the average values obtained in the various theses differ from a minimum of +1 mm (P1) to a maximum of +12 mm (P3) compared to the project value.

About the comparison between the synchronized groups, the distance among the plants in the row were analysed (project value: 1 m), in order to evaluate

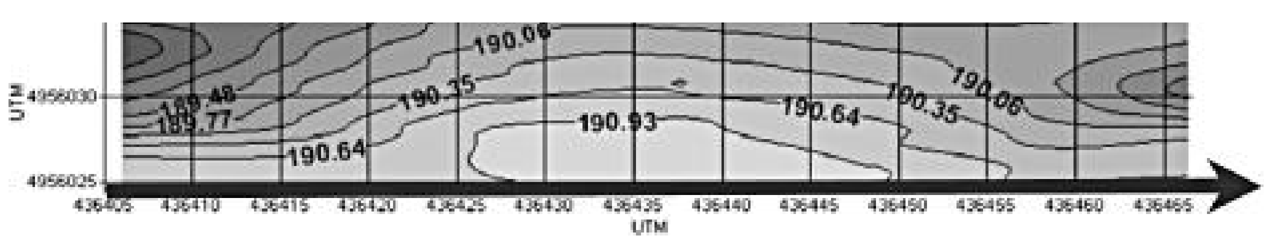


Fig. 3 - Contour map of the field where transplant tests were carried out. The arrow indicates the working direction.

	T		P1		P2		P3	
Parameter	*Row*	*Interrow*	*Row*	*Interrow*	*Row*	*Interrow*	*Row*	*Interrow*
Average (m)	1.000	2.004	0.997	2.001	0.999	2.010	0.997	2.012
Standard deviation (m)	0.039	0.036	0.049	0.033	0.032	0.025	0.043	0.034
Mode (m)	1.002	2.002	0.954	1.999	0.973	2.007	1.012	1.998
Median (m)	0.998	2.006	0.995	1.999	0.995	2.007	0.996	2.007
N. of surveys	200		200		100		100	

TABLE 3 - Comparison results among T, P1, P2, P3 theses.

planting precision (relative point-laying location). Results analysis shows that both systems allow good planting precision, with standard deviation from 3.2 to 4.9 cm for the P_i theses, compared to 3.9 cm of the T. Modal values are more favourable for the wire synchronizer (1.002 m) compared to the electric motor system (values between 0.954 and 1.012 m).

The analysis of frequency distribution schemes for the four theses examined (Figure 4) shows that even by modifying the working speed (2 km/h) by ± 10% (Theses P2 and P3) no appreciable variations are found in the result of the planting. In fact, the σ calculated with the electric motor synchronizer is very similar to the minimal resolution obtained using the GPS updated to 10 Hz (5.6 cm). Therefore, for reduced speed variations, this frequency is the right compromise between planting precision and hardware stability, making it suitable for the intermittent control of the disk planting unit, built for continuous working conditions.

A further elaboration was carried out to verify the correspondence planting results with the absolute values of the project. To this aim, positions collected for each thesis were projected by CAD software on a regular 1 m × 2 m orthogonal grid, with the origin set on the first vine cutting planted. For each thesis, the deviations measured between the real vine cutting setting points and the theoretical ones of the grid, were represented on a dispersion diagram (Figure 5), where the circumference in the 95th percentile is contextually indicated (R95, m radius). Values are shown in Table 4.

Comparing percentile values for the T and P1 theses (analogous for speed and number of tests) , we notice again the superior performance of the wire system (above all with reference to the distance in the row) compared to the electric motor (R95 = 0.09 m compared to R95 = 0.11 m), while the successive test carried out to evaluate speed impact on planting precision seems to confirm the independence of the final result from ± 10% speed variations.

Thesis	R95 (m)
T	0.09
P1	0.11
P2	0.10
P3	0.07

TABLE 4 - 95th percentile values calculated for the four experimental theses.

As a further confirmation of the above, a one factor variance analysis was carried out on the deviations measured on the row and among the rows compared to the theoretical grid, including measures of the T thesis. Fischer's test result – separately carried out in the row and among the rows – allows us to accept the null hypothesis of equality between the deviation average (test in the row: F = 0.129; test among the rows: F = 0.818. Critical F = 2.628). Consequently, there is no significant difference between the deviations obtained in the four experimental theses, underscoring the fact that for limited working speed changes, employing a GPS updated to 10 Hz calculation accuracy of the setting position and the planting of the vine cutting are not degraded.

5. Conclusions

The aim of the present work was the description and first trials of an automatic system for commercial transplanters based on DGPS-RTK technology and electric motor synchronizer, developed to improve the effectiveness and productivity of the work while guaranteeing vineyard planting accuracy.

The results are absolutely satisfying, regarding both the precision of the planting (relative distance among the plants and among the rows) and accuracy compared to project values (orthogonality compared to an absolute regular grid). In fact, the performance of the new control system is comparable to a conventional wire synchronization system. During the tests, the system was stable and efficient, and no problems of any sort arose. From an operational point of view, the proposed system reduces manpower (the worker responsible for the laser and the wire at the beginning of the row is no longer needed), while increasing work rate of the transplanting equipment. The originality and efficiency of the system, confirmed by the considerable interest it drew from workers in the sector, have made it possible to patent it in Italy and in Europe (N° MI2005A002165) the owners being Università degli Studi di Milano and the Arvatec s.r.l. company of Rescaldina, Milan, Italy.

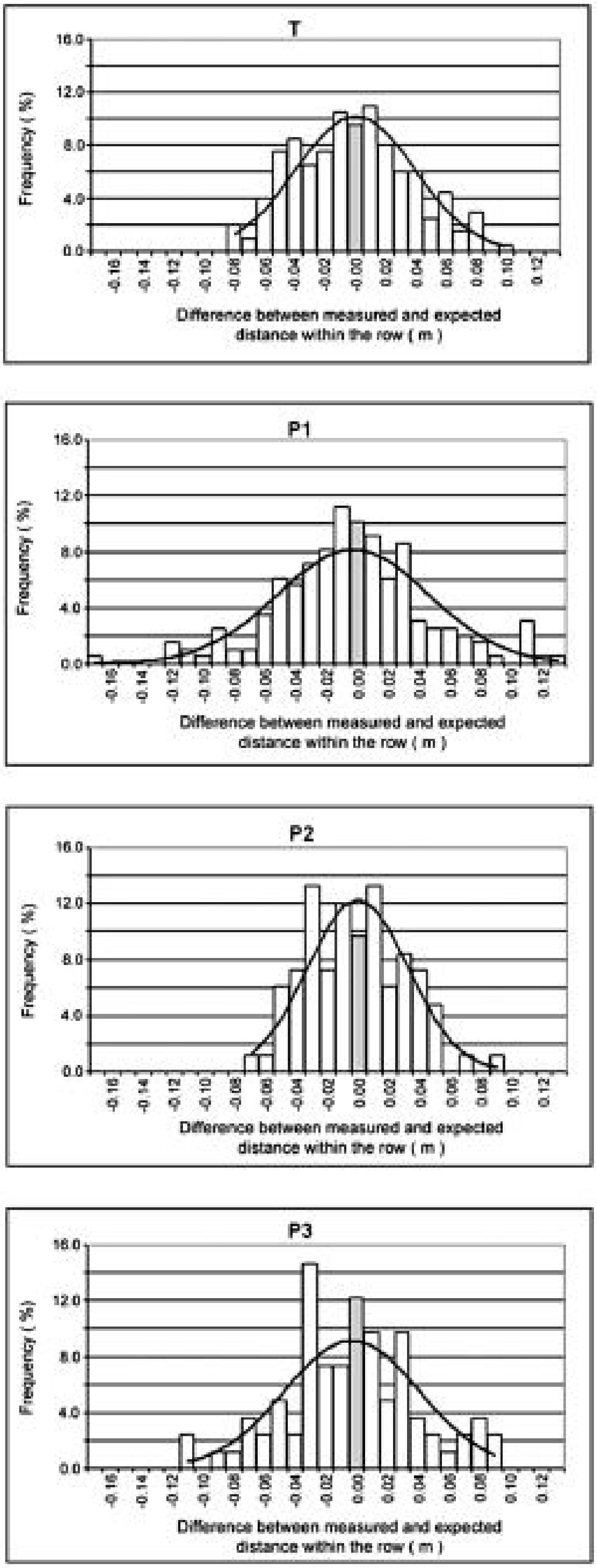


Fig. 4 - Error distribution of the measured planting-system distance compared to the expected one, for the four theses tested (T, P1, P2, P3).

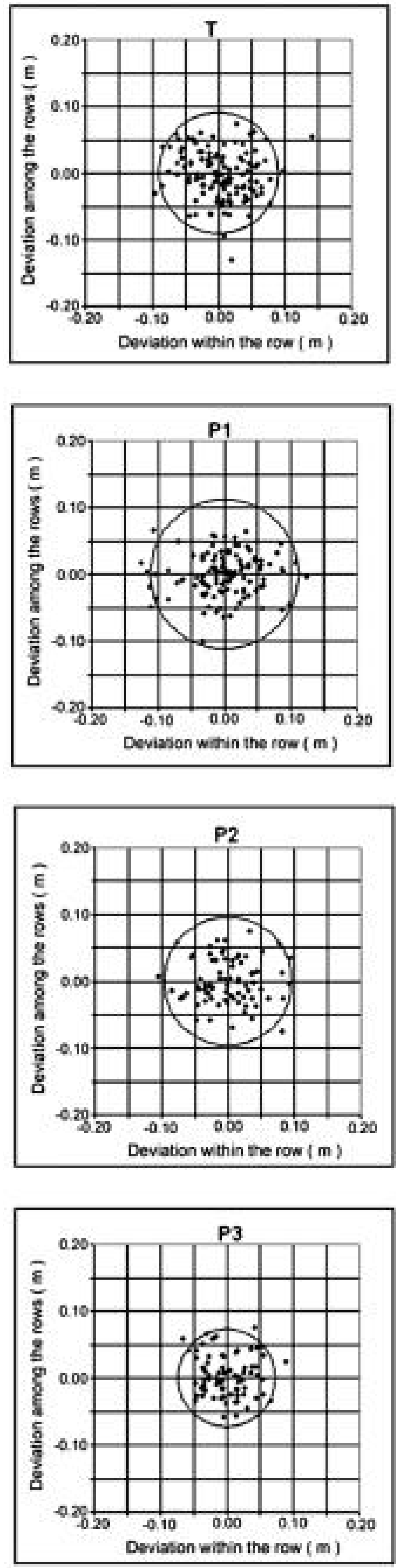


Fig. 5 - Comparison between planting-system results and absolute project values.

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SUMMARY

The aim of this paper is the proposal of an innovative system for commercial transplanter to allow the automatic point-laying location of each vine cutting, without any kind of field preliminary squaring.

A DGPS-RTK system is able to calculate the vine cutting location according to the project values; the transplant operation, carried out by electro-hydraulic and electro-mechanical components, is completely automated.

The goal is to increase the work rate of the transplanting equipment and reduce the necessary skilled labour, without losing the accuracy of the vineyard planting.

Keywords: transplanter, vineyard, automation, GPS.