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Robotics and Automation for Crop Management: Trends and Perspective

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Abstract
Current automated machines in agriculture and, particularly, in protected crops mainly consist in ad-hoc equipments able to perform one specific operation (sowing, transplanting etc.) obtaining high performances in terms of speed and work accuracy.
Available equipments for greenhouse productions are not enough to fulfil the specific demand of specialized machines and there is a strong need of high level of automation machines that could move and operate autonomously in the production site. The introduction of robotics in glasshouses or tunnels could represent a viable solution once robotized multitasking platforms, which can autonomously perform repetitive tasks, will be available. Autonomous robots could be adopted for localized high precision chemical applications, as well as to perform other operations such as products handling, mechanical weed control, precision fertilization and cutting.
Aim of this paper is to discuss, also on the base of the recent results appeared in literature, future trends and application of robotics in protected crops.

Keywords: automation, robotics, greenhouses

Introduction
Robotics and automation (R&A) are widely diffused in many production sectors. At present, agriculture has been only partially involved in this process. The reasons of the delay in the technological transfer of R&A towards agriculture and, in particular, protected crops have been thoroughly analyzed in Kassler (2001) and Belforte et al. (2006).
Despite that, many researches have been conducted to develop reliable technologies, based on ICT, R&A, artificial vision and intelligence, and prototypes for agricultural applications. Twenty years have been passed since the publication of the first results and until now many hundreds of papers have been published. Different approaches and prototypes typologies have been presented and some of them have been successively revised and improved.
Scope of this paper is to analyze a selected subset of 45 papers, that authors considers among the most relevant, with the aim to outline a general framework and to summarize whose that turn out to be the most promising solutions.
This study has been focused on robots and high-level of automation machines that can autonomously perform operations on crops. The general features of prototypes and robotics systems proposed in the selected literature have been grouped according to four main headings: the operative environment (greenhouse or open field), the typology of the solution (autonomous robots, guided navigation robotic platforms, fixed point cells and tractor implements), the performed operation on the crop, the navigation and control strategies. The results of this analytical study is summarized in Table 1 and discussed in the next sections.

Operative environment

Researches can be firstly classified considering if the applications are in open field or in protected crops, mainly in greenhouses. Although many operations are performed in both environments, some important factors influence the design strategies and the reliability of the equipments, in particular for what concerns the displacement of the robot or, in the advanced applications, the autonomous navigation.

Many contributions are devoted to the use of robots in open field (see Table 1), with particular emphasis to automatic guided machines. Open field is strongly unstructured, without fixed reference points, subject to variable climate and, often, presents severe conditions (humidity, powder…) for robots. In this context, many studies concern robotic weeding in organic farming, where the employment of herbicides is not allowed (see e.g. Sørensen et al. 2005). Greenhouses have a higher predisposition to the introduction of robotic systems than the open field, for a number of technical and economical reasons (Belforte et al., 2006; Belforte et al., 2007; Sandini et al. 1990). Crops are intensively cultivated following regular schemes, in the presence of infrastructures, on regular surfaces and taking advantage of facilities (power supply, irrigation plants, pressured air…). In addition, greenhouses are typically equipped by climate, lighting and irrigation control systems that make environment condition more controlled than in open field. Finally, the intensive production of high value crops justifies the investments needed for the introduction of new technologies.

Typology of the robot machine

A first classification within this heading can be made between stand-alone robotic platforms (fixed or mobile) and tractor implement. In the latter case, studies concern the development of "intelligent" implements as, for example, the automatic driving of steerage hoes for mechanical inter-row weed control (Tillet et al., 2002; Tillet and Hague, 1999), or different intra-row weeding implements (Nørremark et al., 2008; Tillet et al. 2008; Blasco et al., 2002). Other kind of automated implements can be found in Bulanon and Katoaka (2010), and in Leemans and Destain (2007) where robotic harvesting of apples and precision seed drill guidance are presented, respectively.

Among robotic platforms, many studies were focused on mobile autonomous vehicles able to follow crop rows, performing specific operations on crop (see Table 1). Most of them have been conceived to operate in open field for weeding or distribution of chemicals on crops. Only few examples have been specifically developed for greenhouse applications (Balloni et al., 2008; Sandini et al., 1990). With regard to the motion system, wheels have been preferred to tracks, which have been employed only in Chatzimichali et al. (2009), Belloni et al. (2008) and Hayashi et al (2002). Although a better traction and a less soil compaction, tracks suffer steering operations in narrow spaces (Bakker et al., 2010). Four driving and steering wheels give a high manoeuvrability to the vehicles both along crops rows and in headlands respect to other solutions, thus this travelling gear is adopted in more recent autonomous robots (Bakker et al., 2010; Sørensen et al., 2010 and 2007; Slaughter et al., 2008; Bak and Jakobsen, 2004).

Robotic cells that operate at fixed point or that move thank to a fixed navigation system are typically employed in greenhouses. In the first case the product is provided to robotic station by conveyor belts or mobile benches (Rath and Kawollek, 2009; Belforte et al., 2006; Cho et al, 2002; Reed et al., 2001; Ryu et al, 2002), whereas in the second case the robotic cell moves on fixed path along crops rows. Rails are the most frequent solution to displace robotic stations through the greenhouse. They can be installed on floor (Hayashi et al. 2009; Tanigakiet et al, 2008), exploiting greenhouse structures as proposed by Belforte et al. (2007)

or existing facilities (e.g. exploiting heating plant pipes as in Van Henten et al., 2003 and 2007).
Fixed point and fixed navigation systems avoid the autonomous navigation, which is technically quite complex, devoting hardware and software resources to crop operations (Belforte et al., 2007). A number of high throughout fixed-point machine are already available on the market for seeding, potting and transplanting in plant nurseries (see e.g. Urbinati, 2010).

Operations on crops
Among the operations that could be performed by agricultural robots, weed control has been the most studied so far, as can be observed in Table 1. Robotic weeding is considered a valid solution to reduce the employment of herbicides in the next future, improving the sustainability of the agriculture (Slaughter et. al, 2008; Griepentrog et al., 2004).
A first solution to reduce the usage of herbicides is the precision spraying. This technique consists in the application of herbicides only in regions of the field in which a weed emergence occurs. Product distribution is typically performed using spraying bars equipped with valves driven by an artificial vision system, which identifies weed emergencies (Slaughter et. al, 2008; Soegaard and Lund, 2007).
More studies have been focused on physical weed control. Inter-row weeding can be improved introducing automation for driving conventional steerage hoes with an artificial vision system (Tillet et al., 2002; Tillet and Hague, 1999). Regarding to physical intra-row weed control numerous autonomous robots were developed. Besides the autonomous navigation along crops rows, the control unit of these robots have to identify and separate crops and weeds in order to remove each weed seedling with by a specific tool. Some examples of implementation of this kind of mechanical actuators for intra-row weeding are in Bakker et al. (2010), Sørensen et al. (2007), Åstrand and Baerveldt (2002), Lamm et al. (2002). For the inactivation of the weed, Lee et al. (1999) proposed the employment of an air pressure jet, whereas Blasco et al. (2002) applied an electrical discharge. Jeon and Tian (2009) developed a direct chemical application end effector that cuts the stem of weeds and wipes chemical on its cut surface, promoting the penetration via the vascular tissue.
Distribution of chemicals for diseases control is a further important item in agriculture, in particular in protected crops, where the climatic conditions and the intensive practice impose several treatment cycles. In this case the main challenge is to avoid the presence human operators inside greenhouses during treatments using autonomous vehicles (Balloni et al., 2008; Mandow et al. 1996; Sandini et al., 1990) or fixed robotic cell in the case of pot crops (Belforte et al., 2006 and 2007). Robotic systems can also perform a precise application of chemicals reducing product leakages with significant economical and environmental advantages. In this case, an automatic crop recognition system is required (Belforte et al., 2006 and 2007; Tillet et al. 1998, Sandini et al., 1990).
Several studies have also been dedicated to the harvest or fruit, vegetables and flowers with the aim to reduce the labour requirement, especially when this operation is exclusively manually performed. Excluding a mobile robot for asparagus harvesting in open field proposed by Chatzimichali et al. (2009), two tractor implements developed by Bulanon and Kataoka (2010) and Peterson et al. (1999) for apples and the oranges harvesting proposed by Muscato et al. (2005), harvesting robots developed so far have conceived to operate in greenhouse with highly structured growing schemes (Kondo et al. 1996) adopting fixed point (Rath and Kawollek, 2009; Cho et al., 2002; Reed et al., 2002) or fixed navigation platforms (Hayashi et al. 2009 and 2002; Tanigakiet et al, 2008; Van Henten et al., 2003). Harvest is the most difficult crop operation since involves the direct interaction of the robot with extremely

delicate targets. For this reason particular tools have been developed in order to manipulate the objects avoiding damaging them. Usually, these end-effectors consist of two parts: a gripping mechanism, often in combination with a suction device, and a peduncle-cutting system that in most cases are a sort of shears, whereas Van Henten et al. (2003) propose a thermal cutting device for cucumber harvesting.
A feature that we consider fundamental is the ability to host different tools carrying out a number of tasks. It has to be noted that most agricultural robots are able to perform only a single specific operation. Only in Belforte et al. (2006 and 2007) and Van Henten et al. (2003 and 2007) multipurpose robots are presented. In the first case two different fixed-point robotic cells were equipped with a set of tools (precision spraying, precise grain fertilization, pot handling, mechanical weed control) operating on pot crops, whereas cucumber harvesting and de-leafing were performed in the second one.

Navigation and control strategies

Core technologies for agricultural robots implemented as autonomous vehicles are the localization and guidance systems. Among the number of guidance-sensing technologies investigated in last decades two type of sensors have achieved a commercial maturity: Global Position System (GPS) and machine vision (see e.g. Slaughter et al. 2008). These technologies were employed alone or together to increase the accuracy (see Table 1). The operating environment typically conditions the choice between the two systems. The employment of GPS based navigation systems is not recommended in protected crops, in particular in glasshouses, where the presence of metallic structures strongly attenuates the satellite signals. As an example, Soegaard and Lund (2007) developed an autonomous robot able to operate both in field and indoor, but GPS is activated only outdoor. On the contrary, the performances and the robustness of machine vision based systems strongly depend on light conditions (Slaughter et al., 2008), therefore particular row tracking algorithms have to be developed in particular for open field. To cope with this problem, some robots have been designed to work during the night, under artificial light conditions. Information provided by GPS and/or artificial vision were integrated with other sensors such as encoders installed on traction and steering system, electronic compass and accelerometers. Ultrasonic sensors were also considered to assist the autonomous guidance as proposed in Cho and Lee (2000), Harper and McKerrow (2001), and Mandow et al. (1996).
With regard to control of tools, machine vision is widely employed since the spatial position of the operations targets (crops, weeds or parts of them) is generally unknown. When the contact with the target is foreseen, such as precision spraying, the same vision system adopted for autonomous navigation could be exploited (Tillet et al. 1998). Otherwise, for example in the case of GPS based mobile robots or robotic cells, tools are controlled by a proper artificial vision system. Many researches were focused on the development of algorithms able to separate the objects in different classes (crop, background, weed…). Even in this case, light conditions variability affects the artificial vision system performances, thus some authors adopted illumination systems, in combination with shields, in order to acquire images in standard light conditions. Åstrand and Baerveldt (2002) and Lee et al. (1999) apply this technique for robotic weeding in open field.
Harvest needs more complex artificial vision systems, usually based on stereovision, because objects (fruits, vegetables or flowers) have to be identified and located in a three-dimensional space.

Table 1. Features of agricultural robotic systems grouped within four main categories

	Greenhouse	Open Field	Autonomous robot	Fixed navigation	Fixed point cell	Tractor implement	Multiporpose	Spraying on crop	Precision spraying W C	Mechanical/Phisical WC	Harvest	Other operations	Vision navigation	Vision Tools Control	GPS	Other sensor	Giudelines	Perspectives	Review
Åstrand and Baerveldt (2002)		x	x							x			x	x		x			
Bak and Jakobsen (2004)		x	x										x		x	x			
Bakker et al. (2010)		x	x							x					x	x			
Bakker et al. (2010)		x	x							x			x	x	x	x	x		x
Balloni et al. (2008)	x		x					x					x						
Belforte et al. (2006)	x				x		x	x				x		x			x		
Belforte et al. (2007)	x			x	x		x	x		x		x		x			x		
Blasco et al. (2002)		x				x				x				x					
Bulanon and Kataoka (2010)		x				x					x			x					
Chatzimichali et al. (2009)		x	x								x		x						
Cho and Lee (2000)		x	x					x							x	x			
Cho et al. (2002)	x				x						x			x					
Griepentrog et al. (2004).									x	x								x	
Hagras et al. (2002).			x																
Hague et al. (2000).		x	x										x			x			
Harper and McKerrow (2001)	x		x													x			
Hayashi et al. (2002)	x			x							x			x					
Hayashi et al. (2009).	x			x							x			x					
Jeon and Tian (2009).	x	x	x						x	x				x					
Kassler (2001).																		x	
Kondo and Monta (1999).				x							x			x					
Kondo et al. (1996)											x							x	
Lamm et al. (2002)		x	x							x			x	x	x				
Lee et al. (1999)		x	x							x			x	x	x				
Leemans and Destain (2007)		x				x						x		x					
Mandow et al. (1996)	x		x					x					x			x			
Muscato et al. (2005)											x								
Nagasaka et al. (2004)		x	x									x			x	x			
Nørremark et al. (2008)		x				x				x					x				
Pedersen et al. (2006)																		x	
Peterson et al. (1999)											x								
Rath and Kawollek (2009)	x				x						x			x					
Reed et al. (2001)	x				x						x			x					
Ryu et al. (2001)	x				x							x		x					
Sandini et al. (1990)	x		x					x					x						
Slaughter et al. (2008)			x						x	x			x	x	x	x			x
Soegaard and Lund (2007)	x	x	x						x					x	x	x			
Sørensen et al. (2007)		x	x							x			x		x				
Sørensen et al. (2010)	x																x		
Tanigakiet al. (2008)	x			x							x			x					
Tillet and Hague (1999)		x				x				x				x					
Tillet et al. (2002)		x				x				x				x					
Tillett et al. (2008)		x				x				x				x					
Tillett et al. (1998).		x	x					x					x	x		x			
Van Henten et al. (2003)	x			x			x				x			x					
Van Henten et al. (2007)	x			x			x					x							

Conclusions and perspectives

The introduction and diffusion of robotics systems will represent an important opportunity for agriculture in next future. The employment of robotic systems will improve sustainability and work safety in many agricultural sectors as well as a consistent production costs reduction. Distribution of chemicals by means autonomous robots would avoid the presence of human operator during treatments in particular in greenhouses where this operation is still manually performed. At the same time, a significant reduction of pollutants can be obtained with precise application of pesticides. Environmental friendly practises as physical weed control would became economically feasible with consistent costs depletion in particular in organic farming (Sørensen et al, 2005; Griepentrog et al., 2004). Pedersen et al. (2006) demonstrate the economical feasibility of applying autonomous robotic vehicles, compared to conventional systems, in micro-spray robotic weeding, crop scouting and grass cutting in golf courses. However some technical and economical challenges will have to be faced in next years to achieve a real diffusion of robotics in agricultural practices and its consequent benefits. The high costs and reliability of guidance systems as well as the small throughput are still an obstacle that increase the cost of robotic systems (Pedersen et al., 2006). Detection and identification of crops and/or weeds under a wide range conditions common to agricultural scenarios remains another important challenge (Slaughter et al., 2008).

In the authors opinion there are some interesting perspectives in R&A for agriculture. First of all, the development of light robots, that could perform simple operations, using the simplest possible technologies, without the presence of human operators. This kind of machines could be primarily devoted to spraying operations, but could also be used in other repetitive simple tasks. To reduce costs and complexity, these robots could be designed to use fixed references (laser pointers, straight magnetic or optical line etc.) for the navigation, favouring greenhouse applications. Furthermore, research efforts should be addressed to develop more flexible robots in terms of row distance and parcel size as well as of ability to host different tools. In this way the same robotic platform (fixed or mobile) could perform many operations on different crops, optimizing the costs.

References:

Åstrand B, Baerveldt A J 2002. An Agricultural Mobile Robot with vision-based perception for mechanical weed control. Autonomous Robots, 13, 21-35

Bak T, Jakobsen H 2004. Agricultural robotic platform with four wheel steering for weed detection. Biosystems Engineering, 87 (2), 125-136.

Bakker T, van Asselt K, Bontsema J, Muller J, van Straten G 2010. Systematic design of an autonomous platform for robotic weeding. Journal of Terramechanics, 47, 63-73

Balloni S, Caruso L, Conti A, Schillaci G, Longo D, Muscato G 2008. Preliminary Study for the Development of an Electrical Autonomous Vehicle for Safe Agricultural Chemicals Distribution Inside Greenhouses. International Conference: "Innovation Technology to Empower Safety, Health and Welfare in Agriculture and Agro-food Systems", September 15-17, Ragusa, Italy

Belforte G, Deboli R, Gay P, Piccarolo P, Ricauda Aimonino D 2006. Robot Design and Testing for Greenhouse Applications. Biosystems Engineering, 95, 309-321

Belforte G, Gay P, Ricauda Aimonino D 2007. Robotics for improving quality, safety and productivity in intensive agriculture: challenges and opportunities, in Industrial Robotics: Programming, Simulation and Applications. Low Kin Huat, Advanced Robotic Systems, Vienna, Austria

Blasco J, Alexios N, Roger J M, Rabatel G, Moltò E 2002. Robotic weed control using machine vision. Biosystems Engineering, 83, 149-157

Bulanon D, Kataoka T 2010. A Fruit Detection System and an End Effector for Robotic Harvesting of Fuji apples. Agricultural Engineering International: The CIGR Journal, 12 (1), 203-210

Chatzimichali A P, Georgilas I, Tourassis V 2009. Design of an advanced prototype robot for white asparagus harvesting. International Conference on Advanced Intelligent Mechatronics, AIM 2009, Singapore, 14-17 July

Cho S I, Lee J H 2000. Autonomous Speedsprayer using Differential Global Positioning System, Genetic Algorithm and Fuzzy Control. Journal of Agricultural Engineering Research, 76 (2), 111-119

Cho S I, Chang S J, Kim Y Y, An K J 2002. Development of a Three-degrees-of-freedom Robot for harvesting Lettuce using Machine Vision and Fuzzy logic Control. Biosystems Engineering, 82 (2), 143-149

Griepentrog H, Christensen S, Søgaard H 2004. Robotic weeding. Proceedings of EurAgEng04 - Leuven, Belgium, 12-14 September

Hagras H, Colley M, Callaghan V 2002. One Learning and Adaptation of Autonomous Mobile Robots for Sustainable Agriculture. Autonomous Robots, 13, 37-52

Hague T, Marchant J A, Tillet N D 2000. Ground based sensing system for autonomous agricultural vehicles. Computers and Electronics in Agriculture, 25, 11-28

Harper N, McKerrow P 2001. Recognising plants with ultrasonic sensing for mobile robot navigation. Robotics and Autonomous System, 34, 71-82

Hayashi S, Shigematsu K, Yamamoto S 2009. Evaluation of a strawberry-harvesting robot in a field test. Biosystems Engineering, 105 (2), 160-171

Jeon H, Tian L 2009. Direct application end effector for a precise weed control robot. Biosystems Engineering, 104 (4), 458-464

Kassler M 2001. Agricultural automation in the new millennium. Computers and Electronics in Agriculture, 30, 237-240

Kondo N, Monta M, Fujiura T (1996). Fruit harvesting robots in Japan. Adv. Space. Res., 18 (1/2), 181-184

Kondo and Monta (1999). Strawberry Harvesting Robots. Proceeding ASAE/CSAE-SCGR Annual International Meeting, Toronto, Ontario, Canada, July 18-21, Paper n. 993071

Lamm R D, Slaughter D C, Giles D K 2002. Precision weed control system for cotton. Transactions of ASAE, 45, 231-238

Lee W S, Slautghter D C, Giles D K 1999. Robotic weed control system for tomatoes. Precision Agriculture, 1, 95-113

Leemans V, Destain M 2007. A computer-vision based precision seed drill guidance assistance. Computers and electronics in agricolture, 59 (1), 1-12.

Mandow A, Gómez de Gabriel J M, Martínez Rodríguez J L, Muñoz V F, Ollero A, García-Cerezo A 1996. The Autonomous Mobile Robot AURORA for Greenhouse Operation. IEEE Robotics and Automation Magazine, December, 18-28

Muscato G., Prestifilippo M., Abbate N, Rizzuto I (2005). A prototype of an orange picking robot: past history, the new robot and experimental results. Industrial Robot: An International Journal, 32 (2), 128-138

Nagasaka Y, Umeda N, Kanetai Y, Taniwaki K, Sasaki Y 2004. Autonomous guidance for rice transplanting using global positioning and gyroscopes. Computers and electronics in agricolture, 43 (3), 223-234

Nørremark M, Griepentrog H, Nielsen J, Søgaard HT 2008. The development and assessment of the accuracy of an autonomous GPS-based system for intra-row mechanical weed control in row crops. Biosystems Engineering, 101 (4), 396-410

Pedersen S M, Fountas S, Have H., Blakmore B. S. (2006). Agricultural robots – system analysis and economic feasibility. Precision Agriculture, 7, 295-308.

Peterson D L, Bennedsen B S, Anger W C, Wolford S D 1999. A system approach to robotic bulk harvesting of apples. Transactions of ASAE, 42, 871-876

Rath T, Kawollek M 2009. Robotic harvesting of *Gerbera Jamesonii* based on detection and three-dimensional modelling of cut flower pedicels. Computers and electronics in agriculture, 66 (1), 85-92

Reed J N, Miles S J, Butler J, Baldwin M, Nobel R 2001. Automatic mushroom harvester development. Journal of Agricultural Engineering Research, 78, 15-23

Ryu K H, Kim G, Han J S 2001. Development of a Robotic Transplanter for Bedding Plants. Journal of Agricultural Engineering Research, 78 (2), 141-146

Sandini G, Buemi F, Massa M, Zucchini M 1990. Visually guided operations in green-house. IEEE International Workshop on Intelligent Robots and Systems IROS '90,
Slaughter D, Giles D, Downey D (2008). Autonomous robotic weed control systems: A review. Computers and electronics in agricolture, 61 (1), 63-78

Soegaard H, Lund I 2007. Application accuracy of a machine vision-controlled robotic micro-dosing system. Biosystems Engineering, 96 (3), 315-322

Sørensen C G, Madsen N A, Jacobsen B H 2005. Organic farming scenarios: operational analysis and costs of implementing innovative technologies. Biosystems Engineering, 91 (2), 127-137

Sørensen C, Nørremark M, Jørgensen R, Jensen K, Maagaard J, Jensen L A 2007. Hortibot: Feasibility study of a plant nursing robot performing weeding operations - part IV. ASABE Annual International Meeting, Minneapolis, Minnesota 17 - 20 June 2007.

Sørensen C G, Jørgensen R N, Maagaard J, Bertelsen K K, Dalgaard L, Nørremark M 2010. Conceptual and user-centric design guidelines for a plant nursing robot. Biosystems Engineering, 105 (1), 119-129

Tanigaki K, Fujiura T, Akase A, Imagawa J 2008. Cherry-harvesting robot. Computers and Electronics in Agriculture, 63 (1), 65-72

Tillett N D, Hague T, Marchant J A 1998. A Robotic System for Plant-Scale Husbandry. Journal of Agricultural Engineering Research, 69, 169-178

Tillet N D, Hague T 1999. Computer-vision-based Hoe guidance for cereals an initial trial. Journal of Agricultural Engineering Research, 25, 225

Tillet N D, Hague T, Miles S J 2002. Inter-row vision guidance for mechanical weed control in sugar beet. Computers and Electronics in Agriculture, 33, 163-177

Tillett N, Hague T, Grundy A, Dedousis A 2008. Mechanical within-row weed control for transplanted crops using computer vision. Biosystems Engineering, 99 (2), 171-178

Urbinati. 2010. www.urbinati.com

Van Henten E J, Hemming J, Van Tuijl B A J, Kornet J G, Bontsema J, Van Os E A 2003. Field test of an autonomous cucumber picking robot. Biosystems Engineering, 86, 305-313

Van Henten E J, Van Tuijl B A J, Hoogakker G J, Van Der Weerd M J, Hemming J, Kornet J G, Bontsema J 2007. An Autonomous Robot for De-leafing Cucumber Plants grown in a High-wire Cultivation System. Biosystems Engineering, 94, 317-323

Mechanical Distribution of Natural Enemies in the Open Field

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Abstract

For experimental trials in strawberry open field, two different applications of a new version of a prototype, built for mechanical distribution of natural enemies, were used: one mounted on a bar carried by an operator with a shoulder strap and lateral handle; the other mounted on a carrying bar connected to three linkage points to a tractor. In this case, three prototypes were attached to three support rods and connected electrically to one another in parallel, powered by a single battery and commanded by a single switch, positioned near the tractor driver.
In this configuration, laboratory trials to evaluate the throw direction, the spatial distribution, the quantity distributed, the uniformity of throw in time were carried out.
Previous laboratory trials were carried out to assess the performance of the new version of the prototype and to set the suitable flow rate for the distribution in open field with reference to the forward velocity of the tractor.
With these applications of the new version of prototype, the manoeuvrability has been much improved and consequently better results can be obtained in terms of both work capacity and uniformity of distribution. The high values of the Uniformity Index and Similarity Index confirm that the application of the prototype mounted on the carrying bar could represent a suitable solution for the distribution of natural enemies in strawberry crops. Also the work capacities show the advantage using the machine tested as opposed to the manual distribution generally adopted for biological and integrated crops.

Keywords: machines for biological plant protection, sustainable agriculture, safety, prototype

Introduction

The manual release of natural enemies onto infested plants takes up a considerable amount of the operator's time and, moreover, does not ensure uniform distribution. In order to contain the production costs connected with defence operations and to favour a wider use of biological products, various solutions have been examined (Baraldi *et al.*, 2006; Drukker *et al.*, 1993; Giles *et al.*, 1995; Giles & Wunderlich, 1998; Gill *et al.*, 1999; Maini *et al.*, 1988; Opit *et al.*, 2005; Pezzi *et al.*, 2002; Pickett *et al.*, 1987; Van Driesche *et al.*, 2002). The Department of Agricultural Engineering at the University of Catania has realised a prototype to mechanise the release of natural enemies, which are commonly used for biological control on vegetable crops in protected environments and in the open field. The results obtained were such as to lead to the conclusion that the prototype is suitable for use in biological control programmes (Blandini et al., 2008; Tropea Garzia *et al.*, 2006).
Since then, a second version of the prototype has already been built This differs from the preceding one not only as regards the hopper, doser and distributor disc but also as regards materials and size. It can directly carried by the worker by means of an handle.
To evaluate the functionality of the new prototype several laboratory trials were carried out

The Authors equally contributed to the present study.

and three prototypes were built and installed on a bar tractor mounted for treatments in the open field in order to demonstrate their versatility in various agronomic and environmental conditions. Finally open field trials on two different strawberry fields (with and without cover tunnel in plastic film) were carried out.

Materials and Methods

The most recent version of the prototype and his applications

The prototype used during the experimental trials is a new version of the initial one described in Blandini *et al.* (2006). The modifications regard some of its components (Figure 1):

- the hopper is smaller (about 1.5 dm^3) than the previous version and is made of aluminium to permit better centring of the doser with respect to the exit hole for the product;
- the doser, rotating inside the hopper, is obtained from the tip of a drill for concrete, with the cutting elements at the end removed; it has two holes in the stem for the attachment of two fins;
- the fins are made of a flexible plastic material, which are positioned at different heights and ensure that the product flow towards the exit hole;
- the finned distributor disc has a diameter of 300 mm instead of the 200 mm of the previous version and it is made of aluminium;
- the connection between the bar, held by an operator, and the prototype is realised by means of a cylindrical hinge made up of two circular plates, bolted together, one applied to the end of the bar and the other in the posterior area of the prototype frame (Figure 2);
- the two plates have small frontal teeth along a circular crown, in order to permit almost continuous regulation of the angle of tilt of the bar's axis with the plane of the distributor disc and guarantee its constancy while the prototype is working.

Figure 1. The most recent version of the prototype used for the test.

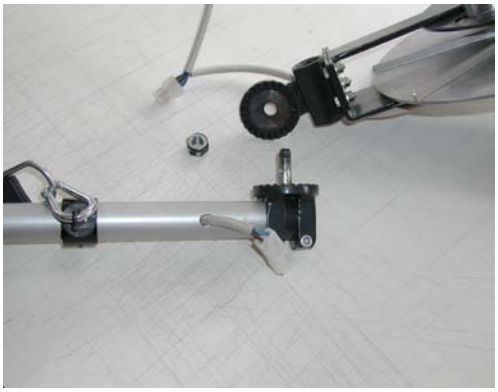

Figure 2. The cylindrical hinge.

The hopper contains the arthropods to be distributed together with the substrate (humid vermiculite at 30% for the *Phytosiulus persimilis* Hathias Herriot and buckwheat husks mixed with vermiculites for the *Orius levigatus* (Fieber)) with which they are marketed.

The doser and the distributor disc are directly activated by two electric motors powered by continuous 6 V current, positioned below the disc and fixed to the lid of the hopper respectively.

The doser has a rotating motion coinciding with the axis of the hopper and, therefore, of the exit hole for the product. Regulation of the amount of the product to be distributed takes place by varying the diameter of the exit hole of the hopper by means of bushings of different diameters with external thread, which can be screwed to the hopper. Moreover the tightening

of the bushings makes possible to fix the hopper to the supporting disc, which has a radial loop. Regulating the position of the hopper along the loop and rotating the support disc around the point of anchorage to the frame, it is possible to vary the launch direction of the natural enemies onto the crops from the distributor disc.
Two different applications of this version were used for experimental test in open field:
- one mounted on a bar carried by an operator with a shoulder strap and lateral handle;
- the other mounted on a carrying bar connected to three point linkage to a tractor.

For this second application, three prototype was applied on three support rods with an hexagonal cross-section arranged vertically. The prototypes were connected electrically to one another in parallel, powered by a single 12 Ah rachargeable battery and commanded by a single switch, positioned near the tractor driver.
The height of the prototypes can be regulated and the best distance separating them can be chosen according to the arrangement of the crop in the field (equidistant and twin rows, etc.).

Laboratory trials to assess prototype performance
It is known by literature that in greenhouse it is necessary to distribute 10-15 examples of *P. persimilis*/m^2) and 1-3 examples of *O. laevigatus*/m^2. Taking into account the mass of the substrate and the amount of arthropods in a package and hypothesising a forward speed of 3 km/h and an effective distribution range of 1 m, the optimum capacity of flow is about 9 g/min for the *P. persimilis* and about 6 g/min for *O. laevigatus*.
To obtain this flow, several trials were carried out positioning the hopper and its doser over a precision balance so that it was possible to constantly weigh the quantity of product released by the machine. It was measured for dosers with different diameters (14 and 15 mm) and for different hopper exit hole diameters (14, 15, 16 and 17 mm). The uniformity of release in time was assessed by measuring - at 30-second intervals - the quantity of antagonists dispersal material. Each trial was repeated 3 times filling the hopper with the mass of one (*O. laevigatus*) or two (*P. persimilis*) packages every time.
Particular attention was paid to the length and orientation of the flexible fins in the doser, so as to guarantee continuity as regards product flow.
The assessments of the material launch distance were carried out (with the collaboration of entomologists) positioning the prototype at a height of 40 cm from a horizontal purpose-built plane. This 180×140 cm plane was divided into 15 sectors (5×3 rows). For the collection of the *P. persimilis* 36×47 cm plastic trays containing a thin veil of water were used. Instead, for *O. laevigatus* the point at which each individual fell was marked on a sheet of paper.
Other tests were carried out with the prototypes carried by the tractor and using only the dispersal material of the natural enemies. For each of the two substrates and for each prototype:
1. the position of the hopper was regulated to optimise the direction of the jet;
2. the quantity and uniformity of the product distribution in time was assessed;
3. the transversal profile of this was checked.

The quantity of product simultaneously distributed (g/s) by the 3 prototypes was studied by weighing the material released by each prototype inside purpose built boxes. The trials were repeated at 2-minute intervals.
The transversal profile of product distributed was measured for the two substrates at two different prototype heights (50 and 100 cm from the ground). The material was collected in 32 of 33×39 cm aluminium trays (8×4 rows) for a covered horizontal surface of 156 cm long and 264 cm wide. The trials were repeated 3 times for each trial condition and for each substrate.
In order to express an assessment of the transversal uniformity for each trial condition, the Uniformity Index (UI) calculated with the following equation (Cerruto *et al.*, 2009) was used:

$$IU = 1 - \frac{\sum_{i=1}^{n} \left| \frac{y_i}{y_m} - 1 \right|}{2n} \qquad (1)$$

where:

- y_i is the quantity of product collected in every row;
- n is equal to the number of rows;
- y_m is the arithmetic mean of the quantity of product collected in all the rows.

This index, which will have a value between 0 and 1, is a measurement of how far the real profile obtained differs from the ideal one, which is constant and equal to its corresponding average value.

The difference between two profiles, y_1 e y_2, was measured by calculating the Similarity Index (SI), defined by the equation (Cerruto *et al.*, 2009):

$$IS = 1 - \frac{\sum_{i=1}^{n} \left| y_{1i} - y_{2i} \right|}{\sum_{i=1}^{n} \left| y_{1i} + y_{2i} \right|} \qquad (2)$$

which again gives values between 0 and 1: the nearer the result is to 1, the more similar the profiles are. This formula refers to profiles obtained in the same conditions and so to compare values obtained in different conditions (in terms of material distributed and/or prototype height), the data were first normalised in such a way that $\sum_{i=1}^{n} y_{1i} = \sum_{i=1}^{n} y_{2i} = 1$

The open field trials

Open field trials on two different strawberry fields (without and with cover tunnel in plastic film) were carried out. Both fields were located in the commune of Cassibile (SR) on sloping flat land. The cultivation takes place on 0.8 m large ridges covered with black plastic film to give a mulch effect. The distance between two ridges was around 0.6 m.

The first trials were on Camarosa cultivar strawberry fields without cover tunnel. On every ridge there were two rows of plants 0.3 m apart; the inter-row distance of two plants was 0.25 m, so the plant density was 8 plants/m^2. Instead, the other trials were on Carmela cultivar strawberry fields with cover tunnel. In this case the inter-row distance was 0.2 m and consequently the plant density was 12 plants/m^2.

For the distribution trials in the first field three prototypes mounted on a 3.2 m carrying bar and connected to three point linkage to a 2 WD tractor were used (Figure 3). During the trials the prototypes were regulated at an average height of 50 cm from the ground and at an inter-row distance of 1.4 m, so that each one was also positioned in correspondence of the centre line of each ridge. Consequently, the work width was 4.2 m. The area considered for the experiments was about 600 m^2 and included a total of 6 ridges.

Instead, in the second strawberry field, the trials were carried out on a surface of 150 m^2 including 3 ridges and the prototype applied to the bar carried directly by an operator was used (Figure 4). In this case two treatments with both natural enemies a fortnight apart were carried out.

Figure 3. The distribution with three prototype carried by a tractor.

Figure 4. The distribution with a prototype carried by an operator.

Results

The laboratory trials to assess prototype performance

The trials carried out to define the right flow show to use:

– the 14 mm diameter doser for both substrates;
– the 17 and 15 mm bushing diameters for the buckwheat husks mixed with vermiculite (*O. laevigatus*) and vermiculite on its own (*P. persimilis*) respectively.

The results of the trials carried out with the *O. laevigatus* substrate show (Figure 5) that the quantities released every 30 seconds vary between 5.56 and 2.48 g, with an average of 3.12 g, as expected, and a CV of 21%. Only the highest extreme value can be considered to be influenced by the loading and starting phase, while the quantities of product distributed are fairly constant.

The results obtained with *P. persimilis* and its substrate show that the quantities distributed vary between 18.18 and 3.70 g (an average of 7.21 g), with a CV of 67%. There is, in fact, a significant difference between the first 8 samples (where more than half of the product in the hopper is released) and the remaining 15; this is caused by the effect of the mass present. From the 9th sample onwards, on the other hand, the quantities distributed are fairly constant. This is demonstrate by distributing half mass of product: in fact only the first sample was very different from the average because of the effect of the load. The other values were found to be very uniform (Figure 6) and the CV was 13%.

As regards to the launch distance, it was observed that about 85% of the natural enemies distributed on the horizontal plane were within a distance of 90 cm from the prototype while the inert material exceed one metre.

The transversal distribution profiles, shown in figure 7, represents the average quantities of product collected in the 8 rows and 3 repetitions. They are substantially symmetric and have a CV of 30-34%. Only the lower values found at the lateral edges of the distribution zone can be compensated for a programmed superimposition in subsequent runs.

The results of Uniformity Index exceed always 0.86 for both prototype heights. This means that the product can provide homogeneous cover of the surface treated. Also the Similarity Index exceed 0.92 and therefore the profiles can be considered very similar to one another regardless of the height of distribution of the inert material.

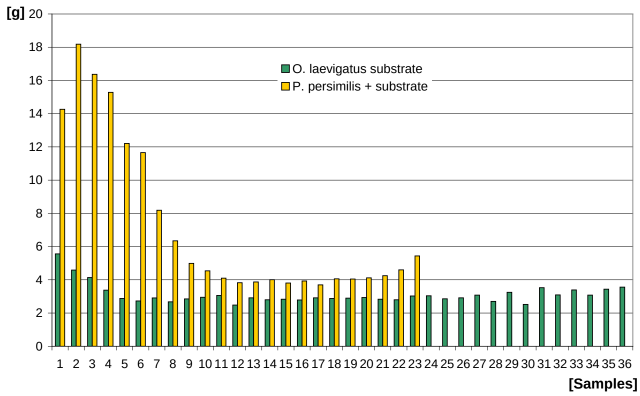

Figure 5. Average values [g] of product released every 30 s.

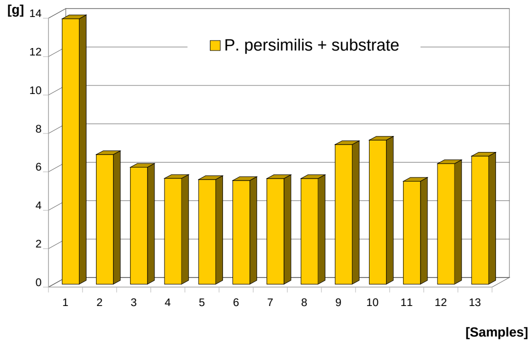

Figure 6. Average values [g] of humid vermiculite released every 30 s with half mass inserted into the hopper.

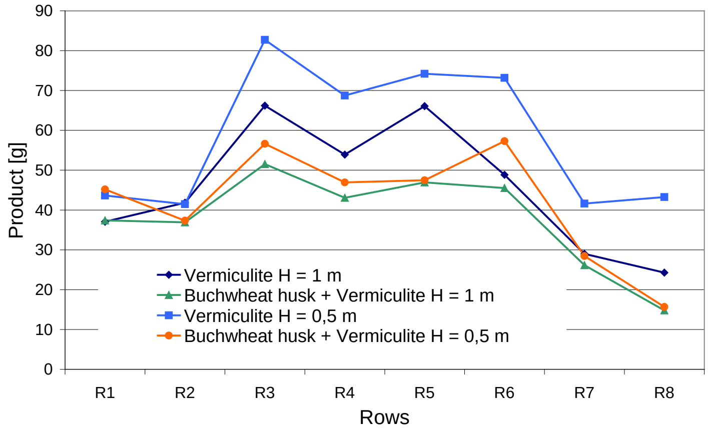

Figure 7. Transversal distribution profiles.

The open field trials

The trials carried out with the three prototypes applied to the 2 WD tractor permitted an effective work capacity of about 0.6 ha/h in the case of *O. laevigatus* and about 1 ha/h in the case of *P. persimilis* to be reached. In fact, the average forward speeds were 1.4 km/h (0.4 m/s) and 2.3 km/h (0.6 m/s) respectively.

For both the natural enemies three packages were used, one for each hopper, distributing about 0.2 g/m^2 in the case of *O. laevigatus* and 0.4 g/m^2 in the case of *P. persimilis*. With respect to the values shown in Table 1, an increase in quantity was observed, particularly for *P. persimilis*, due to spillage from the doser during turning manoeuvres caused by the vibrations transmitted by the tractor. In fact, the headlands were not large enough to allow the fast turning of the tractor equipped with the carrying bar; moreover, the farmer carried out the plant protection treatments with a spray gun carried directly by the operator, so the field was not suitable for mechanised cultivations.

The same increase in quantity was not recorded with the *O. leavigatus* because of greater dimensions of its dispersal material (buckwheat husks mixed with vermiculites) with respect to that used for *P. persimilis*: only vermiculites of small dimensions.

Table 1. Distribution parameters in the first strawberry field where three prototypes in parallel were used.

Prototypes	Distributor disk velocity (rpm)	Doser velocity (rpm)	Flow (g/s)	
			O. laevigatus	*P. persimilis*
1	530	29	0.13	0.55
2	453	27	0.10	0.54
3	448	26	0.19	0.42
mean	*477*	*27*	*0.14*	*0.50*

In the case of the trials carried out in the second strawberry field using only one prototype applied to the bar carried by an operator, the work capacity were significantly lower (about 0.06 ha/h) than those obtained with the tractor carried prototypes. This result was due both to the ability to carry out the treatment on only one ridge at the same time (effective work width of 1.4 m instead of 4.2 m with the tractor) and to the lower forward speed, only 0.43 km/h (0.12 m/s), that was needed to keep the distribution of the packages on the established surface. Finally, it is worth pointing out that on the basis of the information provided by the farmers hosting the trials, it would seem that the productive yield obtained with biological treatments and those with chemical treatments were comparable.

Conclusions

The distribution mechanism of the prototype seems well suited to biological pest control strategies also in the open field. With the two applications of the new version of prototype, the manoeuvrability has been much improved and consequently better results can be obtained in terms of both work capacity and uniformity. The high values regarding Uniformity Index and Similarity Index confirm that the prototype mounted on the carrying bar connected to three point linkage to a tractor could represent an suitable solution for the distribution of natural enemies in strawberry crops. Also the work capacities show the advantage using the machine tested as opposed to the manual distribution generally adopted for biological and integrated crops.

However, it seems useful to consider the use of bigger hopper to reduce the time taken to fill up the hopper when the machine is working, even if this could have negative consequences on the flow's constancy of the doser. Moreover, to increase the work capacity the headlands would be large enough to allow the fast turning of the tractor and the reduction of the stopping times of the prototypes, so to limit the product lost because of the not inconsiderable vibrations transmitted by the tractor. At last, if there were no problems with turning, it would be possible to increase the work capacity by increasing the work width and consequently the bar length and thus the number of prototypes used.

Economic assessments regarding the relative cost of treatments with natural enemies would supply additional information that could contribute to a global evaluation.

References

Baraldi G., Burgio G., Caprara C., Lanzoni A., Maini S., Martelli R., Pezzi F. (2006). Distribuzione meccanica di Phytoseiulus persimilis. *Atti su CD Giornate Fitopatologiche*. Riccione (RN) 27-29 marzo 2006. Vol. 1 563-570.

Blandini G., Failla S., Manetto G., Tropea Garzia G., Siscaro G., Zappalà L. (2006). Prove preliminari di distribuzione meccanica di antagonisti naturali. *Atti su CD Giornate Fitopatologiche*. Riccione (RN) 27-29 marzo 2006. Vol. 1 557-562.

Blandini G., Emma G., Failla S., Manetto G. (2008). A Prototype for Mechanical Distribution of Beneficials. Atti dell'International ISHS Symposium GreenSys2007 on "High Technology for Greenhouse System Management". Napoli, 4-6 ottobre 2007. Printed on Acta Horticulturae (ISSN 0567-7572 0567-7572 - ISBN 978-90-6605-621-3), n. 801, Vol. 2 1515-1522.

Cerruto E., Balloni S., Conti A., Emma G., Caruso L. (2009). Vertical Spray Boom Profiles for Greenhouse Applications. Proceedings XXXIII CIOSTA—CIGR V Conference "Technology and Management to Ensure Sustainable Agriculture, Agro Systems, Forestry and Safety", Reggio Calabria (ITALY), 17–19 giugno 2009, ISBN 978-88-7583-031-2, vol. 1, 391–395.

Drukker B., Yaninek J. S., Herren H. R. (1993). A packaging and delivery system for aerial release of Phytoseiidae for biological control. *Exp. Appl. Acarol.*, 17, 129–143.

Giles D. K., Gardner J., Studer H. E. (1995). Mechanical release of predacious mites for biological pest control in strawberries. *Transact. of the ASAE* 38 (5) 1289-1296.

Giles D. K., Wunderlich L. R. (1998). Electronically controlled delivery system for beneficial insect eggs in liquid suspensions. *Transact. of the ASAE* 41 (3) 839-847.

Maini S., Gattavecchia C., Libé A. (1988). Impiego di velivolo ultraleggero per i lanci di Trichogramma maidis Pint. e Voeg. contro Ostrinia nubilalis (Hb.). *Atti Giornate Fitopatologiche* 2, 203-212.

Opit G. P., Nechols J. R., Margolies D. C., Williams K. A. (2005). Survival, horizontal distribution, and economics of releasing predatory mites (Acari: Phytoseidae) using mechanical blowers. *Biological Control*, 33, 344-351.

Pezzi F., Rondelli V., Baraldi G. (2002). Mechanical distribution of Phytoseiids in greenhouse crops. *Rivista di Ingegneria Agraria*, 33 (3), 33-39.

Pickett C. H., Gilstrap F. E., Morrison R. K., Bouse L. F. (1987). Release of predatory mites by aircraft for the biological control of spiter mites infesting corn. *Journal Econ. Entomol.* 80 (3) 906-910.

Tropea Garzia G., Zappalà L., Siscaro G., Blandini G., Failla S., Manetto (2006). Mechanical distribution of beneficials: laboratory tests. In corso di stampa su *Bulletin IOBC/WPRS Working Group "Integrated Control in Protected Crops, Mediterranean Climate"*, 14-18 Maggio 2006, Murcia, Spagna.

Van Driesche R. G., Lyon S., Sanderson J., Smith T., Lopes P., MacAvery S., Rusinek T., Couch G. (2002). Greenhouse trials in Massachusetts and New York with Amblyseius cucumeris: effects of formulation and mechanical application. IOBC/wprs Bulletin, 25 (1), 273-276.

A Multifunctional Tracked Vehicle Able to Operate in Vineyards Using GPS and Laser Range-finder Technology

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Abstract

Work in agriculture and in particular in some local sloping vineyards require a great deal of resources and effort. But regular geometry of most vineyards rows can help the automation of some cultivation processes. With the aim to facilitate workers during harvesting, pruning and to carry bins full of bunches of grapes up to the end of the rows, a versatile multifunction electrical vehicle is under development.
The vehicle, named U-Go, has been built in order to be used as a multipurpose outdoor vehicle in different applications, so the control electronics have been designed to provide different choices for control modalities. The simplest one is the teleoperated modality. In this situation a remote user, using a joystick, can send direct commands to the robot in order to move forward, backward or turn left or right at different speeds. In order to allow the totally autonomous operations in the vineyards, different sensors were tested. In this work, system test using a Laser Range Finder and a DGPS have been performed using an obstacle avoidance methodology named Potential Field Method (PFM). This algorithm allows the robot to follow a specified trajectory, defined by means of some GPS waypoints, while avoiding unexpected obstacles. This control algorithm has been developed using the Microsoft Development Robotic Studio that allows for code development and simulation for robotics application.
Different tests on the U-Go Robot have been performed in order to demonstrate its capabilities on the two different modalities with promising results.

Introduction

In viticulture the development of autonomous systems able to remove or facilitate the operators in the workplace comes from the sensitivity to the issues of health and safety. In the vineyards with a close layout and in steep slope, the distribution of agrochemicals, the handling of the bins with the grape, during the harvest, from the spin to the trailer, is performed mostly by hand and place the operator at risk to his health (chemical risk, effort the back and upper limbs). In the low strain vineyards (goblet, spurred cordon and Guyot), typical Mediterranean viticulture, some cultivation operations (green pruning, sucker removal, vine tying) lead the operator to work bent toward the ground, in difficult and incorrect positions. There are commercially available electric trucks (Damascus, VITIJAMBEUR) fitted with seats built with the aim to reduce operator fatigue and increase productivity, but the seat position is often not adapted to the habits of the worker who, while working sitting, continues to maintain an incorrect posture of the back.
There aren't in literature, till this moment, existing systems, reliable and robust, suitable to be used in vineyard. In general, the potential of robotics has not been fully exploited in the field mentioned above and there aren't robots, to be created and commercialized, as dexterous and

skilful as trained workers. From the robotics viewpoint, there are some advantages to use a typical structured vineyard environment such as: controllable and/or partially known position of the plants, controllable shape of the plants (e.g. the growing direction and the height), ground floor (at least in the drivable surface) more regular than in the open field etc. (Will J. D. et al, 1998).
In literature, different automatic guidance systems that allows to reduce driver stress and a more relaxed working and an efficient use of machines and resources, were presented. Auto-guidance, also called auto-steer, of tractors and self-propelled agricultural machines that is based on a global navigation satellite system (GNSS) represents one currently available technology that can provide significant benefits for crop production in different growing environments. Today, numerous farmers have suspended the use of conventional markers from their operations and rely on cost-effective alternative methods to steer their farm equipment based on continuously measured geographic coordinates. There are several companies that sell such GPS systems for tractors or machines and other automated solutions (e.g. sprayers) (Deere, Trimble, Arvatec). Some papers highlight different approaches for guiding a vehicle using a Differential Global Positioning System (DGPS) based position sensor as the only external posture sensor. (Builk R. 2006; Heraud J. A. and Lange A. F., 2009). Some machine adopts multiple guidance sensors (Holpp et al, 2006; Ming et al, 2009; Wan et al, 2008; Murakami et al, 2008; Toru et al, 2000).
The objective of this research is to develop a versatile multifunction electrical vehicle able to operate in high density planting vineyard to facilitate the workers during harvesting and cultivating.

Vehicle Description

The robot structure

The mechanical structure has been designed in order to be compliant to different requirements. First of all, the robot must be able to move inside vineyard corridors; moreover it must be able to move on different uneven terrains and must not generate too high pressure on the terrain (in order to meet agricultural requirements). The robot must be able to carry at least 200 kg payload over a flat road (in order to be able to transport boxes full of bunches of grapes, an agricultural spraying machine or other tools) and climb on sloping roads with a suitable payload.
According to these specifications, the robot two main dimensions are 0.6 m wide and 1.2 m in lenght. Moreover it uses rubber tracks instead of wheels for locomotion and its weight is about 250 kg. Figure 1 shows the U-Go Robot.
Four sealed lead-acid batteries are mounted on the mechanical structure on the rear side of the robot. Each rubber track is actuated by means of brushed DC motor and suitable gearboxes. Finally, on the top of the robot there is another box that contains a computer, all the necessary electronic circuits needed for autonomous navigation, the emergency stop button and the safety flashing light.

Figure 1. The tracked U-Go Robot during a teleoperated outdoor test.

Robot moving modalities

The control electronics have been designed to provide different choices for the control modalities. The whole control architecture is managed with a joystick which allows to select the Navigation Modality and to manage the motor drivers (i.e., reverse, gears and emergency stop). The simplest one is the *teleoperated modality* (Livatino S. et al,2008, 2009). In this situation a remote user, using a joystick or simply a computer keyboard, can send direct commands to the robot in order to move forward, backward or turn left or right at different speeds.

The other two possible modalities for controlling the robot are *semi-autonomous mode* and *autonomous mode*. All the implementations of these modalities relay on an onboard computer, on several sensors mounted on the robot and on a remote base station. Next chapters will briefly describe the different sensors and algorithms used.

Semi and totally Autonomous Operations

The system control architecture is shown in Figure 3. It mainly consists of one computer, in which reside software modules used to receive information from the various sensors

One of the possible applications of this electrical tracked robot is as a semi-automatic barrow to carry bins with grapes out of the rows. To perform these tasks, the operator can just drive the robot between two different rows, while the robot can autonomously move along the row using GPS and Laser range finder. In this way the operators can concentrate in the harvesting task, while the robot performs the transport task; it also has special safety algorithms in order to not be dangerous for operators and vineyards. Moreover, because the robot is electrically powered, there is no danger for operators of toxic exhausts. When the robot uses a D-GPS, it can be fully autonomous. The on-board sensors suite is composed by a Laser range finder (LRF, SICK LMS200) and a Global Navigation Satellite System (GNSS) receiver (Ashtech Z-Extreme).

Navigations algorithms have been developed using the Microsoft Robotics Developer Studio (MRDS) tool (Microsoft). This programming platform is developed by Microsoft just to interact with different and customizable robotic devices and integrate also a Visual Simulation Environment (VSE). This permits easily to simulate control algorithms and architectures before real robot testing. MRDS is particularly useful for moving easily a project from simulation toward the real robot implementation. It is in fact possible to replace each simulation entity with a corresponding tool of the real world. The control module, therefore, resides in a PC that receives and processes sensors information provided by the GPS device and the laser scanner.

The navigation algorithm, running on the MRDS platform, takes care of generating the control reference for the used robot; in our case the code has been customized for the U-Go Robot. First of all, different algorithms were tested using data coming from the laser scanner and the DGPS. Relying on these data an Obstacle Avoidance (OA) algorithm was developed. One of the techniques used for OA was the Potential Field Method (PFM) which allows the motion control to avoid collisions with the obstacles detected by sensors during the motion itself, without losing the main task. For example to achieve a target configuration identified by a GPS waypoint. The result of this technique is a sequence of movements that allows to safely drive the vehicle towards the target without collisions.

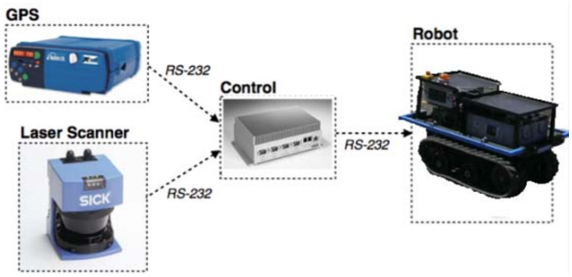

Figure 2. First autonomous navigation tests: robot configuration

Results

Different test have been performed using the U-Go Robot. During the first trials, teleoperated mode has been used on a volcanic environment in order to test the system reliability and payload capabilities. About 180kg of materials and instrumentation were carried on the top of the Mt. Etna volcano (about 3300 m asl) on behalf of INGV (Istituto Nazionale di Geofisica e Vulcanologia) in order to allow their technicians to build some gases monitoring stations. In Figure 4a the U-Go Robot during this test is shown. Other teleoperated tests were done in greenhouses (Figure 4b).

Figure 3. Teleoperated robot test on the Etna volcano(a) and inside a greenhouse (b)

Other tests were regarding autonomous navigation capabilities. During these tests, the robot, with the configuration shown in Figure 2 and the navigation algorithms described before, had to travel along a pre-defined path.

The Figure 4a shows a predefined winding path performed by the robot. The red circles show the GPS waypoints assigned by the user; the small blue circles represent the real path of the robot during the trial while the solid line represents the ideal trajectory.

The Figure 4b shows as the robot was able to reach different targets (waypoints) avoiding some boxes positioned (black square) along a rectangular path in an outdoor area situated near our laboratory. The results of these tests were satisfactory.

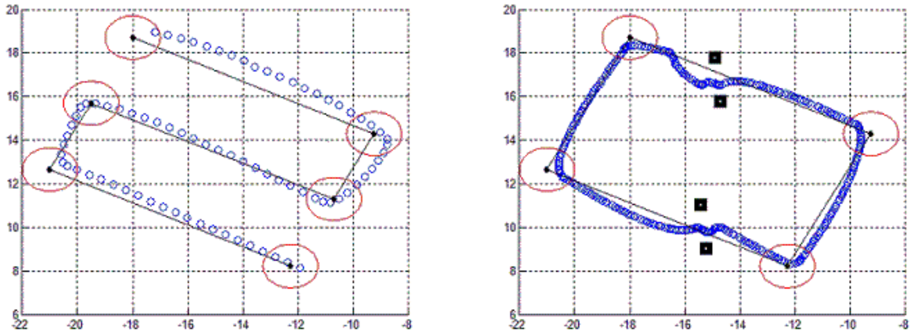

Figure 4. U-Go robot while travelling along a predefined winding path (a) or while moving along a rectangular path avoiding obstacles (b)

In order to test both teleoperated and autonomous modalities and related performance, other trials were carried out in some vineyards of Monte Serra - Viagrande (Catania), showing the accuracy and the reliability of the system as well as the benefits that could derive from his use.

Figure 5. U-Go Robot test on the vineyard of Monte Serra - Viagrande (Catania)

Conclusions

The U-Go Robot has been built in order to be used as a multipurpose outdoor vehicle in different application. Its technical specification meets requirements both for teleoperated as for autonomous motion. Different sensors were tested to allow for autonomous operations in wineyards or greenhouses. In this work, system test using a Laser Range Finder and a DGPS have been performed using an obstacle avoidance methodology named Potential Field Method (PFM). This algorithm allows the robot to follow a specified trajectory, defined by means of several GPS waypoints, while avoiding unexpected obstacles. This control algorithm has been implemented by using the Microsoft Development Robotic Studio that allows fast code development and simulation for robotic applications. Different tests on the U-Go Robot have been performed in order to demonstrate its capabilities on the two different modalities with promising results. The mechanical structure of the robot described in this study, will be adopted to transform a small self-propelled sprayer, already under development for the vineyards and the confined environment of the greenhouses, which can operate by remote control. The sprayer will be equipped with a suitable donor of pesticides and with monitoring devices (remote controller) with on board sensors.

References

Arvatec, http://www.arvatec.it/index_eng.php?view=categoria&categoryId=5&Agriculture
BUIK R. 2006. Gps guidance and automated steering renew interest in precision farming technique. Trimble Navigation Limited. July, pp. 1-10.
Damascus Corporation, Electric Vineyard Vehicles, www.vineyardvehicles.com
Deere, http://www.deere.com/servlet/com.deere.u90785.productcatalog.view.servlets.ProdCatProduct?tM=FR&pNbr=0500_PC
HERAUD J.A.,LANGE A.F. 2009. Agricultural Automatic Vehicle Guidance from Horses to GPS: How we got here, and where we are going. Presentation Agricultural Equipment Technology Conference,9-12 february 2009. American Society of Agricult And Biological Engineers. 33. February 2009. pp. 1-67
HOLPP, M. DURR, L., "A Automatic guidance system for tractors in fruit farming", VDI BERICHTE, 2006, VOL 1958, pages 207, Germany
Livatino S., G. Muscato, S. Sessa, C.Koffel, C. Arena, A. Pennisi, D. Di Mauro, E. Malkondu. 2008. “Depth-Enhanced Mobile Robot Teleguide based on Video Images”. IEEE Robotic and Automation Magazine, Special issue on New Vistas and Challenges in Telerobotics. 15 (4) pp.58-67
Livatino S., Muscato G., Privitera F. 2009. “Stereo Viewing and Virtual Reality Technologies in Mobile Robot Teleguide”. IEEE Transactions on Robotics, 25 (6) December 2009.
Microsoft Robotics Developer Studio http://www.microsoft.com/Robotics/
Ming Li, Kenji Imou, Katsuhiro Wakabayashi, Shinya Yokoyama, "Review of research on agricultural vehicle autonomous guidance", Int J Agric & Biol Eng, Vol. 2 No.3, pag 1 - 16, 2009, DOI: 10.3965/j.issn.1934-6344.2009.03.001-016
N. Murakami, A. Ito, Jeffrey D. Will, Michael Steffen, K. Inoue, K. Kita, S. Miyaura, "Development of a teleoperation system for agricultural vehicles", Computers and Electronics in Agriculture, Volume 63, Issue 1, August 2008, Pages 81-88
Toru Torii, "Research in autonomous agriculture vehicles in Japan", Computers and Electronics in Agriculture, Elsevier, Vol. 25 (2000) pag 133–153
Trimble, http://www.trimble.com/agriculture/guidance.aspx
VITIJAMBEUR, http://Groupeecb.free.fr
Wan, X. and Liu, G., “Automatic Navigation System with Multiple Sensors” 2008, in IFIP International Federation for Information Processing, Volume 259;Computer and Computing Technologies in Agriculture, Vol. 2; Daoliang Li; (Boston: Springer),pp. 769–776.
WILL J. D., STOMBAUGH T. S., BENSON E.R., NOGUCHI N., REID F.J. 1998. Development of a flexible platform for agricultural automatic guidance research.Presentation Annual International Meeting Asabe. July 12-15.pp 1-12

An Early Warning Device for Identification of Tractor Accidents, Rapid Alert and Assistance

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Abstract

Although today's tractors are safer then before, they are still involved in many farm accidents. Statistics show that most machinery-related accidents occur due to human negligence, due to errors involving improper or lack of machinery maintenance, taking shortcuts to save time, failure to follow safety rules, failure to read the operator's manual or ignoring machine's warnings.

While a lot of effort in researches has been devoted to the optimization of protective devices (ROPS-Roll Over Protection Structures), little attention has been devoted to post-accident medical assistance.

In particular, statistically, in fatalities or in serious injuries accidents is frequently found a condition in which the driver is prevented in making requests for immediate help, being immobilized as a consequence of rollover crushing or due to the impact of the tractor with trees or with the ground. In these cases time in alerting a rescue team is a key factor in saving operator's life. In this work a combined rapid alert device is presented, developed integrating a GPS-GSM chip with a MEMS (Micro Electro-Mechanical Systems) tilt sensor, including miniaturized accelerometers and inclinometers in order to detect rollovers and collisions in real time.

Keywords: rollover, safety, gps

Introduction

Accidents due to of agricultural vehicles such as tractors represent a primary cause of death or serious injury in agriculture.

The Roll-Over Protective Structure (ROPS) was developed to protect tractor operators from death and disability from these events by providing a protective zone for the operator in during a tractor overturn. ROPS are most effective when used in conjunction with a seatbelt, which keeps the tractor operator inside the protective zone during an overturn. Nonetheless, a lot of fatal accident still happen.

In particular the dynamics of the incidents historically presents critical points in timing and in the mechanisms of rescue.

Indeed, it is often verified by the fact that the person incident was not able to report the incident as trapped beneath the overturned vehicle, and also that access for emergency vehicles to the accident site has been further complicated by the missing reporting of the access paths to the place itself.

<u>Tractor's accidents statistics</u>

Tractor overturns are the leading cause of occupational agricultural deaths.

In Italy data about tractor accidents are dramatic: a statistic (with approximated defective data, because obtained by collecting data on newspapers and unrelated different sources) published by ASAPS (ASAPS, 2010)- Ossevatorio "Il Centauro" during the period May 2009-May 2010, reported 296 accidents, including 174 fatalities involving 140 drivers, and 174 seriously injured persons.
Among the reported accidents, 199 cases (67%) are referred to off-road operations, especially in wood and fruit related agricultural operations.
In the United States, between 1992 and 2005, 1,412 workers on farms died from tractor overturns (NASS, 2008).

Type of injuries in agricultural tractor accidents: going beyond ROPS

In 1965 Rees published on the British Medical Journal an interesting analysis of agricultural tractor accidents, analyzing 14 fatal and severe injuries cases. Three of them were fatal, in four of them he noticed the presence of fracture of pelvis, in two the fracture of spine, and in other four cases the operator was found pinned beneath the tractor. In one fatal case, Rees wrote *"A 67-year-old married farmer was found dead in his farmyard. He was lying beneath an overturned tractor. The metal seat of the vehicle had pressed upon and crushed his chest. He had died from multiple injuries to the thorax. No one witnessed the accident."*
Although the large amount of studies devoted to improve safety of agricultural off-road operations and tractor stability and the technological advances, a large number of tractors related accidents still happen nowadays.
Analyzing Rees' study we could underline the following key-points:

1) in most of tractor's accidents, operators are locked beneath the tractor;
2) severe injuries involving fractures of pelvis or spine are often present;
3) accidents happen often without any witness and as a consequence medical care could not be provided promptly.

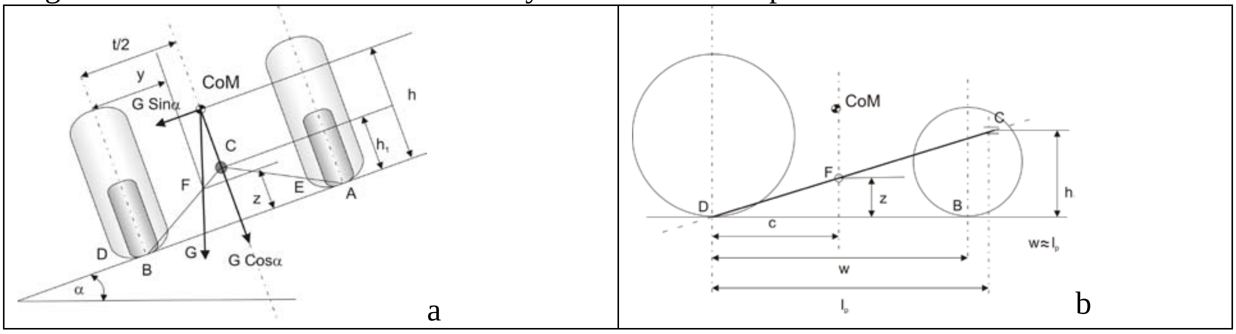
Once the accident happens, a key point to save human lives relies in the possibility to provide a fast medical care, which means fast accident detection warning, precise geographical localization and fast and appropriate medical care.
In order to find an effective solution to the points highlighted by Rees analysis, we decided to develop an early warning device using "on the shelf" components and industrially available technology.

Materials and methods

Lateral rollover angle

As the purpose of this work was to develop a device for early warning in case of accidents, our interest was focused in the detection of accidents, and rollover angle was chosen as a warning parameter.
The static lateral stability criteria are determined using classic rollover theory, developed by Coombes (1968) and other workers in the late 1960's, and later completed by Chisholm (1979a, 1979b, 1979c).
The limit of stability is reached when the resultant force of all the forces acting on a vehicle reaches the boundary of the stability plane, providing that the wheels have not started to slide along the contact surface.

Figure 1a and 1b can be useful to shortly remind the concepts.



The stability plane for a vehicle with a pivoting axle is described by an inclined triangle: the apex of the triangle is the (front) axle pivot point; the triangle base being a line connecting the ground contact points of the wheels on the non-pivoting axle (rear wheels). The sides of the triangle join the ends of the base line to the (front) axle pivot point. A typical inclined triangular plane is shown in the schematic Figures 1, joining points C, E and D.
Figures 1a and 1b show the front and side views of a vehicle which is about to roll-over laterally.
The vehicle body will rotate about points of support at the rear wheel contact D and front axle pivot pin C. At instability the support force at the third corner of the stability plane, i.e. the rear wheel contact E, will be reduced to zero. The resultant force, G (due to the vehicle weight) is about to pass outside the stability plane intersecting the boundary line DC at point F.
The slope angle (α), at which lateral roll-over of a pivoted-axle vehicle commences, defines the first of two stages of instability. At this angle all weight comes off the upper wheel on the non-pivoting axle. However, as the vehicle body continues to roll around line DC, a point will occur, on most vehicles, when the travel limit of the pivoting axle is reached. At this point roll will occur about a line joining the base of the lower front and rear tyres (points D and B in Figures 1). This is the point or angle β, that depicts the second stage of stability. For simple 4-wheel rigid frame vehicles, only the second stage instability angle applies, due to the absence of a front axle pivot. Referring to Figures 1, it can be deduced that the second stage instability slope angle β (not shown) is given by Equation (4):
Different considerations are required if we consider light tractors (mass <= 600 kg) or heavy tractors (mass > 600 kg).
In the first case, Scarlett et al, 2006 reported a general classification and experimental data about first and second instability angle in case of static and dynamic conditions.
Following consideration and classification of the small vehicle types available on the market , they found that within each group a significative number of vehicle variants are present and that there were some vehicles types which lay on the borderline between groupings. In order to classify the vehicles, consideration was given to the basic vehicle physical characteristics: namely the number and position of the wheels; which axle was steered (front or rear); the possible incorporation and location of an axle lateral pivot; the approximate weight distribution between axles (often indicated by the operator seating position); and whether the mass and mass distribution of the vehicle changed during operation (e.g. by collection of cuttings).
Three general configuration were defined:

1) configuration A: 4-wheel, rigid chassis, non-pivoting axle or independent suspension;
2) configuration B: 3-wheel ,forward-facing ,single front wheel or 4-wheel with pivoting front axle;

3) configuration C: 3-wheel ,rearward-facing , single rear wheel or 4-wheel with pivoting rear axle.

In their work, the first instability angle ranged from a minimum of 30.3° (30.5° in dynamic conditions) to a maximum of 46° (45.2° in dynamic conditions).

For heavier vehicles, we followed the work of Guzzomi et al, with data pertaining to 102 narrow-track tractors fitted with front ROPS, with masses in the range 780–2380 kg used to calculate COG and rollover theoretical angle.

The data was used to theoretically calculate, from geometry, the angle required to cause 'lateral' rollover. In the latter, it was assumed that there was no deformation (tyres/surface, etc.) and no front axle pivot, hence rollover occurs at the angle when the COG exits the base defined by the tyres.

Experimental data showed a theoretical angle ranging approximately from 36° to 50° , where the first data refers to tractors with a mass higher then 2500 kg and a COG over 0.8 m.

Hardware platform

Previous application of GPS technology in tractor rollover problems was mainly focused in increasing off-road vehicle stability mapping integrating GPS/GIS and video technology (Liu et al 1999). In the aforementioned paper a site-specific driving safety management and stability

mapping system was developed utilizing a measuring system of tractor stability, Differential Global Positioning System (DGPS) and Geographic Information System (GIS) and Video Mapping System (VMS). In our case we are interested in developing a fast hardware platform, able to transmit essential information about the accident in short time, avoiding possible black out due to platform failure as a consequence of the accident itself.

Several handheld device or smartphones today incorporates tilting sensors and a GPS chipset.

Nonetheless their GPS fix is often poor, and tilt sensors do not provide the necessary reliability, time resolution and vibration filtering.

For this reason we decided to assemble high quality sensors already used in critical applications.

Two platform were developed: a high computational power platform based on a 100 MIPS processor interfaced with a MEMS integrated tilting sensor, and a low cost platform with self assembled sensors a a reduced computational power.

In this paper we will focus on the first one.

The purpose of the hardware platform is the following:

1)to determine the dynamics of rollover;

2)localize geographically the location of the accident through a GPS tracking system;

3)communicate data to central control base the accident by phone SMS message to immediately activate the medical care rescue.

In order to fulfil the mentioned task, the hardware was composed by

1) a microcontroller board, the "thinking" brain of the system. Compared to a programmable logic system, a microprocessor system allows greater flexibility and expansion of functions; the motherboard is a FOX LS832, based on Axis 100 MIPS processor, 32 MB RAM, 8 MB Flash (which hosts the file system), Ethernet interface, two USB Host ports, three UART interface for Secure Digital cards and three RS232 interfaces. This card uses Linux operating system, thus allowing rapid application development.

2) a three-axis tilt sensor for the detection of three-dimensional positioning of the vehicle; we used U.S. Digital X3M Multi-Axis Absolute MEMS Inclinometer (US Digital, 2009), which is a digital three-axis high precision MEMS tilt sensor.
The sensor X3M is an absolute inclinometer using MEMS technology (micro-electro mechanical systems), and allows the detection angles on 360 ° of extension. The X3M sensor is a very flexible device, allowing the user to connect via the serial interface RS232, across six programmable outputs or through both. The X3M sensor can also be configured to operate as a precision tilt switch to 1 or 2 axes.
The sensor calculates the angle of tilt (tilt) sensing acceleration from MEMS accelerometers embedded in a monolithic integrated circuit, since the acceleration of gravity, centrifugal forces, and speed changes are all forms of linear acceleration Configurations and parameters are stored in non-volatile memory, and the sensor is interfaced to the microcontroller board via a serial port.
The sensor can use only two axis simultaneously, in our case roll and pitch axes.

3) A GPS / GSM board for the localization of the vehicle and the transmission of alarm messages; we used a Telit GM862-GPS chip connected to the microcontroller via a serial port embedded in a specially purpose designed carrier board.
The GM862 module has a quad-band dialer GSM / GPRS modem functionality with an integrated 20-channel GPS receiver based on the high-sensitivity SiRFstarIII ™ single-chip. The GPS receiver features low power consumption has a resolution of the position with precision of less than 2.5m, SBAS (WAAS and EGNOS) as well as high sensitivity for indoor fixes.
The hardware interconnection is shown in Figure 2, while the assembled prototype in shown in Figure 3a and 3b.

Figure 2 – Hardware connections

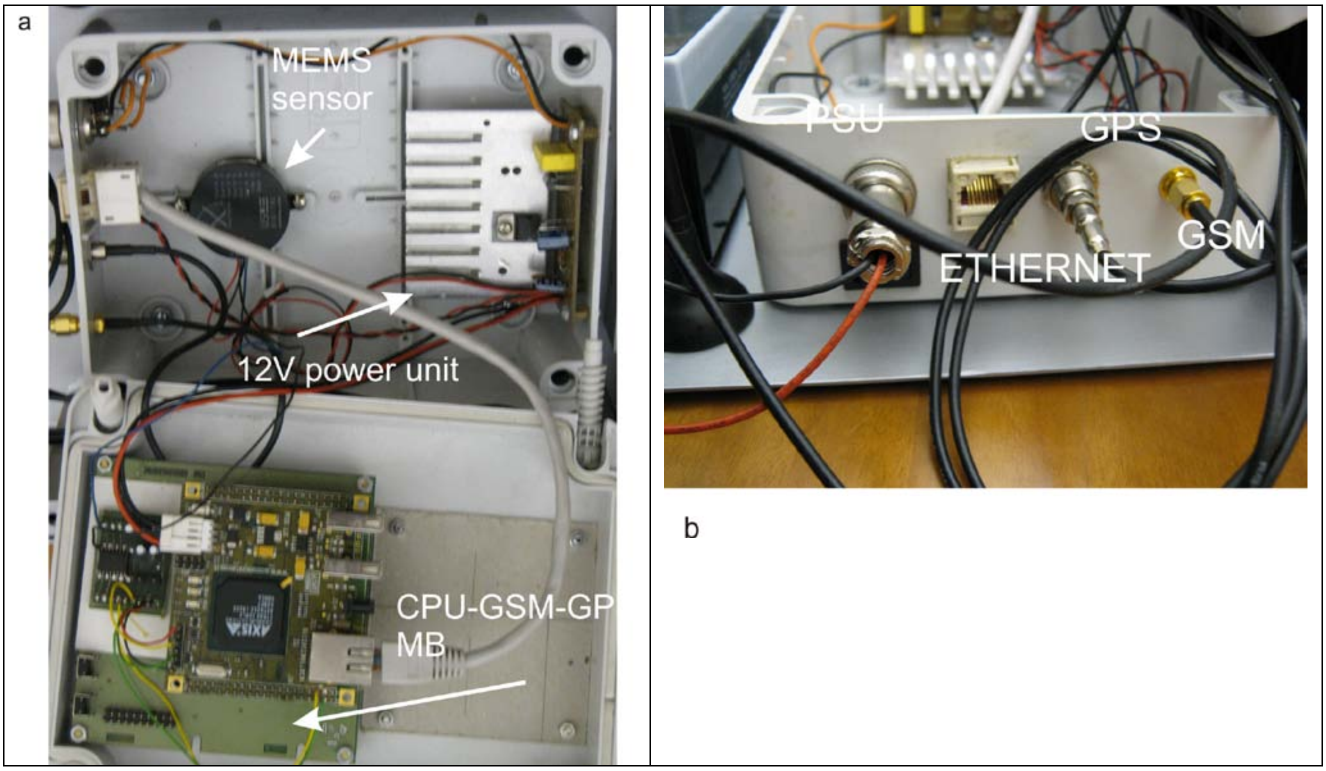


Figure 3 – Assembled prototype

Results

<u>Sensor validation and setup</u>

The X3 sensor uses a FIR (Finite Impulse Response) digital filter to provide electronic damping of the angle readings, and the response has a triangular weighting that decays linearly to zero.
The damping time is user programmable from 2 milliseconds to 5000 milliseconds: the higher the damping time, the lower the effects of local spurious acceleration.

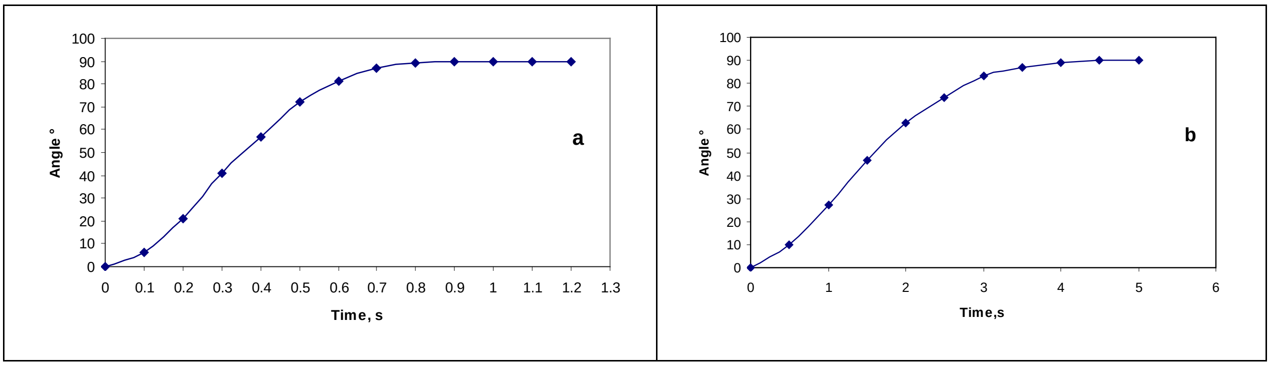


Figure 4: effect of dumping time of 1s and 5s filtering width on sensor response for a 90° step change

Effect of dumping time are shown in figure 4a and 4b, reporting the X3's angular output with a 90 degree step change in position for 1 second and 5 second damping times In fact, increasing the damping time will average more samples together in order to form the reported angle: this will reduce noise in the output but increase the response time.

A laboratory test was performed on a continuous artificial rollover for 360° with an angular velocity from 1 rad/s to 3 rad/s , which is the usual range in case of lateral rollover (Sillelia et al, 2007), in order to setup the appropriate filtering window time , and the value was set to 50 ms; results are shown in Figure 5a (200 ms) and b (50 ms).

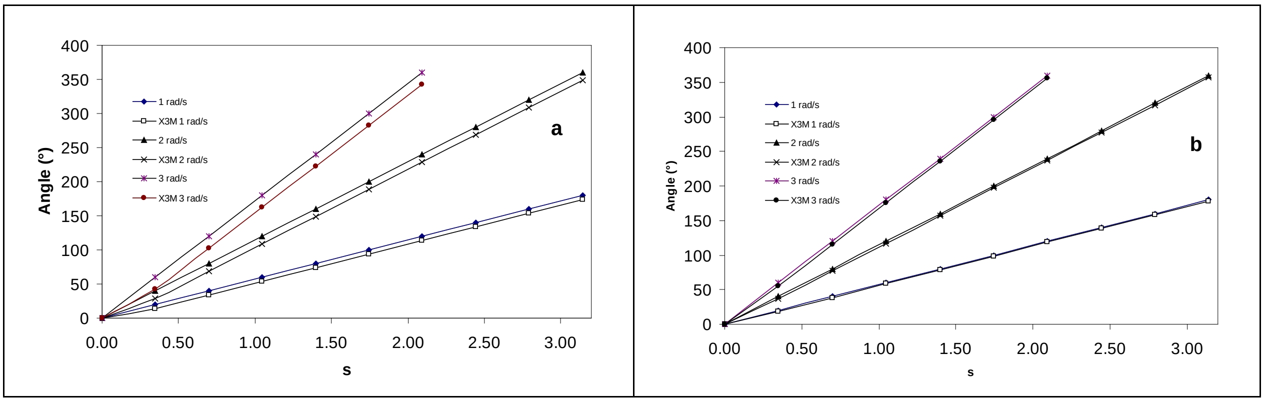


Figure 5 Effect of dumping time on a 360° constant speed rollover: 200ms (a) and 50ms(b)

Software platform

The software platform, written in C, was designed to detect an initial lateral rollover, and to report the operator the incipient danger with an acoustic alarm.
It can work as a data logger of the inclination and position of the vehicle for the analysis of rollover dynamics, and in case the vehicle overturns or in case of shock due to a frontal impact, it sends an SMS to one or more phone number including an alert message, including NMEA GPS coordinates.
A server with a GSM receiver is then able to import GPS data into Google Earth software.
In the future experimental campaign a GIS database including access road to local sites will be linked to NMEA data.

Conclusion

The proposed hardware system represents a simple and low cost solution to reduce the number of fatal accidents in agricultural operations involving tractors and to provide a fast and appropriate medical rescue in case of accidents, further reducing the effects of injuries.
At the moment a major test project is under development, focused on a wide test on 100 vehicles operating in different terrain conditions; and advanced version of the hardware platform is under development, providing a better interface (a touch LCD screen), more computational power, and an improved 9 DOF inertial measurement system at a lower cost.

References

Associazione Sostenitori e Amici della Polizia Stradale, http://www.asaps.it

A J Scarlett, J N Reed, D A Semple P C Seward, A D Stockton & J S Price, 2006, Operator roll-over protection on small vehicles, Silsoe Research Institute report no. 432 for the Health and Safety Executive 2006

Chisholm, C.J. (1979a) A Mathematical Model of Tractor Overturning and Impact Behaviour. Journal of Agricultural Engineering Research (24), 375-394. Silsoe, UK.

Chisholm, C.J. (1979b) Experimental Validation of a Tractor Overturning Simulation. Journal of Agricultural Engineering Research (24), 395-415. Silsoe, UK.

Chisholm, C.J. (1979c) The Effect of Parameter Variation on Tractor Overturning and Impact Behaviour. Journal of Agricultural Engineering Research (24), 417-440. Silsoe, UK.

Coombes, G.B. (1968) Slope stability of Tractors. Farm Machine Design Engineering, September 1968, pp.18-33.

Guzzomi A.L., Rondelli V., Guarnieri A., Molari G., Molari P.G., Available energy during the rollover of narrow-track wheeled agricultural tractors, , Biosystem Engineering, 2009, 104, pp. 318 – 323

Liu, J., P. D. Ayers and M. Vance. 1999. Off-road vehicle stability mapping integrating. GPS/GIS and video technology. ASAE Paper No. 99-7047

National Agricultural Statistics Service. [2008]. 2006 farm and ranch safety survey. Report No. Sp Cr 3-1 (1-08). Washington, DC: U.S. Department of Agriculture, National Agricultural Statistics Service.

Silleli H., Dayıoglu M.A., Gultekinb A., Ekmekcic K.,. Yıldız M.A, Akay E., Saranlı G., Anchor mechanism to increase the operator clearance zone on narrow-track wheeled agricultural tractors: Prototype and first tests, Biosystem Engineering, 97 (2007), pp 153 – 161.

Telit SpA ,http://www.telit.co.it

U.S. Digital, http://www.usdigital.com

Topic 4
"Agricultural mechanisation, automation and management (included assistive technology)"

Poster Presentation

An Innovative System for Air-Assisted Distribution of Beneficial Organisms on Protected Crops

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Abstract

The distribution of chemicals on protected crops is often a critical moment for the operators who are forced to make frequent treatments in an enclosed environment and in the presence of high pesticide concentrations.
The introduction of organic farming techniques improves these aspects but generally requires a substantial commitment of manpower and forces the operator to stay for a long time in environments characterized by temperature and humidity that cause discomfort and fatigue. Increasing the level of mechanization improves the effectiveness of the treatments and it also permits a quicker approach with relevant improvement on workers’ health and safety, particularly in greenhouse crops. We therefore developed a prototype for the distribution of beneficial organisms that can increase the labour productivity and distribution quality on protected crops.
Experiments were conducted to assess the efficiency of this prototype, the reduction of working time and the possible effect on the viability of organisms distributed.
The effectiveness of the distribution has been verified through laboratory and field tests to evaluate the effects of the releasing on viability and fertility of beneficial organisms.
The prototype has been demonstrated to properly perform the releasing of arthropods without compromising the viability and fertility of two species of phytoseiids (Phytoseiulus persimilis and Amblyseius swirskii), whereas in the case of nymphs of the anthocorid Orius laevigatus, the survival immediately after the distribution and the post-release survival (reaching of the adult stage) are influenced by the action of the mechanical device.

Keywords: mechanical distribution, protected crops, safety, beneficial organisms

Introduction

Biological pest control is a fundamental tool for crop health, worker safety and environmental protection. Although based on techniques consolidated by decades of experience, biological interventions have so far had little support from mechanization. In the different intervention strategies the few types of mechanization mainly involve weed control, such as flame-weeding, mulching with biodegradable materials and the use of new hoeing techniques. The only concrete example in pest control is the distribution of *Bacillus thuringiensis* in a liquid solution by normal sprayers. Instead, the mechanical distribution of beneficial organisms for biological pest control is still limited to a few examples of an experimental nature (Pezzi *et al.*, 2002; Opit *et al.*, 2005; Baraldi *et al.*, 2006; Blandini *et al.*, 2006).

Various technical and operative conditions restrict mechanical intervention. For example, the necessity to mix the beneficial organisms with inert substrates makes it difficult to handle and above all, to dose the mixtures, because the substrates must almost always be used moist and present a high friction coefficient.

The main limitation to mechanical distribution is due to the possibility of the beneficial organisms being damaged by the machine parts.

Within the ambits of the national project "Mechanization of phytophage control in organic farming", a prototype was developed for the distribution of beneficial organisms that could increase work productivity and distribution quality (Caprara et al., 2007). Tests were conducted to evaluate the efficiency level of this prototype and any effect on the viability of the distributed organisms.

Materials and methods

The prototype was designed to take the following aspects into account:

- direct use of the containers in which antagonists are marketed, to avoid unnecessary and harmful handling;
- controlled extraction of the substrate, to guarantee a wide choice and precision of the dosages;
- pneumatic distribution, to adapt the operation to different working conditions;
- apparatus of small dimensions that can be used as an accessory for pneumatic equipment already available on the farms (backpack sprayers, blowers, etc.).

A system was therefore designed that involves the phial, in which the beneficial organisms are marketed, being inserted directly onto the releasing system of the machine. The extraction of the organisms dispersed in the substrate is facilitated by the presence of a push rod with reciprocal movement generated by an electromagnet. Regulation of the movement (frequency and stopping position) controls the amount of material that emerges and falls into the pneumatic diffuser of the device.

The distributor was installed on an electric-powered blower commonly used for cleaning parks and gardens. The machine was equipped with a 1.6 kW motor, regulation of the air flow on two levels (256 and 360 m^3/h) and output section of flow of 2374 mm^2.

To define the best working conditions the air flow was measured with a fan anemometer (Höntzsch Instruments µP–ASDI) positioned at different distances and heights from the delivery section.

The moisture content, bulk density, texture and friction coefficient of the substrates used (vermiculite and buckwheat chaff) were also measured.

The effect of the mechanical distribution was evaluated on *Phytoseiulus persimilis* Athias-Henriot, *Amblyseius swirskii* Athias-Henriot (Acari Phytoseiidae) and *Orius laevigatus* Fieber (Rhynchota Anthocoridae).

The viability test was conducted with a mechanical release of the beneficial organisms, setting the machine at the slower air flow, and collecting the product dispersed on a test bench composed by containers (0.5 x 0.5 m) lined up in front of the dispenser. The released individuals were collected manually and placed in test tubes for the viability tests. The manual distribution simulated that used traditionally on crops, distributing the organisms on the test bench and using the same amount of mixture as that used in the mechanical distribution

After the release, 20 females of each species of phytoseiid were isolated from both treatments (mechanical and manual) and placed individually to lay eggs in Plexiglas cylinders of Ø 40 x 40 mm (or Petri dishes Ø 90 mm for *A. swirskii*) containing a thin layer of agar and a bean leaf infested with *Tetranychus urticae* Koch (with frozen eggs of *Ephestia kuehniella*

Zeller for *A. swirskii*). The specimens were maintained in a climatic chamber at 26 °C, UR 75%, photoperiod 16L:8B. The checks for egg laying and mortality were made after 72 and 120 hours for *P. persimilis* and after 72 and 192 hours for *A. swirskii*. The data relating to the number of eggs and larvae were elaborated by one-way ANOVA. When the assumption of homogeneity of the variances could not be satisfied the Mann-Whitney non parametric test was used. The data on the mortality were elaborated with the chi-squared test. The effect of the mechanical release on population growth was measured using the *instantaneous growth rate* (r_i) calculated on the basis of equation 1:

$$r_i(t) = \frac{1}{t}\ln\left(\frac{N_{(t)}}{N_{(0)}}\right) \qquad (1)$$

where $N_{(0)}$ represents the initial number of individuals (20 females), $N_{(t)}$ the number of individuals present on day t, and t the number of days since the start of the experiment. Positive values of r_i indicate an increasing population, negative values a population in decline and $r_i = 0$ a stable population.

The laboratory trials with *O. laevigatus* were conducted to verify the effects of mechanical release on the mortality of neanids and nymphs of the anthocorid. In particular, the survival of individuals immediately after being released with the machine was evaluated and compared with the manual release. A sample of distributed specimens was reared f for 10 days in Plexiglas cylinders (Ø 50 x 70 mm) on green bean to check for any deaths until the adulthood. The Mann-Whitney non parametric test was used to compare mortality during and after the release.

Results

The physical characteristics of the two substrates (vermiculite for *P. persimilis* and *A. swirskii* and buckwheat chaff for *O. laevigatus*) are reported in Table 1.

Neither of the materials showed a great aptitude for mechanical distribution. The vermiculite, very plastic because of the high moisture content used to guarantee the survival of the phytoseiids, had high values of friction coefficient and bulk density. The average particle size was 1.74 mm in diameter, with a rather high variability of the texture.

The buckwheat chaff, which is drier and lighter than the vermiculite, showed a lower friction coefficient, with a more homogeneous and larger average particle size (maximum diameter 2.06 mm). Despite these apparently better characteristics, difficulties emerged in the emptying of the phials during the mechanical distribution, probably due to the shape of the individual particles.

In the trials of distribution and viability of the arthropods, the machine, positioned at a height of 1 metre, was used with the lowest air flow (256 m^3/h) that was considered more suitable for the distribution. At this setting the air emerged at 30 m/s and generated a fairly regular flow that reached a distance of approximately 9 m (Fig. 1).

Table 1. Physical and texture characteristics of the substrates used for the conservation and distribution of the arthropods

SUBSTRATE	VERMICULITE	BUCKWHEAT CHAFF
Apparent bulk density (kg/m3)	346	140
Friction coefficient	0.62	0.40
Moisture content (%)	35.9	20.1
Average diameter (mm)	1.74	3.06
Distribution by diameter class (mm)	(%)	(%)
>4.0	0	2.3
>3.15-4	2.6	32.7
>2.5-3.15	14.7	61.7
>2.0-2.5	13.2	1.8
>1.6-2.0	23.9	0.8
>1.25-1.6	22.1	0
>0.5-1.25	21	0
<0.5	2.5	0.7

The movement of the push rod was set at the frequency of 2.25 Hz., which emptied the phial in 2 and 4 minutes, for the vermiculite and buckwheat chaff respectively, corresponding to flows of 7.5 and 3 dm^3/h.

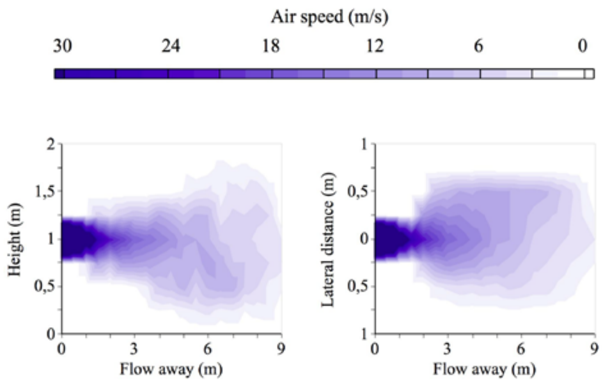

Figure 1. Air speed measured at different heights and distances from the delivery point of the blower.

With these settings and positioning the machine at a height of 1 m provided the distribution diagrams of the two substrates shown in figure 2. The vermiculite reaches a range of up to 7 m, with most of the product falling between 3 and 4 m. The lighter buckwheat chaff reduces the range to less than 5 m, with a peak at 3 m.

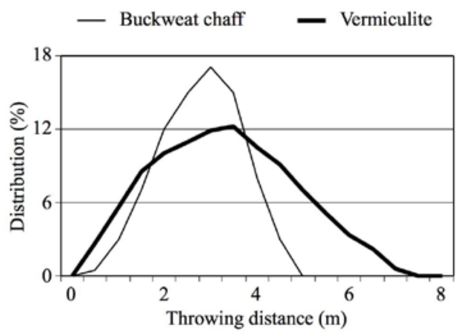

Figure 2. Diagrams of distribution with the two substrates

The laboratory trials demonstrated that the prototype guarantees a correct execution of the release of arthropods without compromising the viability and fertility of the two species of phytoseiid used. In particular, as regards *P. persimilis*, the best performances were recorded for the mechanically released individuals 72 hours after release (figure 3), mainly due to the larger number of larvae (p<0.01) present in this treatment. This is also pointed out by the higher value of r_i after 72 hours in the mechanical release treatment compared to the manual (table 2). However, at five days after the release these differences had been annulled for all the parameters analyzed (figure 3 and table 2). Instead, in both periods, mortality presented no significant differences between the two treatments (table 2).

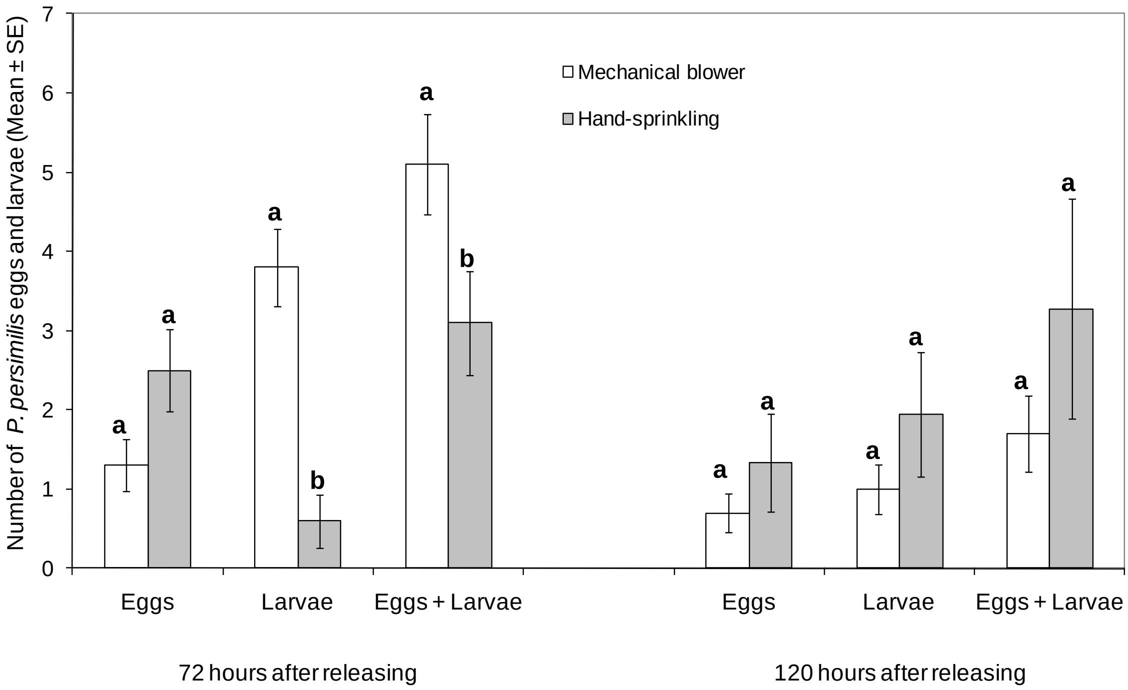

Figure 3. Fertility of *P. persimilis* females after mechanical or manual release in the two periods considered. Different letters indicate significant differences (p<0.05)

Table 2. Instantaneous growth rate (r_i) and survival of *P. persimilis* after mechanical or manual release in the two periods considered. Different letters indicate significant differences (p<0.05)

Treatment	72 hours		120 hours	
	r_i	Survival (%)	r_i	Survival (%)
Mechanical blower	0.543	100a	0.383	60a
Hand-sprinkling	0.377	90a	0.360	66,7a

With *A. swirskii*, neither fertility nor survival were influenced by the mechanical release, as there were no significant differences in these parameters between the two treatments at either 72 or 192 hours after the start of the experiment (figure 4 and table 3). However, the value of r_i in the mechanical treatment was slightly lower than the manual control (table 3). This indicates a tendency that might be worth further investigation.

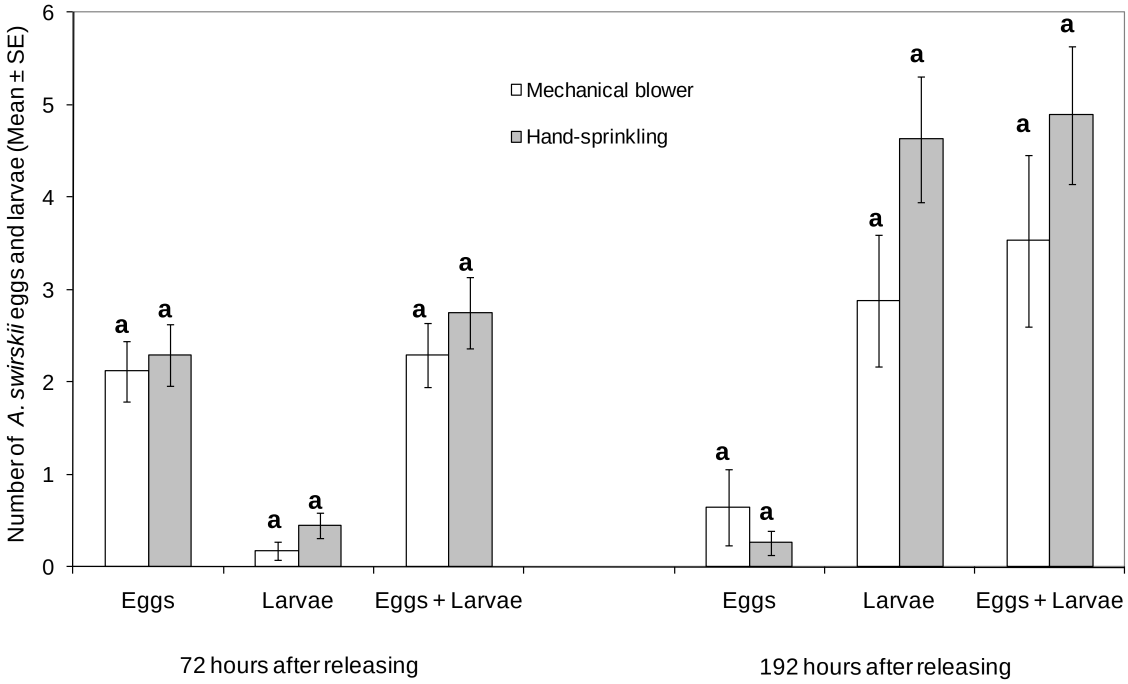

Figure 4. Fertility of *A. swirskii* females after mechanical or manual release in the two periods considered. Different letters indicate significant differences (p<0.05)

Table 3. Instantaneous growth rate (r_i) and survival of *A. swirskii* after mechanical or manual release in the two periods considered. Different letters indicate significant differences (p<0.05)

Treatment	72 hours		192 hours	
	r_i	Survival (%)	r_i	Survival (%)
Mechanical blower	0.277	100a	0.158	76,5a
Hand-sprinkling	0.337	95a	0.192	73,7a

Unlike the findings for the two phytoseiids, for the juvenile stages of *O. laevigatus*, both the survival immediately after the release and the post-release survival (reaching the adult stage) are significantly reduced by the action of the mechanical device (p<0.01) (figure 5). However, the higher mortality in the individuals distributed mechanically is not particularly negative as *O. laevigatus* is generally used in strategies that involve seasonal inoculative releases (Nicoli and Tommasini, 2000) in which it is the progeny of the released individuals that are important for the success of the control. This higher mortality can be managed, in terms of cost, by means of an increase of the dose released or by repeated releases. This latter practice is advised for a better efficacy of the action of *O. laevigatus* (Nicoli and Tommasini, 2000), and may also be considered preferable in terms of the reduction in the working times guaranteed by the mechanical distribution of the organism (Lanzoni *et al.*, 2007).

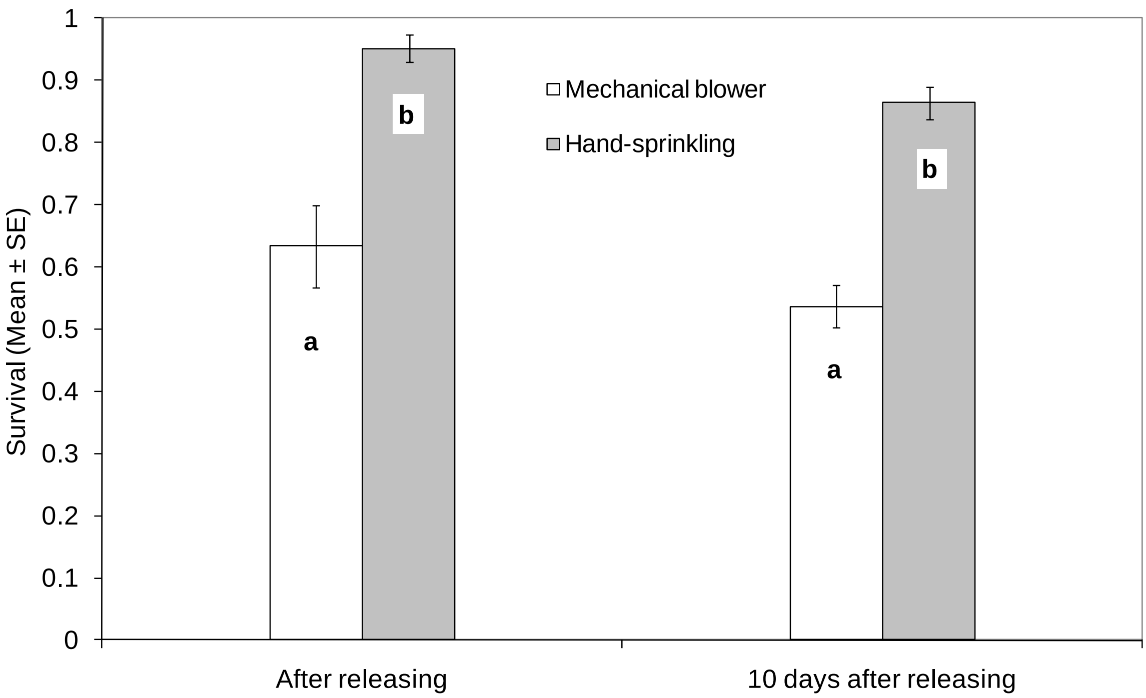

Figure 5. Comparison between survival of the juvenile stages of *O. laevigatus* depending on the type of release. Different letters indicate significant differences (p<0.01)

Conclusions

The functional check of the prototype built for the mechanical distribution of beneficial organisms in biological pest control has provided satisfactory results from both the operational and biological point of view. The practicality of the device designed for the extraction and dosing of the product directly from the phial in which it is marketed has resulted as satisfactory, despite the unfavourable physical characteristics of the substrates (vermiculite or buckwheat chaff) in which the arthropods are dispersed. The distribution and flow of the air generated by the blower guarantees a particularly suitable range (3-4 m) for working in the rather confined spaces of the greenhouses where biological control is widely used.

The trials have demonstrated that the use of the prototype does not reduce the viability and fertility of the two studied phytoseiid species. The efficacy of the mechanical release of *P. persimilis* has already been confirmed in greenhouse experiments (Baraldi *et al.*, 2006), but further work is needed on *A. swirskii*. The use of the prototype for the release of *O. laevigatus* has instead entailed a marked reduction in the viability of the anthocorid, but this can be managed at the time of release.

The results obtained demonstrate that the prototype built for the mechanical distribution of entomophages may be a solution that is simple, economical and adaptable to many types of beneficial organisms.

References

Baraldi G., Burgio G., Caprara C., Lanzoni A., Maini S., Martelli R., Pezzi F. 2006. Distribuzione meccanica di *Phytoseiulus persimilis* in serra. Atti Giornate Fitopatologiche, Riccione (RN), 27-29 marzo, I, 563-570.

Blandini G., Failla S., Manetto G., Tropea Garzia G., Siscaro G., Zappalà L. 2006. Prove preliminari di distribuzione meccanica di antagonisti naturali. Atti Giornate Fitopatologiche, Riccione (RN), 27-29 marzo, I, 557-562.

Caprara C., Martelli R., Pezzi F., Baraldi G. 2007. Distribuzione meccanica di artropodi nella lotta biologica in colture protette, In: Strategie di Difesa Biologica, Cesena (FC), 19-28.

Lanzoni A., Burgio G., Maini S. 2007. Prove di lancio meccanico di *Phytoseiulus persimilis* e *Orius laevigatus* in colture protette. In: Strategie di Difesa Biologica, Cesena (FC), 29-38.

Nicoli G., Tommasini M.G. 2000. *Orius laevigatus*. In: Gli ausiliari nell'agricoltura sostenibile, (G. Nicoli, P. Radeghieri, Coord.) Calderini Edagricole, Bologna, 85-95.

Opit G.P., Nechols J.R., Margolies D.C., Williams K.A., 2005. Survival, horizontal distribution, and economics of releasing predatory mites (Acari: *Phytoseiidae*) using mechanical blowers. Biological Control 33, 344-351.

Pezzi F., Rondelli V., Baraldi G. 2002. Mechanical distribution phytoseiids in greenhouse crops. Rivista di Ingegneria Agraria 3, 33-39.

Influence of Mechanical Aspects of Distribution on Viability of the Biological Control Agent *Steinernema carpocapsae*

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Abstract

The distribution of entomopathogenic nematodes (EPNs) for pest control in organic and conventional agriculture is usually carried out with traditional boom sprayers normally used for the distribution of pesticides. Nevertheless there is a reasonable possibility that this operation may induce a state of stress due to sudden pressure changes and mechanical stress, especially during the passage through the pump and nozzles or as a consequence of the effect of hydraulic or pneumatic agitation inside the tank.

This work aims to evaluate the effects of some mechanical distribution parameters on the viability of the entomopathogenic nematode Steinernema carpocapsae Weiser which may become significant during the distribution.

To assign the mechanical effects to specific components of the distribution, liquid suspensions of the nematode were subjected to different levels of static pressure, and various conditions of agitation and distribution using different types of nozzles.

Preliminary results show no significant effect of static pressure on the viability of nematodes. The passage through the nozzles and the use of a elastic rotor pump induces a 7% decrease in viability, but no difference was detected between different nozzles, while the intensity of hydraulic agitation appeared to affect the nematodes viability.

Keywords: Application technique, Entomopathogenic nematodes, Organic agriculture, Pest control

Introduction

The entomopathogenic nematode *Steinernema carpocapsae* plays an important role in the biological and integrated control of various phytophages (in particular the larvae of lepidopterans that attack fruit trees, noctuids, coleopterans and orthopterans). In Italy it is currently successfully used in the biological control of two new parasites on palms: the Asian palm weevil, *Rhynchophorus ferrugineus* Olivier, and *Paysandisia archon* Burmeister. The nematode can be distributed with the irrigation or by means of mechanical distribution on the crop or directly on the soil.

Normal sprayers are commonly used for the mechanical distribution of these antagonists, but there is a real possibility that this operation may induce a state of stress due to abrupt pressure variations in the tank and mechanical stress, which the organisms are subjected to in different points of their route inside the machine, particularly while passing through the pump and nozzles. Further mechanical stress may be caused by the effect of the hydraulic or pneumatic agitation inside the tank (Nilsson and Gripwall, 1999; Łaczyński et al., 2004) and by the rise in temperature produced by the agitation system mixing the suspension (Łaczyński et al., 2006). However, studies on the reduction in viability of the nematodes following mechanical distribution do not provide uniform results. Whereas Fife et al. (2003, 2004) reported that a single passage through different types of pump, when the pressure difference is no greater than 13.8 bars, did not influence the viability of *Heterorhabditis bacteriophora*, *H. megidis* and *Steinernema carpocapsae*, Nilsson and Gripwall (1999) observed a 10% reduction in viability of *S. feltiae* after passing through a piston pump. Grewal (2002) reported the negative effect of excessive hydraulic agitation on the viability of nematodes and Łaczyński et al. (2004) indicated a linear decrease in the viability of *H. bacteriophora* with respect to the duration of the hydraulic agitation.

This paper evaluates the effects of some mechanical parameters of the distribution on the viability of entomophages when undergoing different levels of mechanical stress that may occur during distribution. To attribute the mechanical stress caused by the specific components of the distribution (static pressure, dynamic pressure, mixing), 3 different trials were conducted to evaluate the influence of the following mechanical aspects on nematode viability:

- static pressure;
- response to the distribution using a traditional sprayer with different types of nozzles;
- effect of the pump and agitator.

Materials and methods

A commercial formula, NemoPAK-S®, of desiccated *S. carpocapsae* larvae was used, containing 625,000 individuals per gram in a mixture of chitosan (a polysaccharide obtained from the chitin of crustaceans). Prior to each trial the nematodes were rehydrated by diluting 2 g of product in 1 litre of water (22 °C) from an artesian well to simulate the usual composition of the suspension distributed on the field. A sample of 0.25 litres was then further diluted in 5 litres of water to obtain a final concentration in the suspension of 62,500 individuals per litre.

For each test, a sample of 100 ml of suspension was taken and stored in plastic test tubes in the dark at a temperature of 14-16 °C for 18-20 hours to limit the reduction in nematode survival following conservation (Molyneux, 1985). Around 30 minutes before the count, a sample of nematodes (1 ml) was extracted using a calibrated pipette and left at ambient temperature in the dark to encourage mobility and facilitate the counting of the individuals (Łaczyński et al., 2006). The sub-samples, diluted with 3 ml of distilled water, were placed in Petri dishes with a grid base, and the nematodes were counted with the aid of a binocular microscope (model Zeiss 12x - 100x), lighting the sample with an incandescent lamp that projected the light from top downwards to avoid causing the death of any not very lively individuals. Only whole nematodes were counted; fragments were not considered as they may have already been present in the commercial formula (Łaczyński et al., 2006). The nematodes were identified as alive based on their active movement (Grewal, 2002) and a needle was used to stimulate those that appeared immobile. For each sample the relative viability, V_r, was determined as a percentage of the total number of nematodes.

2.1 Evaluation of the effect of static pressure

The effect of static pressure was reproduced by means of a test bench composed of a 150 ml capacity metal container connected to a manually operated hydraulic jack, equipped with a manometer. The instrument allowed the pressure applied to the suspension to be graded and the load maintained for the specified times (figure 1).

Figure 1. Equipment for the application of static pressure

During this trial viability of the nematode was evaluated subjected to levels of static pressure comparable to those which the organism is subjected to during traditional distribution. Six treatments were considered characterized by four pressure levels (0, 2, 8 and 14 bar) and different times of application of the intermediate pressure (table 1). Each treatment was replicated three times.

Table 1. Resistance to static pressure, pressures and times applied

treatment	pressure (bar)	time (s)
1 test	0	0
2	2	15
3	14	15
4	8	5
5	8	15
6	8	25
7	8	35

When the pressure had been applied for the established time, a sample of suspension was taken from a valve situated in the lower part of the compression chamber. The relative viability in the samples was then measured according to the trial protocol.

2.2 Evaluation of mechanical stress caused by passing through the nozzles

A test bench was set up to examine, in the laboratory, the effect of the nematode suspension passing through different types of nozzle.

Three types of TeeJet XR flat fan nozzles (TeeJet, Spraying Systems, Wheaton, ILL, USA) of different sizes were considered (table 2). To avoid the introduction of any mechanical stress in addition to that caused by passing through the nozzles, a flexible impeller pump (Liverani mod. INV MIDEX 3/4) was used without a filter, which guarantees, thanks to its construction characteristics, the absence of peaks of pressure that occur next to the valves in diaphragm and piston pumps. The electric motor of pump was equipped with a frequency converter for a continuous regulation of the rotational speed (range 180 and 1400 revs/min). Intake was through a pipe sucking the suspension from a mixing tank in which the product was maintained in constant agitation. The pipe was connected to a boom fitted with only one nozzle, which was changed for the different treatments.

Table 2. Test conditions of passage through the nozzles

treatment	nozzle	colour code	flow (l/min)	pressure (bars)	revs/min
1 test	-	-	-		-
2	XR11008	white	3.16	3	1400
3	XR11004	red	1.58	3	1150
4	XR11001	orange	0.39	3	900
5	-	-	88	0	1400

A control was also considered, taken directly from the central part of the tank. In the fifth treatment the sample was taken without the passage through the nozzle, in order to point out any difference in viability between the effect of the double passage through pump and nozzle, and the single passage only through the pump. All treatments were replicated three times.

2.3 Evaluation of the mechanical stress caused by the recirculation

A test bench was set up in the laboratory to check the combined effect of the recirculation in the tank and the delivery through the nozzles on the viability of the nematodes. The trial aimed to demonstrate any contribution of the ejector to the death of nematodes following the mixing of the suspension.

The system was composed by a 300-litre capacity tank equipped with a hydro-ejector hydraulic mixer, a traditional boom sprayer, with constant pressure regulation system, equipped with flat fan nozzles and a low-pressure piston-diaphragm pump (Comet BP 75). The filter installed between the pump and the tank was removed to allow the nematodes to pass through.

Figure 2. Boom sprayer used for the trials of resistance to agitation in the tank

To increase the mixing action of the hydraulic ejector, which was insufficient at the low pressures used, the return circuit in the tank was shut with a valve. Two agitation levels were considered, L_1 and L_2, obtained with pump speeds of 252 and 380 revs/min respectively. The flow-rates and the pressures of this trial are reported in table 3.

Table 3. Test conditions of agitation in the tank with a traditional sprayer

level of agitation	ejector flow-rate (l/min)	pump speed (revs/min)	delivery pressure (bar)
L_1	23.9	252	3±0.1
L_2	36.9	380	3±0.1

For both agitation levels, 4 treatments were considered (table 4). The first (control) was a sample taken directly from the tank. The other treatments were taken, at the outlet of the nozzles, at successive intervals corresponding to decreasing volumes of the suspension in the tank: 75%, 50% and almost empty tank. These levels of volume delivered correspond to increasing amount of recirculation and mixing times. The pressure was maintained at 3 ± 0.1 bar throughout the time of delivery. Each sampling was replicated three times.

Table 4. Test of resistance to agitation. It is reported the theoretical average number passages of each organism in the agitation-return circuit throughout the emptying cycle

treatment	level in the tank (l)	average number of passages	
		L_1	L_2
1 test	300	0	0
2	225	0.11	0.16
3	150	0.16	0.25
4	25	0.96	1.47

Results

3.1 Effect of the static pressure

The average values of relative viability are between 58.1% for the sample subjected to a pressure level of 8 bar for 5 seconds and 67.8% for the control (table 5).

The results did not demonstrate any variation in the viability of the organism related to mechanical stress. In particular the static pressure had no significant effect on the viability of the nematode within the range considered (2, 8 and 14 bar). Different durations of application of the pressure of 8 bars (5, 15, 25, 35 seconds) did also show no significant differences.

Table 5. Effect of static pressure on the relative viability (V_r) of the organisms

treatment	pressure (bar)	time (s)	V_r (%)	homogeneous groups
1 test	0	0	67.8	a
2	2	15	59.9	a
3	8	5	58.1	a
4	8	15	58.9	a
5	8	25	64.1	a
6	8	35	61.0	a
7	14	15	64.0	a

3.2 Mechanical stress caused by passing through the nozzles

The combined effect of the mechanical stress caused by the elastic rotor pump and by the mixture forced through the nozzles shows that the viability of the control is higher (81.3%) than and significantly different ($p<0.05$) from all the samples subjected to mechanical stress, including the case of a single passage through the pump at free discharge (75.6%).

The use of different types of nozzles did not significantly affect the viability of the nematode and did not increase the mortality with respect to the single passage through the pump (figure 3).

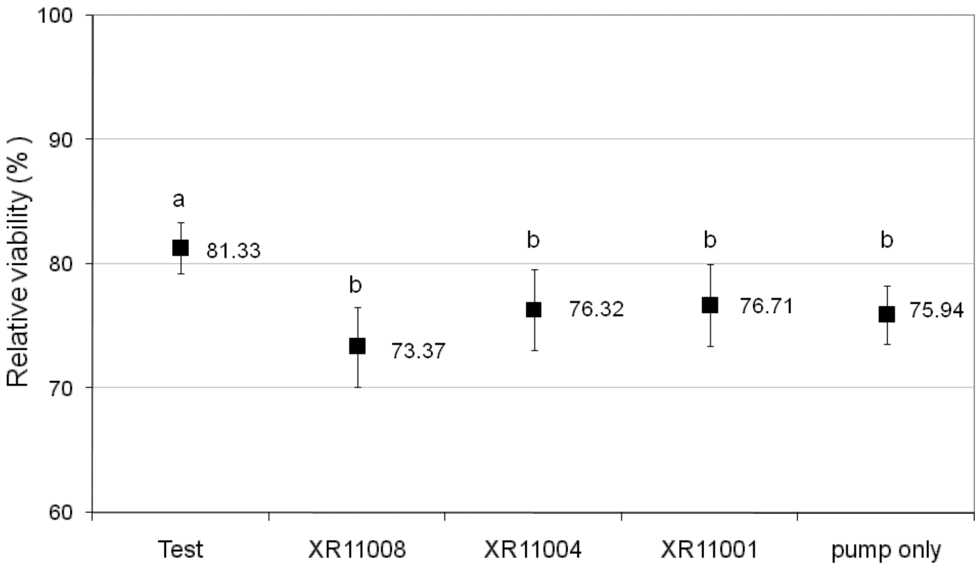

Figure 3. Viability of nematodes that passed through the nozzles (vertical bars represent the 95% confidence interval)

3.3 Mechanical stress caused by traditional distribution

Lastly, the nematodes subjected to two agitation systems did not show any reduction, but in both trials, when the tank was nearly empty, their concentration in the suspension was about 20% higher than the initial one, sign of a not quite satisfactory agitation.

Table 6. Results of the check on the viability for the two levels of agitation-return (the homogeneous groups are calculated for $p<0.05$)

test	level of the tank (l)	viability (%)	homogeneous groups	viability (%)	homogeneous groups
		agitation level L_1		agitation level L_2	
1 test	300	89.2	a	94.5	a
2	225	88.3	a	91.1	b
3	150	85.1	a	92.4	b
4	25	87.0	a	91.2	b

Conclusions

The results of the trials demonstrated that a static pressure up to 14 bar, even protracted for some seconds, causes no significant damage to the specific organism examined (*S. carpocapsae*). It was not considered worth testing any higher pressure levels as the use of flat fan nozzles was hypothesized, which normally operate at maximum pressures of 3 or 4 bar. This type of nozzle, used at low pressure, can be considered suitable for the distribution of live nematodes, due both to the relatively large size of the drops that are produced, and the absence of the core, typical of the cone-nozzles, which would make the flow of the liquid more turbulent.

The effect of passing through the nozzles was verified using a elastic rotor pump. The choice of this pump was initially suggested by the hypothesis that the other traditional pumps would produce anomalous peaks of pressure, much higher than the average pressure. In this way it was thought to be able to isolate the effect of the nozzles from that of the pump. The results appear instead to demonstrate that the slight difference in the viability is to be ascribed more to the pump, than to the calibre of the nozzles. On the other hand, the trials of recirculation carried out with the traditional sprayer have shown that repeated passages of the organisms in the hydraulic system may affect their viability more than other factors, including the diaphragm pump.

It can therefore be considered that in normal pressure conditions and with flat fan nozzles of any calibre, *S. carpocapsae* may be safely distributed with traditional sprayers, maintaining the level of the agitation-return low, perhaps reducing the rpm of the p.t.o. and taking into account an increase in concentration when the tank is almost empty.

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References

Fife J.P., Derksen R.C., Ozkan H.E., Grewal P.S. 2003. Effect of pressure differential on the viability and infectivity of entomopathogenic nematodes. Biological Control, 27, 65–72.

Fife J.P., Ozkan H.E., Derksen R.C. 2004. Physical effect of conventional spray equipment on a biological pesticide. Aspects of Applied Biology, vol. 71, International Advances in Pesticide Application, 495–502.

Grewal S.G. 2002. Formulation and application technology. In: Entomopathogenic Nematology, R. Gaugler, Editor, CAB International, 265:287.

Łaczyński A., De Moor A., Moens M., Sonck B., Ramon H. 2004. An application technique for biological plant protection products containing entomopathogenic nematodes. Aspects of Applied Biology, vol. 71, International Advances in Pesticide Application, 489–493.

Łaczyński A., De Moor A., Dierickx W., Moens M., Darius P., Sonck B., Ramon H. 2006. The effect of hydraulic spraying on the viability of the nematode *Heterorhabditis bacteriophora*. Short communication. Crop Protection, 25 (10), 1135-1141.

Molyneux A. 1985. Survival of infective juveniles of *Heterorhabditis* spp. and *Steinernema* spp (Nematoda: *Rhabditida*) at various temperatures and their subsequent infectivity for insects. Revue Nématol., 8, 165–170.

Nilsson U., Gripwall E. 1999. Influence of application technique on the viability of the biological control agents *Verticillium lecanii* and *Steinernema feltiae*. Crop Protection 18, 53–59.

Periodical Inspections and Controls of Agricultural Sprayers Already in Use in Italy Looking at the Directive CE 128/09

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Abstract
The objective of the paper is to show some aspects of the enforcement of the recent European Directive CE 128/09 in Italy and discussing some weakness and strength points of Italian organization of inspections. The framework Directive on the sustainable use of pesticides (CE 128/09) completed the European legislative background aimed at satisfy the "life-cycle" concept to address all major aspects related to the pesticides. For the first time, it is established (article 8) that member states shall ensure that pesticide application equipments in professional use shall be subject to inspections at regular intervals. Italian Regions have started programs aimed at periodical inspection during around the last 15 years, but so far there is not a general and complete organization of controls. Difficulty in implementing an universal mandatory system in Italy can be noticed, considering, for example, that many sprayers are obsolete (especially in small farms) so they cannot pass any inspection, giving a political problem to reject a large number of machinery. In the paper different technical possibilities to overcome the main problems are discussed.

Keywords: pesticide application, plant protection, legislation

Introduction

The European legislation on plant protection products (PPP) adopts the "life-cycle" concept to address all major aspects related to the development, regulation, production, management, packaging, labelling, distribution, handling, application, use and control, including post registration activities and disposal of all types of pesticides, including used pesticide containers.

Following this general approach, a new EU legislation on the sustainable use of pesticides recently entered into force. The overall objective of the European Directive CE 128/09 is to establish "*… a framework to achieve a sustainable use of pesticides by reducing the risks and impacts of pesticide use on human health and the environment and promoting the use of Integrated Pest Management and of alternative approaches or techniques such as non-chemical alternatives to pesticides*".

The measures include a special attention to the application phase.

As well known, this aspect has consequences in: direct risk for the operator (especially during handling and distributing pesticides); diffuse pollution for the drift; point source pollution (especially during mixture preparation, sprayer's cleaning, in case of leakage and other damages); residues of chemicals on food.

The Directive was published in the Official Journal of the European Union on 24 November 2009 (OJ L309) and came into force the following day. The Directive will need to be transposed and implemented by Member States by 25 November 2011 after the adoption of National Action Plans to set up quantitative objectives, targets, measures and timetables to reduce risks and impacts of pesticide use and to encourage the development and introduction of integrated pest management (IPM) and of alternative approaches or techniques in order to reduce dependency on the use of pesticides. Member States have until 14 December 2012 to communicate their National Action Plans to the European Commission. Other provisions include training and certification of all professional users, distributors and advisors; a ban (subject to derogations) on aerial spraying; special measures (i.e. efficient application techniques and mitigation measures such as buffer zones between fields and surface waters) to protect the aquatic environment, public spaces and conservation areas; minimizing the risks to human health and the environment through handling, storage and disposal; adoption of harmonised risk indicators.

The role of equipments

The new European legislation calls attention to the role and importance of application by means of agricultural sprayers and other equipments.

Firstly, the design, construction and maintenance of machinery for pesticide application might be taken in account in reducing the adverse effects of pesticides on human health and the environment. The Directive 127/09 amending Directive 2006/42/EC (the so-called "Machinery Directive") with regard to machinery for pesticide application introduces the concept of environmental safety and some requirements for the inspection and maintenance of machinery for pesticide application. Member States must implement it by 15 June 2011 and apply it from 15 December 2011.

Then, for the first time, it is established (Directive 128/09, article 8) that member states shall ensure that pesticide application equipments in professional use shall be subject to inspections at regular intervals. In fact, in the chain of pesticide usage, the equipment plays a decisive role. In Italy, the total amount of employed PPP reached 149.9 x 10^6 kg (year 2008) (ISTAT, 2009). The quantity distributed per hectare of potentially treated area (i.e. arable land - excluded set aside land - and permanent crops – excluded permanent meadows and pastures) was 10.2 kg. This remarkable amount is mainly distributed by means of sprayers (in Italy 620'715 – ISTAT, 2002). A rough analysis of the previous data shows that in Italy each sprayer distributes about 240 kg of PPP per year. The role of regular control in average pesticide use-reduction potential is estimated to range from 5% to 10% (Gil, 2007), resulting in a potential 12-24 kg product saving per equipment per year.

In the same time, the periodical inspections of sprayers can achieve several results: reduction of the risk to the environment; providing optimum plant protection using a minimum amount of pesticides; ensuring the safety of personnel; assuring best sprayer maintenance (Biocca, 2007).

The most part of European countries have started programs aimed at periodical inspection but so far there is not a general and complete organization of controls.

In some countries, the totality of sprayers have been inspected. For example, in Germany the average number of inspected sprayers in the year 2006-2008 was 91'485 (Wehmann, 2010) equal to more 100% of the total number sprayers to inspect each year (in Germany the inspection must be repeated each second year). On the other hand, some important agricultural countries show a different situation. According to the same author, in Italy in the year 2006-2008 only 1.3% of the sprayers were inspected and in Spain 1.1%.

Discussion points.

The large number of piece of machinery to be inspected – 2'340'627 equipments (Wehmann, 2007) in Europe (25 countries) including only field and orchard sprayers – needs to a great deal in terms of inspection management organization. Actually, there is lack of information about the number and geo-distribution of the sprayers. The true number of all type of equipments is still unknown, since in many countries (including Italy) the most part of statistics are sample statistics and they do not include portable or special equipments .

In Europe, Italy has the biggest number of pieces of machinery for pesticide application (around 620'000). A notable part of them, about 17% (ISTAT, 2002) is more than 10 year old. Many sprayers are obsolete (especially in small farms) so they cannot pass any inspection, giving a political problem to reject a large number of machinery.

The old sprayers present an additional difficulty in adapting the measuring equipment to the non standard devices. Moreover, most of the sprayers were not designed in accordance with UN-EN-907, lacking basic safety features (Biocca and Gallo, 2008).

In Italy a large variety of technical solutions occurs, due both to diversity of regional agricultures across the country and to the high number of manufacturers. This aspect requires a specific preparation and organizations of the inspection personnel, that can deal with many different sprayers and equipment models.

On other specific effort shall be directed to control and inspect the portable (handheld or knapsack) sprayers. For this typology of machineries member states may either apply different timetables and inspection intervals or exempt from inspection handheld or knapsack sprayers. In this case the member states shall ensure that operators have been informed of the need to change regularly the accessories, of the specific risks linked to that equipment and that operators are trained for the proper use.

At European and national level, the monitoring of recognised inspection workshops have been seen as essential and harmonisation is considered necessary. In Italy is now available a software to manage correctly the tests, to store the data and to analyze the results (Biocca, 2010).

Conclusions

The described situation leads to a general difficulty in implementing a universal mandatory system of inspection. The Directive 128/09 recommend the member states to achieve the inspection of sprayers in professional use.

The inspection services of sprayers in use in Italy appear characterized by a large variety of regional situations, depending on both basic differences in terms of condition and average age of sprayers and from different development of sprayer testing service.

In our opinion, new programmed activities both at regional and national level will be indispensable in the next future in order to receive more general standards, including all type of equipments, of which goal it is to create an inspection of sprayers in Europe of equal quality. Moreover it will be useful to support administration in the design of testing networks on the basis of sound economic criteria. A proposed planning method can be useful for this scope (Severini e Biocca, 2004; Biocca e Severini, 2004).

Furthermore it is crucial to collect actual information about the number, the geo-distribution of the sprayers, the state of maintenance and the type of equipments employed. On other important task will be the training and formation of the operators. Actually, the mechanical aspect of pesticide application are neglected during operator training (as in the case of the formation for the authorisation for pesticide purchasing and employ); for this reason, it is indispensable to introduce at different levels of formation and education the information related to the pesticide application equipments. The training of operating personnel shall be particularly decisive in conjunction with the inspection of handheld plant protection equipment and knapsack sprayers and for the regular calibrations and technical checks that shall be obligatory provided by the operators (in accordance with article 8 point 5).

References

Biocca M., Severini S., 2004. Aspects of the organisation of test sprayers in some Italian Regions. In "First European Workshop on Standardized Procedure for the Inspection of Sprayers in Europe – SPISE" 27-29 Aprile, Braunschweig, Germania, 101-105.

Biocca M., 2007. Periodical inspections and testing of sprayers in use: a tool in sustainable agriculture. Presented at: 2007 CIGR Section VI - International Symposium on food and agricultural products: processing and innovations, Naples, Italy, 24-26 September 2007.

Biocca M., Gallo P., 2008. Implication of periodical inspections of sprayers already in use on work safety. Proceedings of International Conference "Innovation technology to empower Safety, Health and Welfare in Agriculture and Agro-food Systems". CD-ROM / ISBN: 978-88-903151-1-4. Ragusa (Italy) September 15-17.

Biocca M., 2010. IrroMono-IrroNet: a software to manage the inspections of sprayers already in use. In: "Third European Workshop on Standardised Procedure for the Inspection of Sprayers in Europe – SPISE 3" H. Ganzelmeier, H. J. Wehmann Eds. Julius Kuhn Institute, Vol. 426, 119-121.

Gil E., 2007. Inspection of sprayers in use: a European sustainable strategy to reduce pesticide use in fruit crops. Applied Engineering in Agriculture, 23,1, 49-56.

ISTAT. 2002. 5th Agriculture Census. http://censagr.istat.it.

ISTAT. 2009. La distribuzione per uso agricolo dei prodotti fitosanitari. Anno 2008. Statistiche in breve. 26 novembre 2009. pagg. 13.

Severini S., Biocca M., 2004. The organisation of testing and inspection of sprayers at regional level by means of a mathematical programming model. Proceedings of AgEng 2004, September 12-16, Leuven, Belgium.

Wehmann H. J., 2007. Actual survey about inspection of sprayers in the countries of Europe. In: Second European Workshop on Standardized Procedures for the Inspection of Sprayers in Europe- SPISE". Ganzelmeier H., Wehmann H. J. Eds. April 10 -12, Straelen, Germany. 22-28.

Wehmann H. J., 2010. Actual survey about inspection of sprayers in the European countries. In: "Third European Workshop on Standardised Procedure for the Inspection of Sprayers in Europe – SPISE 3" H. Ganzelmeier, H. J. Wehmann Eds. Julius Kuhn Institute, Vol. 426, 48-52.

Optimising the Choice of Cows in the Organisation of the Milking Process

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Objectives
As reported in the literature, in double herring bone parlours can be prolonged waiting times for cows with shorter extraction times. In South East of Sicily that kind of parlour is the most spread. Previous trials showed that to reduce milking times it is necessary to focus on the milk extraction time. The same trials showed that to reduce waiting times the milk extraction rate is the parameter by which the animals should be grouped and milked together. The aim of the actual research is to confirm the time reduction obtained with grouping heads in function of milk extraction rate and to determine how many surveys must be conducted to obtain a sufficiently close approximation to the extraction rate of each animal, because only if the surveys are a small number the found way will be really useful. We chose a representative farm of the SE of Sicily in an area very much involved in animal farming. The farm is equipped with a "double herring bone (3+3)" plant, situated in a parlour which the cattle enter without any pre-established order. We study the productive performance of each animal, including the quantity of milk produced at each milking and measured the milk extraction rate. The milking operations were broken down into constituent stages, which were timed. A milking simulation was carried out by grouping cows in function of the same or similar milk extraction rate. Thank to the milking simulation with groups made up of heads with similar rates we con confirm a great reduction in time loss and a dramatic increase in the work capacity of the parlour (head/h). We set up the correct procedure that consists in screening out cows that are sick or close to lactation period and through the research we are able to confirm that with a small number of surveys we can measure the correct milk extraction rate of every heads. We have establish how much time could be saved by forming homogeneous groups.

Keywords: herring-bone parlours, herd, work organisation

Introduction

Herring bone, simple or more frequently double, is a very spread kind of milk parlour and in particular in the south east of Sicily.

Animals enter into the parlour and leave in groups and group milking time is affected from herd very slower than the others: in fact, animals that have already been milked remain in the parlour longer than necessary because of the presence of slower cows.

Herd milking time depends greatly from milk time extraction (71%), while the remaining phases take much less time. Milk extraction time is strictly connected with milk extraction rate and this parameter was found to be constant, reliable and independent of the quantity if milk produced. Usually the milking job is carried out from a specialised operator, thus the routine cannot be further compressed. Therefore, the way to reduce group milking time is to grouping the animals with the same or similar milk extraction rate. Our study regards a small milk parlour and intends to verify if grouping heads results in saving time.

Materials and methods

The research was carried out into a double herring bone parlour (2 + 2) selected as representative in the south east of Sicily. Each survey concerned 36 heads, grouped in 9 groups. Heads formed groups without the intervention of any operator.

The steps involved in the research are:

1 – studying the herd with the aim to eliminate from the observations heads not in health or close to lactation;

2 - using milking extraction rate as parameter for grouping the cows;

3 – carrying out a number of observation concerning the operations in the parlour (work organisation) and the performance of each head (quantity of milk produced at each milking and the milk extraction rate;

4 - determining the lowest number of observation to carry out in the parlour to identify the cows with similar milking extraction rate

5 – proceeding with "simulated milking", forming homogeneous groups in function of similar values of milk extraction rate;

6 – calculating the better performance (head/h) of the simulated milking than real milking (15 milking)

Results

Data statistic elaboration shows that five were the lower number of survey occurring to determine the mean value of milking extraction rate of each head. Taking in account the results of that five surveys we have calculate the simulated cycle times and after the time saving.

The mean milking time of the heard (including the whole routine, from the entrance of the first head of each group in the parlour until the exit of the last) was 78'2". On average, it means about 2'/head and the work capacity of the parlour was found to be approximately around 30 heads/h. Forming simulated groups show a mean time saving of about 13' (17%).

Milking	Observed (min)	Simulated (min)	Time saving (mn)
1	77.1	63.5	13.6
2	82.3	66.6	15.8
3	88.9	68.3	20.5
4	78.8	59.8	19.0
5	80.1	60.1	20.0
6	81.2	61.7	19.6
7	69.9	62.5	7.4
8	79.2	67.8	11.4
9	71.4	61.5	9.8
10	77.1	70.1	7.0
11	79.5	69.6	9.9
12	70.8	62.2	8.6
13	81.5	68.5	13.0
14	77.0	66.5	10.5
15	77.6	66.6	11.0
Means value	78.2	65.0	13.1

Conclusion and prospects

Grouping cows in function of similar values of milking extraction rate results in milking time saving. The research confirms that with a low number of surveys the correct milking extraction values of each head can be assessed. An algorithm could be set up with the aim to facilitate farmer to assess the correct milking extraction values of each head within the lowest number of surveys; with a spreadsheet it can be easily to calculate the time saved milking grouping heads in terms of similar milking extraction rate. As grouping the whole herd can result expensive in terms of time or demanding for the milker (that often works alone), good results can be obtained grouping only slowest cows with the aim to milk them separately from the fastest.

Bibliography

Armstrong D. V., Quick A. J., (1986), *Time and motion to measure milking parlor performance"* J Dairy sci n. 69, 1169-1177.

Armstrong D. V., Smith J. F., Gamroth M. J., (1998), *Milking routine and performance of large herringbone milking parlor,* Proc. milking systems and milking management symposium, Cornell University.

Balloni S., Caruso L., Conti A., Mazzola G., Schillaci G. (2008). *Shortening the Length of Dairy Cow Machine Milking by Grouping Animal in Function of Milk Extraction Rate.* Atti su CD-rom del Congresso Internazionale "Innovation Technology to Empower Safety, Health and Welfare in Agriculture and Agro-food Systems", Ragusa, Italy, 15-17 settembre,ISBN/ISSN: 978-88-903151-1-4.

Cappelletti M., Bisaglia C., (2002), *Gestione ed organizzazione del lavoro con sistemi automatici di mungitura,* L'informatore agrario LIIX(41).

Caruso L., Mazzola G., Schillaci G. (2007). *Work organisation in dairy cow milking parlours.* Atti del XXXII Congresso CIOSTA-CIGR V "Advances in labour and machinery management for a profitable agriculture and forestry". 17-19 september, Slovak University of Agriculture, Nitra, Slovak Republic.

Licitra G., Gambina M. (2004), *Prevenzione e controllo delle mastiti bovine,* Ed. CO.R.FI.LA.C Ragusa.

Pazzona A., (1999), *Impianti di mungitura e di refrigerazione del latte nell'allevamento ovino e caprino.* Dimensionamento, Costruzione e Prestazione, Ed. ERSAT.

Schick M. (2000), Temps de travail nècessaire pour diffèrents procèdès de traite, Station fedèrale de recherches en èconomie et technologie agricoles (FAT), Rapport FAT n. 544.

Schillaci G., Zimbalatti G. (1992), "*Impianti di mungitura valutazione tecniche*" Terra e sole n. 599-600.

Study of Field Production for the Introduction of Precision Viticulture Technology

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Abstract
The wine market had in the last few years deep changes which are due principally, to the always biggest attention of the consumers towards to the wine good quality. The aim of the work is to analyze the spatial variability of the viticulture production and to evaluate the use of a main grid to be used in the control, in order to be able to identify homogeneous zones of production with a sampling methodology. The used sampling scheme is a regular grid with transepts of dimension equal at 10 mt and in total were sampled about the 3% of the plants in production and georeferenced (GRS1 of TOPCON) using a GPS device and, before the vintage, were evaluated the number, the bunch weight and the total production for plant. The data shown a variability of production between various field zones and among the single plants sampled in the biennium. The average production estimated for plant was of 2,77 kg for 2008 and 2.03 kg for 2009 while the total production was ranging from 5,3 t for 2008 to 4,09 in 2009. The productions changes between esteemed crops and the ones truly realized are of 2,0% for the first year of sampling and 2,6% for the second year even if causes of the variability of bound production to the ground and the cultivation management were not explained in adequate way.

Keywords: precision viticulture, field production, grape

Introduction

Precision agriculture (PA) is no longer a new term in global agriculture. It has been the subject of numerous international and European conferences for the past decade. Currently the best definition is "an integrated information- and production-based farming system that is designed to increase long term, site-specific and whole farm production efficiency, productivity and profitability while minimizing unintended impacts on wildlife and the environment". Simplified, PA is an application of new information technologies applied together to maximize production efficiency and quality while minimizing environmental impact and risk. Advances in technology, especially georeferencing systems, have allowed agriculture to move back towards site-specific agriculture and involve the use of any emerging information technology other than just yield sensors. Precision Viticulture (PV), is dependent on the existence of variability in either or both product quantity and quality. Some variables may also be temporarily variable but have a stable spatial pattern, for example climatic variables such as incident radiation and temperature. Viticulture is intensive, highly mechanized, has high value-added potential and is dominated by large companies. The most compelling argument for the adoption of PV is the variability that has been shown in vegetative, yield and quality mapping over the past few years (Bramley, 2004, Hall *et al.*, 2002). Since variability exists in quantity and quality there is an opportunity for site-specific management to improve the efficacy and profitability of production. The objectives of precision viticulture will differ depending on the market for wine and, for example, the use of selective harvesting may also be utilized to optimize quality (Bramley et al., 2003). In the last few years the wine market has undergone profound changes which are due principally to the increasing attention of consumers towards good quality wine. Thus winemakers, need to produce grapes that maintain certified characteristics of good quality over the years and reduce, with specific site methodologies, the interventions now required. In viticulture, vegetative indices derived from canopy imagery at veraison, a few weeks before harvest, are used to identify areas of different vigor within blocks. Grape quality within these different vigor zones is tested using a targeted sampling scheme, and the results are used to formulate differential harvest strategies (Bramley et al. 2005; Best et al. 2005). When maps are delivered, farmers receive a large amount of data which has to be analyzed rapidly. This means that the decision as to whether or not it is appropriate to apply site-specific management (SSM) has to be made in a few days. This step is even more critical in viticulture when the information is delivered and analyzed at the cooperative level. In this case, more than a hundred blocks may have to be analyzed by a viticulturist within a short timeframe of two to three days. The primary technological advance that made precision agriculture feasible is the yield map, which enables the farmer to estimate crop yields for sections as small as a few square yards and to display the collection of these estimates in color-coded maps (Fig. 1). Any area can be mapped. Growers can identify high- and low-yielding regions of the field and precisely quantify the differences between them. Yield mapping is based on three basic technologies: yield monitors, GPS and GIS.

Yield monitor. A yield monitor is a device that periodically (generally about once per second) measures the mass or flow rate of harvested material, and based on this measurement computes an estimate of crop yield. In a combine harvester, the estimate is obtained by measuring the force of the grain against a plate. GPS. The global positioning system, or GPS, uses triangulation of signals from a constellation of satellites to identify the location of the GPS on the Earth's surface, generally within about 1 yard. A fully functional yield-monitoring system includes a GPS that tags each yield estimate with the current location in the field so the data can be matched with the location. These data are stored in a file that can be downloaded after harvest. GIS.

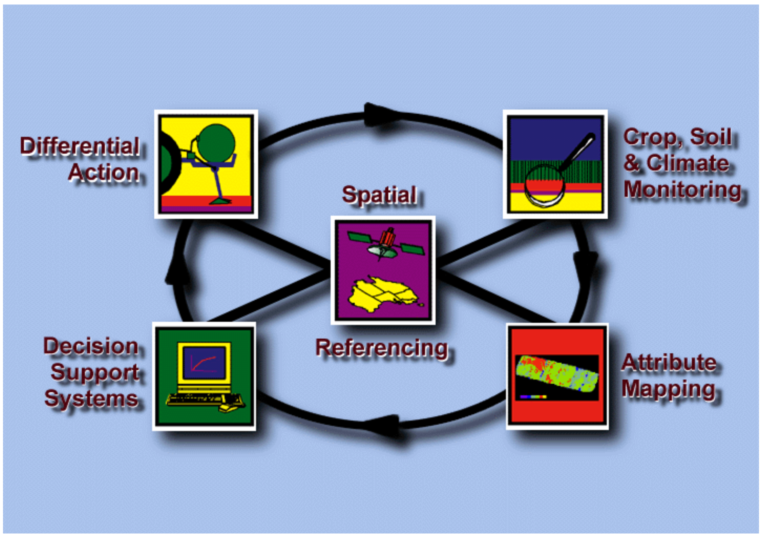


Figure 1. The Precision Agriculture wheel model showing the five main processes for a site-specific management system (Courtesy of the Australian Centre for Precision Agriculture).

A geographic information system, or GIS, is a computer program that combines database-management systems with graphics. It can accept data from an assigned location and generate a thematic map showing the spatial distribution of the data. Data from a yield monitor is downloaded into a GIS and converted into a color coded yield map that displays yield levels throughout the field. A typical yield monitor includes a data card to transfer files from a personal computer.

Aim of the work.

The aim of this work is to analyze the spatial variability of viticulture production and to evaluate the use of a main grid for use in control, so as to identify homogeneous zones of production with a sampling methodology. The monitoring of the grape components during two years of vintages will allow us to verify, through systems of statistical and geostatistical analysis, what may be the most probable factors that affect the variability of the yields obtained in two consecutive years.

Methods

Harvest criteria
This study was undertaken in a commercial "Semidano" vineyard block (0.5 ha) in the municipality of Mogoro (Sardinia, Italy) during the summers of 2008 and 2009. The experimental field is flat; it is prevalently sandy and has a fixed drop irrigation system. Vines were trained on a rammed cord and vine spacing was 2.5 m between rows and 1.0 m within rows (146 plants per row). The number of rows was 13 for a total of 1898 plants, the number of the sampled plants harvested was 64, equal to 3% of the total. During the vintage we verified total vineyard production and Yield production (Yp). The procedure for calculating Yp is described below. Before vintage, we observed the number of bunches, bunch weight, average bunch weight and total production per plant. An average number of bunches per vine and an average bunch mass were calculated. An estimated Yield production (Yp) for the site was calculated with the formula (1) as follows:

(1) **Yp = average number of bunches per vine x average bunch mass x number of vines.**

The vine was harvested following a regular grid (Fig. 2) with transepts having a dimension of 20 m, a plant every 20 in the first and second cases.

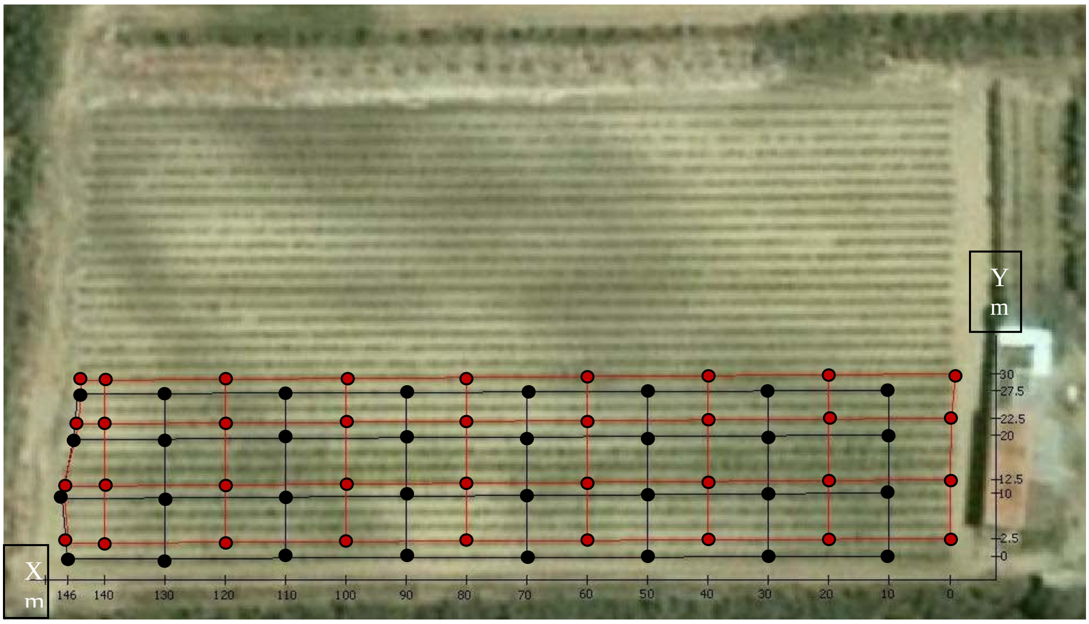


Figure 2. Grid of spatial distribution of the 64 sampling locations within the vineyard in 2008 and 2009.

The plants in production were sampled and georeferenced (GRS1 of TOPCON) using a DGPS device to obtain a yield map of production. The sampling strategy used was a regular grid based on the row and specific vine spacing, with a sampling intensity of approximately 64 vines per hectare. The yield maps of the three variables was obtained with a multivariate geostatistical analysis using ISATIS software (Geovariances). Beyond the numbers, other variables did not have normal distributions and all the variables were normalized and standardized to average 0 and variance 1. Modified two-range structures = 0.09 and 0.34 m with short range change.

Results and discussion

All measured vine properties show significant year-to-year variability in production between various field zones and among the single plants sampled (Tables 1 and 2). From the data observed in the field in terms of production per plant, the weight of the different bunches sampled showed a high variability for single plants in the 2008 vintage, ranging from 0.6 kg/plant (plant number 130 row 1) to 6.2 kg/plant (plant number 90 row 5). The high variability discovered in production between plants and rows in this vintage, is to be attributed to several factors such as the way of pruning, the presence of irrigators arranged at the beginning of rows 1, 7 and 13 which intersect among them every 15 plants on the row from plant number 17 to plant number 136 and finishes 5, 6 stumps to the vineyard head (140 to 146).

Table 1. Results of production by row and plants sampled during the 2008 vintage

Row 1		**Row 2**		**Row 5**		**Row 6**		**Row 9**		**Row 10**		**Row 12**		**Row 13**	
plant n°	kg/ plant	**plant n°**	kg/ plant	**plant n°**	kg/ plant	**plant n°**	kg/ plant	**plant n°**	kg/ plant	**plant n°**	kg/ plant	**plant n°**	kg/ plant	**plant n°**	kg/ plant
10	1.0	**1**	1.5	**10**	1,5	**1**	1,6	**10**	2,9	**1**	4,2	**10**	4,6	**1**	2,4
30	0.5	**20**	0.8	**30**	6,3	**20**	1,6	**30**	3,2	**20**	1,4	**30**	3,2	**20**	6,4
50	1.7	**40**	2.0	**50**	4,8	**40**	2,9	**50**	2,2	**40**	2,8	**50**	2,6	**40**	2,6
70	0.8	**60**	4.5	**70**	4,5	**60**	3,6	**70**	3,5	**60**	3,0	**70**	4,2	**60**	4,8
90	0.7	**80**	1.6	**90**	6,2	**80**	1,6	**90**	2,9	**80**	2,6	**90**	4,0	**80**	3,8
110	1.2	**100**	2.9	**110**	2,7	**100**	1,8	**110**	2,9	**100**	2,6	**110**	2,6	**100**	2,9
130	0.6	**120**	2.3	**130**	5,8	**120**	1,5	**130**	2,9	**120**	2,6	**130**	0,7	**120**	3,8
146	1.8	**140**		**146**	3,0	**140**		**146**	2,9	**140**		**146**	1,6	**140**	
Average production	1.0		2.2		4.4		2.1		2.9		2.7		2.9		3.8

Furthermore, if we analyze the results in terms of average weight per bunch, rows 2, 6, 9, 10 and 12 show comparable data; rows 5 and 13 show greater productivity and row 1 has the lowest production (1.0 kg/plant). This is a row on the field border which is also more shaded by the presence of high windbreaks (about 3 mt) a few meters away (about 3 m). The average number of bunches varied from 4.75 to 10.4 (1st and 5th rows, 2008 vintage) and form 6.75 to 10.13 (9th and 10th rows) in the 2009 vintage. Annual variation in bunch weight followed a different pattern and it was largest in 2008. The average bunch weight went from 0.25 kg/plant to 0.50 kg/bunch in 2008 and from 0.19 kg/bunch to 0.33 kg/bunch in 2009. The average production estimated per plant was 2.77 kg for 2008 and 2.03 kg for 2009 while the total production ranged from 5.3 t in 2008 to 4.09 in 2009 which, if reference is made to the grapes directly conferred to the cellar by the same grower and the same field was to be 5.4 t in 2008 and of 4.2 t for the next year. The changes in production between estimated crops and those actually produced were 2.0% for the first year of sampling and 2.6% for the second year. The causes of the variability in production connected with the ground and cultivation management were not explained adequately (Table 4).

Table 2 Results of production by row and plants sampled during the 2009 vintage

Row 1		**Row 2**		**Row 5**		**Row 6**		**Row 9**		**Row 10**		**Row 12**		**Row 13**	
plant n°	kg/ plant	**plant n°**	kg/ plant	**plant n°**	kg/ plant	**plant n°**	kg/ plant	**plant n°**	kg/ plant	**plant n°**	kg/ Plant	**plant n°**	kg/ plant	**plant n°**	kg/ plant
10	1.1	**1**	2.4	**10**	0.6	**1**	2.6	**10**	1.2	**1**	3.4	**10**	2.5	**1**	2.1
30	1.6	**20**	0.3	**30**	2.9	**20**	0.8	**30**	0.9	**20**	2.7	**30**	4.6	**20**	3.9
50	3.3	**40**	2.0	**50**	1.8	**40**	3.2	**50**	0.7	**40**	2.1	**50**	0.3	**40**	3.8
70	3.1	**60**	3.0	**70**	1.8	**60**	1.1	**70**	3.1	**60**	2.0	**70**	0.0	**60**	1.4
90	3.4	**80**	2.5	**90**	2.6	**80**	3.3	**90**	1.5	**80**	2.9	**90**	2.0	**80**	3.2
110	0.8	**100**	1.8	**110**	0.8	**100**	0.8	**110**	1.4	**100**	1.8	**110**	2.3	**100**	1.8
130	2.3	**120**	6.4	**130**	2.2	**120**	2.6	**130**	0.5	**120**	1.4	**130**	1.3	**120**	0.0
146	2.2	**140**		**146**	1.7	**140**	1.2	**146**	1.4	**140**		**146**	1.2	**140**	
Average production	2.2		2.6		1.8		1.9		1.3		2.3		1.8		2.3

Table 3 Average number and weight of bunches per plant in the 2008 vintage

Row number	**Bunches average number**		**Bunch average weight**	
	Vintage 2008	**Vintage 2009**	**Vintage 2008**	**Vintage 2009**
1	4.75	8.50	0.25	0.33
2	6.71	8.29	0.35	0.22
5	10.38	8.63	0.46	0.30
6	6.57	8.71	0.46	0.22
9	5.25	6.75	0.50	0.21
10	8.25	10.13	0.33	0.22
12	8.63	8.63	0.38	0.23
13	7.88	8.13	0.29	0.19

Table 4 Comparison between estimated and conferred production in two years of vintage (2008-2009)

Vine	**Vintage**		**Differences**
Semidano	**estimated production yield (ton/ha)**	**production conferred to wine cellar (ton/ha)**	**(%)**
Year 2008	5.40	5.30	-2.0
Year 2009	4.20	4.09	-2.6

Data were obtained with the following formula (1): Yp = average number of bunches per vine x average bunch mass x number of vines.

Yield map production

Using approximately 3.0% of the total number of vines, all yield map production was obtained using ISATIS software (Geovariances, 2000). The yield maps of the three variables (average kg/plant, average number of bunches and average weight of bunch) were obtained with a multivariate geostatistical analysis. Beyond the numbers, other variables did not have normal distributions and all the variables were normalized and standardized to average 0 and variance 1. Modified two-range structures = 0.09 and 0.34 m with short range change (Figs. 2, 3 and 4). At this sampling scale anisotropies are not noticed. The average weight of 2009 has high outliers (Fig 3) compared to the 2008 average weight represented by isolated zones of the yield map in the NW and SW directions. The distribution of the population represented had a not normal distribution and this confirmed the presence of outliers in the map and in the distribution of the population. These considerations can be extended to the other two variables. In fact, the same results can be observed in the other two maps (Figs. 4 and 5) for the two years of vintage, where other zones of high and low production were showed in the same orientation of the maps. The maps did not show any clear space structures nor their persistence in time because the sampled lot did not describe very well the spatial and the temporal variability of the vineyard during the two years of vintage. Furthermore, other variables such as brix° content, pH, phenol content and other important information about the quality of the grapes in the field and of course of the wine at the end of transformation are needed to have a more complete study of the importance of the application of an in-the-field strategy to obtain ~~a~~ high product quality and quantity and implement the connection between the field and the cellar during the vintage.

Conclusion

The variables determined provided reasonable predictions of production. However, considering the small number of samples certain affirmations cannot be stated. It is necessary to increase the number of stumps sampled in the grid (more than a hundred) to define the validity of the model and to investigate the presence of anisotropy in order to reduce the high number of outliers that appeared during the vintage. For these reasons the sampling has to be defined carefully. Our results may improve the knowledge base concerning the possibility of using proximal or remote sensing during the vintage implemented by a harvester to check the production of the vineyard during vintage and this method of investigation can be extended to other crops. The study of attributes and capabilities of active and if necessary passive sensors is a goal that our department is able to organize in future works on precision viticulture. The combination between topographic data used with different types of agronomic information can be very useful in explaining the spatial and temporal variability of yield production, as well as its quality composition at the field level. The analysis of spatial and temporal variability of the grapes and wine during vintage will show in the future that its response is extremely dependent on the annual variation of climatic conditions and agronomic practices, and thus which parameters can be used to explain differences in yield production and chemical composition.

References

1) Bramley, R. G. V., & Lamb, D. W. (2003). Making sense of vineyard variability in Australia. In R. Ortega & C. Esser (Eds.), Proceedings of the International Symposium on Precision Viticulture, 9th Latin American Congress on Viticulture and Oenology, Santiago, Chile, pp. 35–54.
2) Bramley, R. G. V., Proffitt, A. P. B., Hinze, C. J., Pearse, B., & Hamilton, R. P. (2005). Generating benefit from precision viticulture through differential harvest. In Proceedings of 5th European Conference on Precision Agriculture, Uppsala, pp. 891–898.
3) Bramley, R. G. V., & Hamilton, R. P. (2004). Understanding variability in winegrape production systems 1.Within vineyard variation in yield over several vintages. Australian Journal of Grape and Wine Research, 10, 32–45.
4) Best, S., Leon, K.,&Claret, M. (2005). "Use of precision viticulture tools to optimize the harvest of high quality grapes". In Proceedings of the Fruits and Nuts and Vegetable Production Engineering TIC (Frutic05) Conference, Montpellier, pp. 249–258. On line on http://www.cemadoc.cemagref.fr/exl-doc.
5) Hall et al., 2002 Hall, A., Lamb, D.W., Holzapfel, B. and Louis, J. (2002) Optical remote sensing applications in viticulture – a review. Australian Journal of Grape and Wine Research, 8:36-47.

Figure 3. Yield map of average kg/plant in two years of vintage (2008-2009).

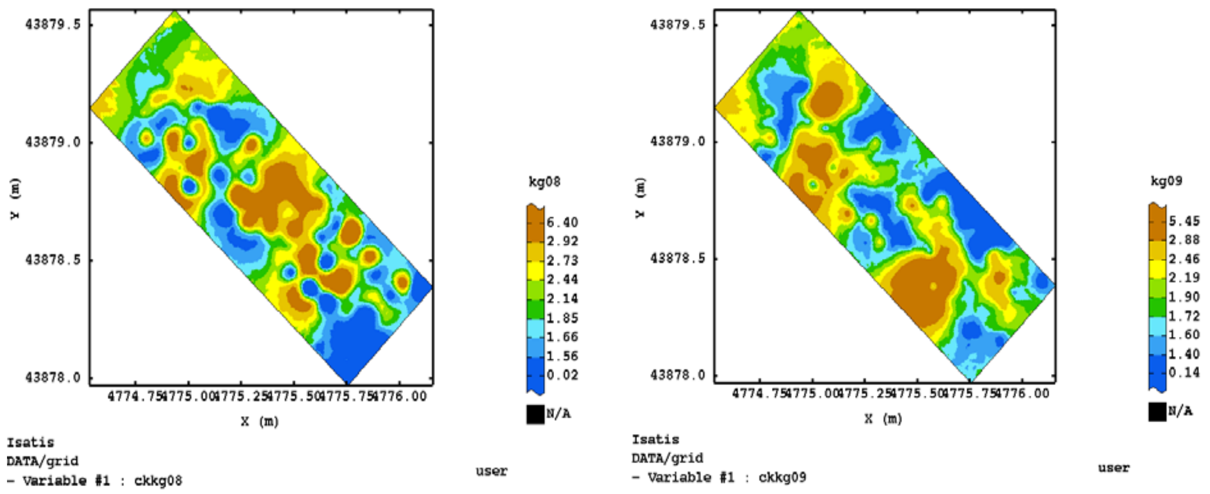


Figure 4 Yield map of number of bunches/plant in two years of vintage (2008-2009).

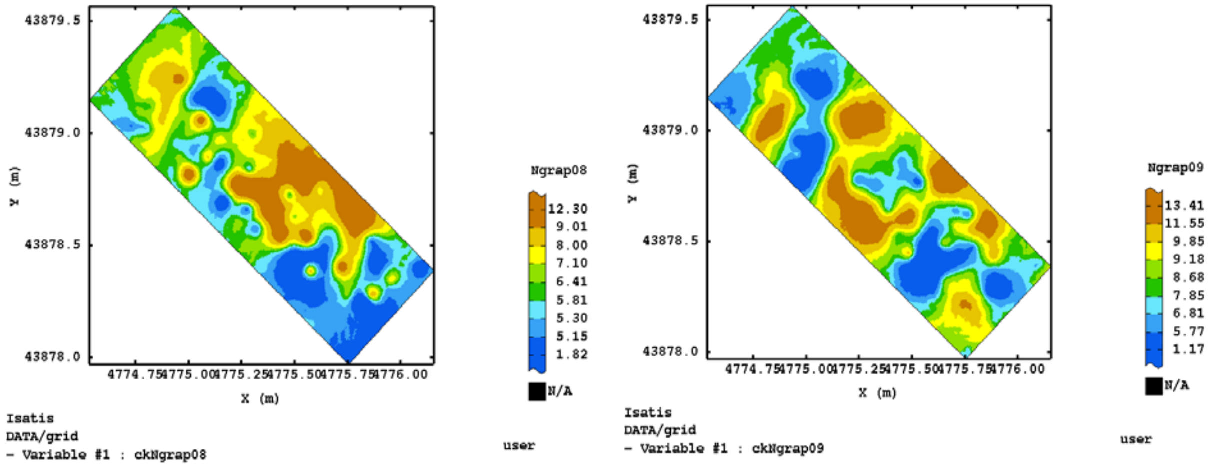
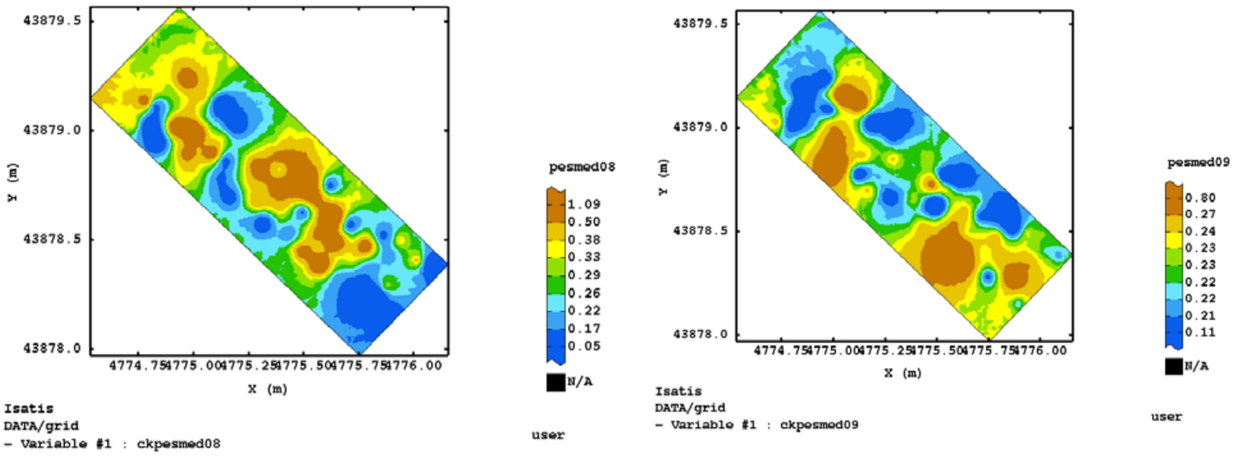


Figure 5 Yield map of average bunch kg/plant in two years of vintage (2008-2009).



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Transplanter with Laser System for Vineyard and Superintensive Olive Plant

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Abstract
In the last ten years we have been assisting to an increasing diffusion of the automatic transplanting machines in the vineyard plant, that allows to plant the vine cuttings with a large root apparatus, which is fundamental in order to obtain a rapid and correct plant growth. The technological evolution of these machines led to fine tuning of laser alignments system to transplant the vine seedlings. This system has been improved thanks to the use of the satellitic receiver, of most recent introduction, which determines the number of necessary poles and vine cuttings, right after having located the borders of the surface.
The aim of this work was to evaluate the technical and operative characteristics of the automatic transplanting machine Wagner, equipped by a laser system, working in two different Puglia localities, characterized by the same climate conditions, but different in the matter of the ground kind. The work quality of the transplanting machine on the strength of taking root percentage of the planted material have been evaluated.
The trials pointed out that the machine efficiency depends, especially, on the structural typology of the ground as well as on the surfaces position, with operative times and intervention costs always very low in respect to those supported with the manual plant.

Keywords: transplanting machine, vine cuttings, vineyard

Introduction

The vineyard plant is a very old practice, executed manually until the eighties. The techniques adopted for the transplant foresee the vine cuts placement into pits or trenches dug along the line row. The new mechanized plant systems uses the transplanting machines, which determines aesthetic and functional improvements of plants, being more easy to work, obtaining a low incidence of dead times. The necessity to reduce the cost of the vine plant and the possibility provided from the evolution of the operative machines, increase the interest about the mechanization of the vine cuttings plant (Carrara M. et al., 2001, Planeta et al., 2001).
In the last years the vineyard changed gradually with regard to the planning phase, that it has been simplified by the introduction of topographic tools allowing to quit the old measure systems, obtaining optimum results due to the precision of the tracing and staking field phases, that in the past implied time and much work.
The laser alignment system has been extended to the plant phase subsequently too, allowing to drive the transplanter, constantly keeping on-axis with the files. A greater production quality it obtains, with a considerable reduction of the costs and time work. We reached to this mechanic innovation later on recruitment difficulties and high costs labour, given that the considerable manually work required by vineyard.

The laser transplanter use increases the vine cuttings number planted per day in respect of the manual transplant, assuring the seedlings alignment along the file at the same time. Furthermore there is the possibility to leave a consistent root apparatus, favouring a rapid growth and a precocious production.
Some researches of the last years carried out that the vine cuttings planted mechanically have a growth 2-4 time greater than seedlings planted manually (Pipitone F., 2006), because with the transplanter the hearth adheres mainly to the roots without to create empty spaces and there is a greater resistance to water stress, thanks to use of vine cutting with a long root.
The aim of this work was to analyze the work quality of a transplanting machine with laser system, for the vineyard plant in three sites, on the base of the results deriving from the trials field. It has been possible to evaluate the incidence of the soil characteristics, typical of site, on the performances machine.

Materials and methods

The analysis, concerning the modalities of the vineyard plant realized by a mechanic laser transplanter, regarded three Puglia zones: Sammichele di Bari, Acquaviva delle Fonti and Putignano. The grounds are extremely different while its climatic characteristics are similar for those localities where the machine worked.
The vine cuttings used in the mechanized plant belong to *Vitis vinifera* species, cv. *Primitivo*, of two years and 0,60 m. Before to the experimental trials an adequate ground preparation has been executed, consisting of a leveling out allowing to the machine to work in a fluid way and the processing to make it untied, assuring an optimum adhesion to the root apparatus.
In the laser tracing the seedlings collocation has been made in a single direction and at the end of file needed to return to the initial headland. The tractor places itself in a new file to plant and it is necessary to put into effect the distance control system between the vines on the row.
This distance is controlled by hydraulic and mechanic system, based on the unrolling of a stainless steel wire, rolled on a reel placed in the overboard machine and previously fixed to its extremity, on a picket driven in the beginning of the file.
The machine used is the Wagner transplanter model Champion, mounted by a tired tractor 73 kW, characterized by a frame with one or two seats for the operators, which prearranges the seedlings on the machine members to position them on the ground. This machine has a rotative distribution mechanism, where the radially pliers brings and releases the vine cuttings (figure 2). The pliers open itself to receive the seedling placed by a worker in the edge machine and opens itself in correspondence to the bottom furrow, putting the seedlings vertically. The furrow has opened previously by a plowshare that works with a variable depth according to the soil and it has closed by two converging wheels, making compact the ground on the root apparatus.

Figure 1. Wagner transplanter.

Figure 2. Pliers for the seedlings taking.

The transplanter machine has equipped by a laser system, based on an aboard receiver (figure 3) and by a sender in correspondence of the file to plant (figure 4), allowing a correct alignment of the transplant device on the row, with an error contained in 3 cm.

Figure 3. Riceiver on the transplanter.

Figure 4. Sender on the file.

The yard was composed by a worker on the helm of the tractor, one or two operators on the edge machine for the seedlings plant, one in the head plat for the laser device displacement and finally a worker for the vine cuttings preparation.
The transplanter is able to plant at a minimum distance between the rows equal to 1.20 m and on the row equal to 0,70 m; in this case the following values was been established.

Table 1. The calibration values of the Wagner transplanter.

Distance among the rows (m)	Distance on the row (m)	Depth (m)
2,40	1,20	0,40

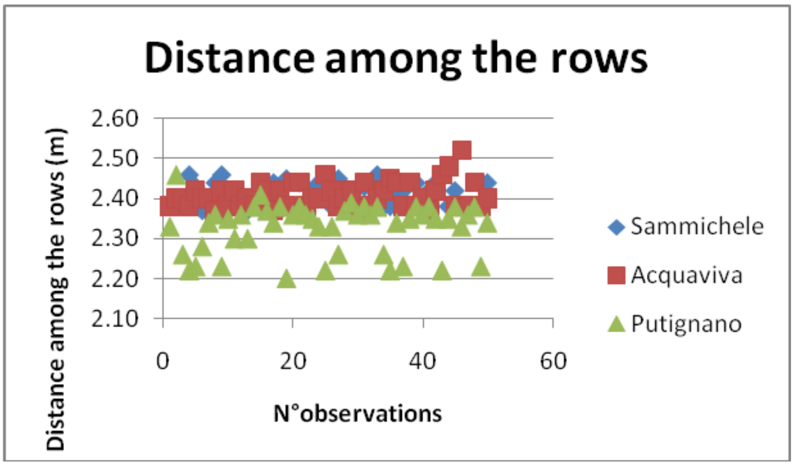
For each plant we proceeded to measure the distance among the rows, the distance on the row and the depth of the vine cutting plant, effecting 50 measurements in each site and for all parameters considered. Specifically the depth value has been obtained from the difference between the total length of the seedling, comprising the root apparatus, and the length of the epigeous portion, after the plant. Finally the data deriving from the field trials have been submitted to the variance analysis with one factor, using the analysis tool of Microsoft Excel 2007. In this manner we analyzed the difference between the arithmetic means of the groups, correspondent to the different localities in respect to three parameters considered and we verified these statistical hypothesis:

- H_0: $\mu_1 = \mu_2 = \mu_3 = \ldots = \mu_t$
- H_1: $\mu_i \neq \mu_j$ for some **i** and **j**

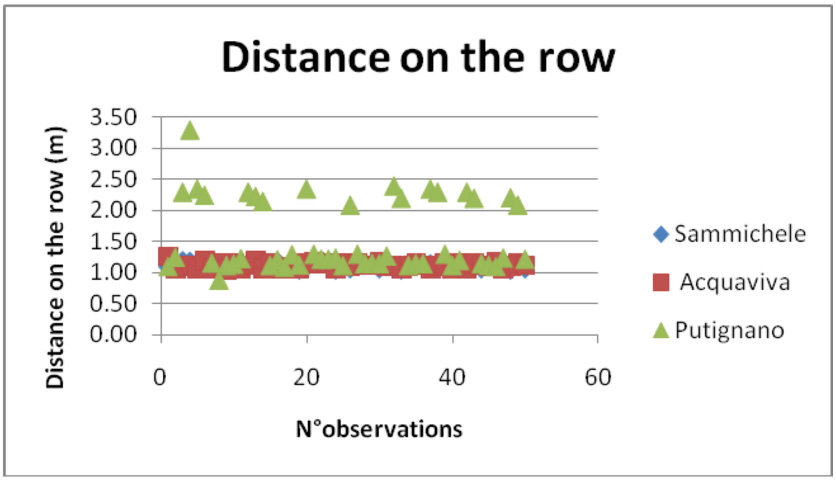
According to the null hypothesis the means are equal between them; in the alternative hypothesis at least two means are significantly different.

Results

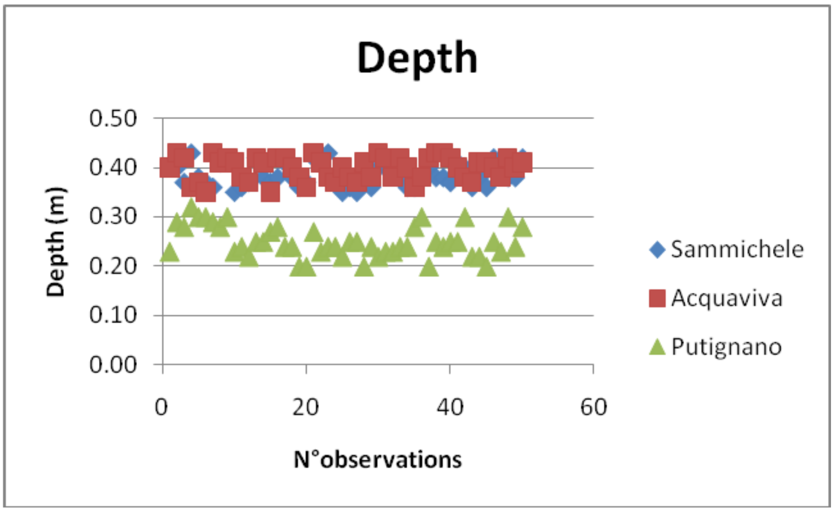
The field trials provide results quite similar for the Sammichele di Bari and Acquaviva delle fonti sites, totally different for Putignano site. In the first two localities the ground has been submitted to a preliminary settling, in order to assure a good nimbleness, avoiding difficulties during the transplanter work.
The following dispersion graphs (graphs 1,2,3) report the values of the three parameters analyzed and shown as the data relative to the first two localities lay upon them often, indicating that the characteristics of these sites are extremely similar, unlike the Putignano plant characterized by values very different in respect to the calibration values of the machine. In this plant the transplanter worked in a difficult ground, very stony, that needed several preliminary operations, such as the break and the smashing of the rocky layer in order to transform them in a cultivable land; these operations have not been effected.
An untied, dry and without stone ground is the optimal condition in order to receive the vine cuttings and to assure an easy work from the transplanting machine. The Putignano site does not shows any of these characteristics.



Graph 1. Distance among the rows.



Graph 2. Distance on the row.



Graph 3. Depth.

The experimentation conducted using the variance analysis with one factor had the aim to evaluate the work executed by the mechanic transplanter, examining the data acquired in the field and comparing them with the initial machine values.
These are the results deriving from the variance analysis for each parameter, in the localities examined.

DISTANCE AMONG THE ROWS
RECAPITULATE

Groups	Count	Sum	Mean	Variance
Sammichele	50	120,38	2,407	0,000985959
Acquaviva	50	120,43	2,408	0,001036776
Putignano	50	116,39	2,327	0,003801184

VARIANCE ANALISYS

Variation source	SQ	gdl	MQ	F	P-value	F crit
Among groups	0,214961333	2	0,107480667	55,36513	1,19445E-18	3,05762
In groups	0,285372	147	0,001941306			
Total	0,500333333	149				

DISTANCE ON THE ROW
RECAPITULATE

Groups	Count	Sum	Mean	Variance
Sammichele	50	55,9	1,118	0,001808163
Acquaviva	50	55,9	1,119	0,001866327
Putignano	50	78,0	1,561	0,327323918

VARIANCE ANALISYS

Variation source	SQ	gdl	MQ	F	P-value	F crit
Among groups	6,54461	2	3,272306	29,65850	1,51182E-11	3,05762
In groups	16,21892	147	0,110332803			
Total	22,76353	149				

DEPTH
RECAPITULATE

Groups	Count	Sum	Mean	Variance
Sammichele	50	19,27	0,3854	0,000564122
Acquaviva	50	19,91	0,3982	0,000570163
Putignano	50	12,52	0,2504	0,000995755

VARIANCE ANALISYS

Variation source	SQ	gdl	MQ	F	P-Value	F crit
Among groups	0,67056	2	0,335280667	472,21724	1,01157E-64	3,05762
In groups	0,10437	147	0,000710014			
Total	0,77493	149				

From the variance analysis results as the F value calculated is greater to F critic for all variables analyzed and that bears out the alternative hypothesis whereby the means are

significantly different among them. Specifically for the Sammichele and Acquaviva sites the mean of the data analyzed is very near to the predetermined value and the variance is very low, that means the data are quite homogeneous. We can infer that the vine cuttings have been planted respecting the calibration values of the transplanter for all parameter.
For the Putignano site the variance values have been greater, because the initial data were heterogeneous and distant from the calibration values; in this case the work executed by the transplanter was totally negative. In fact the machine does not guaranteed the alignment precision and an adequate depth. The lack of the ground settlement and its intrinsic characteristics are the causes of the low quality work obtained in the last plant. To this purpose in this site some ground samples have been taken and the analysis have been effected by the chemical laboratory of our university *(*table 2*).*

Table 2. Analysis of the ground of the Putignano site (Source: Laboratory of Chemical Department of the University of Basilicata).

Ground humidity	9 %
pH	7,45 %
Electric conductivity	3,91
Coarse sand	5,7 %
Fine sand	11,4 %
Clay	29,2 %
Coarse slime	17 %
Fine slime	36,7 %

From this table we note as the ground analyzed is loam-clayey and with a low percentage of sand, fundamental to assure a good drainage. The high quantity of stones makes this site further difficult to work.
The following table reports the results relative to the different performance transplanter in the three sites and the rooting percentage that constitutes the principal indicator of the outcome work.

Table 3. Data work of the Wagner transplanter.

Sites	Advancement speed (Km/h)	Operative capacity (plants/h)	Real capacity (plants/h)	Rooting (%)
Sammichele	2,5	950	650	95
Acquaviva	2,5	950	600	90
Putignano	1,5	470	270	75

The transpalnter in the Putignano site had difficulties in the advancement, due to the lack of the leveling and to the presence of stones on the ground. That allowed to reach a work capacity more low in respect to other two sites equal to about 60%. The ground characteristics influenced the rooting seedlings, satisfactory in the Sammichele site, equal to 95% and limited in the last site considered, equal to 75%.

Conclusions

The research conducted pointed out that the use of the transplanting machine is fundamental to increase the productivity work, to contain the labour needs and to reduce the costs for the vine cuttings plant. The advantages deriving from the high operative capacity working in optimal conditions and from the high rooting percentage, higher to 90%, are undeniable.
If on one hand the purchase money of a transplanter is high for small and middle firms, on the other hand the outsourcers are able to propose the mechanic transplant with advantageous prices. At present the principal problem is the reduced employ of labour and the transplanter use is an alternative to the difficult of its recruitment.
This analysis pointed out that is necessary an adequate preparation of the ground in order to a correct working machine and to assure an optimum adhesion of the ground to the root apparatus; besides the seedlings plant foresees the execution of a furrow, therefore the machine is not efficient in the ground very clay and stony. In fact in the Putignano plant, where the ground presented these characteristics and the settling operations had not been executed, the result of trials has been totally negative.
In conclusion we can assert that are numerous the advantages deriving from the mechanized plant, both technical-agronomic and economic.
The disadvantages, as we observed directly in field, are:

- a greater ground trampling, due to the tractors use, contrary to that happen with a manual transplant;
- the difficult to work on ground with high slope;
- the laser malfunctions with the mist, because the precision and the quality work are not optimal.

The Wagner transplanter has employed widely in the vine and olive plant, besides in the SRF (Short Rotation Forestry) the cultivation of trees woody species (poplar, willow, black locust, eucalyptus) with rapid growth and short turnover for the final production of biomasses. The technologic evolution of these transplanter typologies aims to execute the transplant operation more and more efficiently and to this purpose innovative machine, such as the Biopoplar transplanter model T3, have been patented.

References

Bellomo F., D'Antonio C., D'Antonio P. 2009. Innovative transplanter with satellite system for superintensive olive plant. Proceedings on Volume 2, XXXIII CIOSTA CIGR V Conference, 17-19 June 2009, 813-817.

Eynard I., Dalmasco G. 1994. Viticoltura moderna, Manuale pratico. Ulrico Hoepli.

Morando A. Materiali e tecniche per l'impianto del vigneto. Edizioni Vit. En.

Pipitone F. 2006. Meccanizzazione per le colture specializzate del Mediterraneo. Dipartimento di Ingegneria e Tecnologie Agro-Forestali, Palermo.

Each author contributed in this paper in same measure