The new EU Directives requirements and the innovation in pesticide application techniques

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Summary

First reference to crop protection equipment is dated in the second half of 19th century. From that age until recent years the evolution of crop protection equipment in the developed countries had two fundamental objectives: the adaptation of the machines to the needs of applying the chemicals available on the market and the need to improve their working capacity. Only from 1980's the safety aspects related to the operator and to the environment have been taken into account as priority aspects and these latter have addressed the evolution of crop protection equipment in the last twenty years. This line of evolution will be enforced in future especially in Europe due to the issue of the EU Directive on Sustainable Use of Pesticides and to the amendment of the EU Machinery Directive. These Directives are focussed on the implementation of environmental safety requirements regarding plant protection machinery and address to develop new sprayers and accessories able to improve the users and consumers safety as well as the environmental protection.

Due to the globalisation process, for instance entering in WTO rules systems, also developing countries are now facing the need to promote the development of plant protection machinery in order to improve the quality of spray application (at present spray losses range between 60% and 70% of the applied volume) and to reduce the environmental risks related to PPP dispersals.

Several examples of the use of electronics and Information Technologies to improve the performances of sprayers are reported as solutions for reducing PPP water contamination due to point sources (related to filling and cleaning of sprayers) and to diffuse sources (spray drift and run-off) both for open field and greenhouse pesticide applications.

Finally it is estimated the potential market improvement for sprayers and components due to the entry into force of the new EU Directive that for the next seven years has been calculated in a value of 1,3 billion Euro and it is underlined that techniques and infrastructures are key elements to enable mitigation of PPP risks, but most important is the associated correct behaviour of the operator

1. Foreword

Initially, agricultural sprayers were developed for applying copper and sulphur based products in vineyards. Those were later followed by knapsack sprayers and hand held sulphur dusters (**Fig. 1**). More in details, the first reference to crop protection equipment is dated back to the second half of the 19th century [1]. It deals with manual piston pumps (**Fig. 2**) that were used to feed hollow cone adjustable distributors, not very much different from those that are still in use in developing countries or used in some places for hobby purposes. They were featured by a limited working capacity and required a considerable amount of human energy for their functioning. These reasons led to the development of new equipment, hand-held or trailed by animals (**Fig. 3**), equipped with manually activated pumps or provided with endothermic motors, and fitted with spray lances or spray booms [2; 3].

When first hormonic herbicides appeared in 1960s a new impetus to the evolution of spraying equipment was given. The objective was always to spray leaves, but to spray the leaves of weeds present in arable crops, featured by a lower height and by a relatively wide surface. Firstly, boom sprayers were produced (**Fig. 4**) which led relegation of hoes, weeding machines, and rice weeders, as they facilitated weed control and enabled to save money. Nearly at the same time, spreading of new tractors fitted with three-points links and PTO shafts enabled further development of these equipment into mounted or trailed machines activated by the tractor. The element that differentiated different sprayer types was, and still is, mainly the spray distribution system. It comprised a boom kept as much as possible parallel to the treated surface for arable crops; shaped conveniently (one for each side of the machine), and, since the end of the 1950s, mostly combined with fans to convey the spray droplets towards the top of plant canopies, for spray application on arboreal crops [4].

In summary, the evolution of crop protection equipment had two fundamental objectives until recent years: a) the adaptation of the machines to the needs of applying the chemicals available on the market and b) improving the working capacity of the machines in order to face the shortage of manpower in the agricultural sector. Only starting from 1980s, improving/enhancing the safety aspects related to the operator and to the environment, which are linked to the harmfulness of the used chemical products, have become a priority objective. Therefore the latter has entailed the evolution of crop protection equipment in the last twenty years.

In several European countries, already at the beginning of 1990s, restrictive measures concerning the use of pesticides were adopted. These measures included the ban on very fine atomisation to minimise drift contamination problems in areas adjacent to the treated fields, prescription for using anti-drift nozzles, periodical inspection of sprayers in use to check their functionality, introduction of buffer or no spray zones where the use of pesticides is limited or banned, obligation for using antidrip and other devices to prevent point source contamination, except the obligation to respect all the operator safety requirements listed in the EU reference standard (EN 907). Actually, it is estimated that about 25% of more than 2.5 millions tons of pesticides that are yearly applied in the world is used in the European Union.

It is necessary to underline that the application of Plant Protection Products (PPP) can lead to some unintended losses of these products to water resources. The following are the two main entry routes of PPP into surface water:

a) **Point sources**: mainly relate to the handling of PPP during the transport, storage, filling, cleaning, management of remnant liquids, and the disposal of empty packages (**Fig. 5**).

b) **Diffuse sources**: mainly relate to drift losses during the application and run-off and drainage discharge from treated fields (**Fig. 6**).

Research results show that point source pollution is the main entry route of PPP into surface water and contributes to more than 50% of total PPP contamination [5; 6; 7; 8].

The adoption of EU drinking water Directive in 2000 brought the issue of water contamination by PPP into particular focus. It sets a limit for acceptable concentration of PPP in drinking water at 0.1 µg/l which is nearly a zero tolerance. Exceeding the threshold may result in excluding some PPPs from the market and hence reducing the tools available for farmers to protect their crops. Especially, in the light of resistance management needs and climatic change, a broad spectrum of available solutions is highly desirable. The slow down of new products development [9] will increase the need to keep many options available. It is therefore in the common interest to propose improvements of equipment and infrastructure to enable mitigation of water contamination risks.

In this context, the development of a Thematic Strategy for the Sustainable Use of Pesticides, focussed on the implementation of environmental safety requirements regarding agricultural sprayers, was recently brought up in the new EU Directive on the subject and resulted in the amendment of the EU Machinery Directive. It addresses the design and development of new sprayers and accessories for pesticide application to improve the quality of the environment and safety of the operators.

2. Framework Directive on the Sustainable Use of Pesticides

The new European Framework Directive on the Sustainable Use of Pesticides was firstly proposed in 2002 and its complete draft was issued in 2006 (COM 2006, 372). The final text was approved by the European Parliament on 13 January 2009 and by the European Council on 24 September 2009. Its objective is to provide clear references on how to manage pesticide applications in the field in order to reduce PPP usage, and to prevent the potential environmental contamination. This Directive comes to cover a gap in the EU legislative outline related to pesticide management. The revision of EU Directive 414/91, in fact, is aimed at restricting the criteria for the registration of new pesticides and for the introduction of plant protection products on the market. On the other hand, the Water Framework Directive and the Waste Framework Directive are concerned with the aspects related to the PPP residues and wastes disposal at the end of the spray application. Finally, the European regulation 396/2005/CE takes into account the maximum PPP residues allowed in the food products to prevent health risks for consumers (**Fig. 7**).

The general objectives of the new EU Directive on the sustainable use of pesticides are therefore: 1) the promotion of plant protection strategies enabling to reduce and to optimise PPP usage, for example through the adoption of Integrated Pest Management (IPM) plans, 2) the training of PPP end users aimed at limiting the improper use of PPP, and 3) the refinement of the spraying equipment with the purpose to maximise treatment efficacy and to limit contamination risks for the operators and to the environment.

More specifically, concerning the technical aspects of the sprayers, the Directive foresees:

1) mandatory periodical inspections of sprayers in use,
2) training of farmers about the correct use and adjustment of agricultural sprayers,
3) ban of aerial spray applications (exceptions can be allowed only in special documented cases),
4) mitigation of environmental risks linked to PPP spray applications, especially through the adoption of devices enabling to reduce spray drift and establishing adequate buffer zones,
5) identifying sensitive areas where PPP spray application is strictly prohibited or limited, and
6) proper management of PPP empty containers and cleaning of sprayers at the end of the spray application.

Among the above items, the requirement for the mandatory periodical inspection of sprayers in use is especially important. This activity, if combined with the teaching of farmers on how to correctly adjust their sprayers, may significantly improve the quality of spray application, reduce the volume rates, and minimise off target spray losses. In the European Union, the SPISE (Standardised Procedure for the Inspection of Sprayers in Europe) working group has been active since 2003 with the aim to provide common test methodologies for the inspection of sprayers in use across Europe according to EN 13790 standard and to harmonise the management of this activity in different EU countries. In some countries (e.g. Germany, Belgium, Poland), in fact, inspections of all sprayers in use have been mandatory for several years, while in other countries they are still carried out on voluntary basis or mandatory only for some categories of farmers (for instance for those who receive EU contribution for environmentally friendly agriculture). The enforcement of the new EU directive on the sustainable use of pesticides will make it necessary to inspect all sprayers employed for professional use in the European Union at least once by 2016 and to establish regular inspections schemes in all EU countries.

3. Amendment of the EU Machinery Directive

In order to be consistent with the objectives of the new Directive on Sustainable Use of Pesticides an amendment of the EU Machinery Directive 2006/42/CE concerning the aspects related to agricultural sprayers was proposed in 2008 (COM 2008/172). In the contents, not only the aspects related to operator safety are taken into account but also those concerning the safeguard of the environment. The amended Machinery Directive applies to all types of sprayers including hand held spraying equipment manually operated but fitted with a tank under pressure. The technical sheets provided by the manufacturers will have to report the fulfilment of the standard EN 12761 requirements concerning environmental safety.

More specifically, the amendment of the EU Machinery Directive concerning agricultural sprayers foresees that:

a) Sprayers and their components shall be reliable and so designed that they can be used properly in accordance with their intended use, without harming the environment unnecessarily. They shall be designed so that they can be safely operated, supervised and switched off immediately from the operator's position.

b) Easy and safe filling and complete emptying of the sprayer tank shall be possible. This includes that filling levels and limits shall be determined easily. Unintentional dispersal of liquid shall be avoided.

c) Sprayers shall be equipped with devices enabling the adjustment of the volume application rate in an easy, accurate, and repeatable way.

d) Sprayers shall be designed so that an even distribution and an adequate deposition can be achieved. When the application system is off, any dispersal of PPP shall be avoided.

e) Easy, safe, and complete emptying and cleaning of the sprayer shall be possible, especially regarding the main tank.

f) Changing worn parts shall be possible. For checking the sprayer and verifying its correct functioning, it shall be possible to connect measuring instruments to the sprayer components.

g) Nozzles shall be marked in such a way that they can be identified directly or from information given in the instruction handbook. At least, type and size shall be indicated.

h) Filters shall be marked in such a way that they can be identified directly or from information given in the instruction handbook. At least, type and mesh size shall be indicated.

i) in the instructions handbook the following indications shall be reported:

> 1) filling and precautions to be taken to avoid contamination of the environment,
>
> 2) conditions of use (for example maximum driving speed) and the corresponding adjustment of the sprayer enabling an even spray distribution on the target without dispersals,
>
> 3) type and size of nozzles and type and mesh size of filters,

4) time frequency for checking nozzles and filters,

5) any restriction of use for certain type of pesticides,

6) additional equipment or attachments for the sprayer according to the intended use, and

7) inspections to be made on the sprayer, according to the rules of the pertinent EU Directives.

4. Sprayers innovation perspectives

In the evaluation of sprayer innovation perspectives it is important to distinguish between developed and developing countries.

4.1 Developed countries (with special regard to EU countries)

The evolution of plant protection equipment to match the requirements claimed by the new EU legislative outline can be focussed on different technical aspects related to sprayers. They can be divided according to the target, i.e. point source prevention, diffuse source prevention, and reduction of PPP use.

4.1.1 Point source prevention

Regarding the limitation of point source pollution, improvements can be expected about the sprayers filling and cleaning systems. A large scale adoption of induction hoppers, particularly, also the type not permanently attached to the sprayer, would make it possible to considerably limit the risks of the operator exposure as well as environmental contamination when preparing the PPP spray mixture and introducing it into the main tank. The development of self-standing induction hoppers, working reliably even when fed with tap water (**Fig. 8**), could also help the utilisation of such devices on air-assisted sprayers. At present, those sprayers usually are not fitted with such device, mainly due to the overall dimension limitations. Other devices to prevent tank overfilling and consequent risk of point source contamination (**Fig. 9**) are represented by programmable flow meters (**Fig. 10**). These devices allow setting up the exact water volume for filling the main tank and to automatically stop the filling when the intended volume is reached. They also enable the operator to know the exact amount of water poured in the main tank; therefore, make it possible to more precisely calibrate the sprayer and reduce the leftover spray mixture at the end of the application. Further improvements to facilitate the sprayer filling procedure are realised by the development of smaller PPP containers, which are easily manageable and washable when emptied, and are fitted with safe opening and closing systems that could prevent unintended pouring of the content. An alternative concept for introducing chemicals into the sprayer main tank is the adoption of PPP closed transfer systems (**Fig. 11**). Such systems provide direct suction of the pesticide from its container that could be refilled several times, limiting the problem of empty PPP plastic container disposal. This solution, which is more popular in the US, is not generally adopted in Europe.

Concerning cleaning of sprayers, a few international standards are already available to assess the efficiency of equipment that are designed for internal and external cleaning of sprayers (ISO 22368 Pats 1, 2 and 3). The internal cleaning is normally carried out by feeding the pump, the hydraulic circuit, and the tank rinsing nozzles with the clean water contained in an auxiliary rinse water tank (**Fig. 12**), while the external cleaning is usually made by means of spray lances (**Fig. 13**). Actually, in some European countries some cleaning efficiency thresholds have already been established to guarantee that the diluted spray mixture remaining in the sprayer at the end of the cleaning procedure could be disposed in the field without the risk of environmental contamination. In France, for instance, it is required to guarantee a 100 times dilution ratio of the original mixture. In Denmark, it is required to reduce the PPP concentration in the final residue to less than 2% of the original PPP concentration in the spray mixture.

An important basic element is to reduce, as far as possible, the amount of the remaining spray mixture that can not be applied through the nozzles. This parameter depends either on the technical features of the sprayer (e.g. shape of the main tank and design of the hydraulic circuit) or on the ability of the operator to conclude the treatment without any spray mixture left in the tank. This latter aspect relates to the ability of the operator to precisely know the amount of spray applied per unit area and to prepare the required tank mix accordingly. Therefore, it depends on the presence of sprayer peripherals (such as precise tank content indicators, computers to calculate the actual application rate, etc., **Fig. 14**) to enable the farmer to reach the goal of concluding the spray application with the tank as much empty as possible. Then, there is the necessity to provide the machines with efficient cleaning systems that are able to remove most of PPP residues still present after the treatment on the internal and external parts of the sprayer. Several recent studies [10; 11] have aimed at assessing the most useful procedures to maximise the cleaning efficiency of sprayers using the limited amount of clean water that is available in the rinse water tank. Results generally agree that dividing the use of clean water in several portions can significantly improve the internal cleaning of sprayers and that the use of systems enabling to provide a continuous flux of clean water in the hydraulic circuit may help in saving time and water to obtain good cleaning results. Now the main problem to face is to provide these cleaning systems with automatic functions, to facilitate their operation for the user. Generally most users are not inclined to spend time in opening and closing valves several times to carry out the correct cleaning procedure. Some examples in this sense were already proposed in recent years, as the “Autowash” programme available on the Hardi Commander sprayer (**Fig. 15**). Improvements should also extend to the efficiency of tank rinsing nozzles, which could be better designed and disposed in the main tank in order to obtain a more accurate cleaning of tank walls.

4.1.2 Diffuse source prevention

The most recent developments aimed at preventing PPP diffuse sources include the adoption of new types of air-induction nozzles, working properly at low pressures, to limit the production of droplets under 100 μm size (**Fig. 16**), and the installation of sensors, GPS, and other electronic systems on sprayers. On the basis of the information received by the sensors (**Fig. 17**), real time systems are able to immediately adapt the spray distribution parameters to the presence of the target and to its characteristics, adjusting the volume rate according to the size and density of the canopy, and activating the nozzles only when necessary. This could lead to a drastic reduction of spray losses, either on the ground (run-off) or in the atmosphere (drift). Sensors can also be useful to keep constant boom height on field crop sprayers; therefore, guaranteeing the correct PPP dose applied over the whole treated area and limiting drift risks (**Fig. 18**). Also in using air-assisted sprayers for arboreal crops, the possibility to close the air outlet on the outer side of the sprayer (**Fig. 19**) is useful to limit spray drift when the outer row of the vineyard/orchard is treated.

For several years, the German Federal Biological Research Centre (actually the Julius Kuhn Institute) has listed the plant protection equipment for arable crops that have proven to reduce drift by at least 50, 75 or 90% as “loss-reducing equipment”. Based on this drift classification, the adjusted implement-related minimum distances to surface water resources are listed when plant protection products are approved. This provides the farmer with more flexibility and more leeway for decisions than before. Several authors are actually working on the drift classification of plant protection implements/parts (nozzles) and have already published their results in this field [12; 13; 14; 15]. Meanwhile several EU member states (e.g. Germany, the Netherlands, and the United Kingdom) have introduced official regulations regarding sprayer drift classification and the adjustability of buffer zones for the application of plant protection products [13].

4.1.3 Reduction of PPP use

The GPS and GIS are useful in mapping the fields to be treated and to spray variable application rates according to the characteristics of the target. Mapping systems are especially used for weed control, enabling to identify the areas of the fields where infestations are more present and allowing to vary the spray volume and/or the PPP dose rate in a site-specific way (**Fig. 20**). The use of sensors (e.g. optical or IR) allows to detect in real time the presence and the density of weeds and information acquired can immediately be used to manage the spray application [16; 17]. This can be achieved by switching on/off individual nozzles or boom segments, increasing/decreasing the operating pressure, and adjusting the PPP dose rate in real time when injection system are available (**Fig. 21**). For instance, significant progress in on-line image processing has been achieved, which allows real time site specific spraying [18]. Crops and weeds can be differentiated using gene-technologically marked crop proteins which can be detected optically when excited by light. This enables weeding, fertilising, or harvesting actions to be carried out and controlled very precisely [19]. In spray applications, the use of “green” sensors in not merely limited to gap detection. Current developments also integrate the foliage intensity/density information into the control decision of the PPP mixture application rate [20]. In plant cultivation, attempts are also being made to carry out mechanical weed control only when the weed content exceeds the damage threshold or to adapt the intensity of the tool usage to the changing of soil conditions, as it happens during overall harrowing. [21]. In maize and beet cultivation, opto-electronic sensors for plant detection also open up new perspectives for mechanical weed control with implements featuring large working widths and high area capacity.

An example of application of Information Technology (IT) on sprayers for arboreal crops to significantly reduce the amount of PPP applied and at the same time to limit the environmental damage is the Crop Adapted Spray Application (CASA) prototype [22; 23]. That prototype has been developed within the ambit of the European Research Project ISAFRUIT as shown in **Figure 22**. It is an orchard air-assisted sprayer that is designed to be equipped with three systems (CHS, CIS and EDAS) connected through a CAN bus line to a unique control panel (**Fig. 23**). The Crop Health Sensor (CHS) is an optical sensor able to detect the presence of a disease at early stage (even just after few hours from the infection) in the canopy by analysing the reflectance spectrum of the light directed towards the leaves. Since the reflectance spectrum differs according to the health status of the leaf (**Fig. 24**), it is possible to use this information to adapt the spraying parameters conveniently. The CIS (Crop Identification System) is based on ultrasonic sensors that are placed on both sides of the sprayers at different heights. They have the task to recognise the presence of the target in front of the sprayer and provide information about the size and density of the canopy (**Fig. 25**). The data collected are processed by the central unit to generate a command to activate the nozzles only where the target is present and to adjust nozzle flow rate (based on the number of active nozzles and operating pressure) according to the size and density of the canopy. This system can allow to considerably reduce the application rate volume, especially in the early growth stages (**Fig. 26**). The Environmentally Dependent Application System (EDAS) consists of a GPS antenna and an anemometer. They provide information, respectively, about the position of the sprayer in the orchard and the wind conditions at the time of spray application. Information acquired are used to automatically select conventional or anti-drift nozzles (e.g. when the sprayer passes in the outer rows or close to a buffer zone), to stop spraying at U turns and in the sensitive areas, and to manage the air flow rate (both in terms of total amount and of partition between left and right side of the sprayer) according to the position of the sprayer in the field and according to the wind speed and direction during the spray application (**Fig. 27**).

Use of sensors (optical, infrared, ultrasonic) to detect the presence of the target is applicable to both field crop and air-assisted arboreal crop sprayers. It is a way to optimise the application of pesticides; therefore, limiting the amount of chemicals used. On arboreal crops there is also the possibility of using other systems, like tunnels or recovering shields (**Fig. 28**), to limit the dispersion of the spray beyond the treated row that can be drifted away by wind or can be deposited on the ground. These techniques enable the user to recover part of the spray mixture applied; however, they introduce some limitations in the size and manoeuvrability of the equipment. This makes tunnel sprayers usable mainly in flat areas where the plants are not too tall and no hail nets are present. In Germany, the Julius Kuhn Institute has listed the plant protection equipment that are able to reduce the amount of PPP applied due to the adoption of devices, systems, or apparatus to save spray mixture compared to the conventional sprayers.

4.1.4 Improvement of operator safety during pesticide application

Hazards for operators when preparing and loading undiluted PPP into a sprayer are a particular concern. Induction hoppers are very important components of sprayers as they allow to safely transfer the chemicals to the sprayer main tank. It should be mentioned that in California, USA, the number of pesticide related illnesses among mixer/loader workers decreased by 50% after the introduction of PPP closed transfer systems.

During the spray application in the field the operator is exposed to less concentrated PPP mixtures, but the exposure time is longer; therefore, the presence of the tractor cab, fitted with air filtering systems, has been recommended. The benefit in the use of the tractor cab is not only limited to minimise operators respiratory exposure. It also could minimise dermal exposure to pesticides.

Improvements are especially needed in the design of hand held sprayers widely used in developing countries, where often the protective clothings are not used because they are too expensive. ISO standard (ISO 19932) outlines minimum technical and safety requirements for such equipment.

4.1.5 Pesticide application in greenhouses

Greenhouse area in the Mediterranean region exceeds 350000 hectares [24]. Only about 20% is characterised by the presence of glazing and air cooling/air heating systems. Glasshouse crops are usually closely spaced for the maximum productivity and are present in varying stages of maturity. This presents a widely different array of foliage and flower types and crop canopies, each with a particular group of diseases and pests that will likely require pesticide treatments at one time or another. The problems to face when applying pesticides in greenhouses are even more important with respect to those related to open field treatments for the following reasons:

1) the extension of the growing season associated with high temperature and humidity levels are favourable conditions for the development of pests and diseases, implying the necessity to operate a high number of spray applications per year, and
2) the wide range of crop types and shapes, including potted and bedded growing, makes it impossible to design a “universal” sprayer type suitable for all protected crop conditions.

A rough classification of sprayers used on protected crops may be carried out according to the volumes applied, considering equipment for high and very high volume applications (800 to 6000 l/ha) and equipment for low volume applications (10 to 40 l/ha). In the first case, the VMD of the droplets produced is generally over 100 µm, while for the ultra low volume equipment it is around 20 µm.

Especially in ornamental plants that need almost total disease suppression, there is a high number of spray applications, up to 50/60 per year in roses [25]. The use of traditional equipment and volumes between 2000 and 6000 l/ha causes product losses (on the ground, on the paths, or on the benches) which can exceed 80% of the sprayed product [26] with the consequent pollution of the environment. On the other hand, the use of low volume equipment that is normally characterised by the production of very fine droplets, can lead to undesirable product losses in air (evaporation of the drops with the consequent suspension of the chemical product) or to crop damage (burn) if it is not accompanied by the presence of suitable infrastructure (perfectly sealed greenhouse, ventilation and air circulation system, etc.) and by well prepared personnel.

Very high volume (up to 10000 l/ha) spraying still is the most common technique for pesticide application in glasshouses, using equipment and methods that have changed little over years. Most of the spraying equipment for high volume spraying are carried manually through the crop rows even if a motorised pump is centrally located or mounted on a trolley with long hoses (up to 600 m in length) to a lance with one or more nozzles. Such spraying systems, with a high operating pressure (up to 3.0 MPa), are able to produce droplets featured by a VMD between 85 and 100 µm which would be unacceptable outdoors due to drift concern, but are useful in glasshouses. Apart from being labour-intensive, the uniformity of distribution is very poor and depends on the skill of the operator. Therefore the risk of environmental damages due to pesticide run-off is high.

The use of lower volumes (between 1000 and 2000 l/ha) and longer lances with flat fan nozzles instead of hollow cone ones enhances the uniformity of distribution on the target and reduces ground losses [25]. That is an objective to accomplish in the coming years.

In German Julius Kuhn Institute, a sprayer called "Applimate" has been developed for use in glasshouses with row crops [27]. The sprayer consists of a mobile docking unit and a satellite sprayer vehicle fed with energy and spray liquid from a nursing station. The unit with the parked satellite station is moved by an electric pallet lift truck to the glasshouse where it moves automatically from row to row, on a rail system.

Recently in Italy, a prototype of robot has been built that is designed to perform all the operations in greenhouse, including pesticide application [28]. The robot is composed of a mechanical pantograph structure that allows longitudinal and orthogonal movements, plus a rotating arm, and a vertical prismatic joint (**Fig. 29**). These allow, changing the connected tools, to perform a large number of operations during the growth cycle of cultivation, and to perform different operations during the year.

Another fully automatic sprayer prototype has been developed by Unigreen company in collaboration with DEIAFA – University of Torino in 2009 (**Fig. 30**). It is a sprayer mounted on an electric powered trailer that can be operated with a remote control. The distribution is made through two vertical booms, adjustable in height according to the crop size. The sprayer is also equipped with a small fan and a plastic air duct which facilitates the penetration of spray droplets into the canopy. Because of the remote control, the farmer can operate the sprayer from outside the greenhouse, far away from the spray cloud; therefore, PPP contamination risk for the operator is reduced. It is necessary to underline that using the traditional hand held spray lances, the amount of PPP that reach the operator body could be up to 3.5 kg in one year of spray applications [29].

4.2 Developing countries

In the developing countries like China, the pesticide application efficiency is generally low, thus, PPP wastage and losses are more serious. Volume application rates are quite similar to those applied in developed countries but PPP mixture leftover volumes are ten times larger. The reason is that the pesticide application efficiency is less than 30% and spray losses could range from 60% to 70% of the applied volumes [30].

Due to the globalisation process, for instance entering in WTO rules system, developing countries are now facing the need to promote the development of plant protection machinery in order to improve the quality of spray application and to reduce the environmental risks related to PPP dispersal and specific action plans are set up to encourage this process.

In China, for instance, crop protection machinery are now considered as special agricultural machinery. As such, they have to be certified compulsorily, in order to get a “CCC” mark. This means product quality, manufacturer advisement and market access certifications. Crop protection machinery are then supervised and sampled randomly on the market to verify their compliance with these requirements. As most of spray application equipment, especially in the small farms, are still hand-held and often manually operated equipment, development plans to spread motorised equipment are promoted although the number of larger boom sprayers has been increasing every year. The same devices used in the developed countries to prevent drift are then being introduced (e.g. air induction nozzles, air sleeves on boom sprayer, electronic sensors, IT applications, etc.). Precision agriculture is therefore coming to the developing countries, sometimes with local independent developments (e.g. in China) targeted to the specific needs of an agricultural situation that is rapidly changing.

5. Conclusion

Due the growing attention related to the environmental aspects and with the enforcement of new EU Directive on the Sustainable Use of Pesticides, it is expected that, in the near future, spray application techniques will receive an important input to improve, in order to satisfy the more severe requirements that are foreseen, especially concerning the prevention of environmental contamination with pesticides. This will involve marketing of sprayers and spraying equipment components.

Especially the regular inspection of sprayers in use will provide a stimulus to change the most obsolete sprayers, that are likely not to pass the inspection, and to repair the sprayer components that are not functional or efficient. In this sense, considering that in the European Union there are over 2 million sprayers that, according to the new EU Directive, need to be inspected at least once by 2016 and an average inspection failure of 1.5%, it is estimated that about 30000 old sprayers will need to be replaced with new ones. That means a new potential sprayer market that amounts to about 250 millions Euro (+33% of the present yearly market value). Concerning the components, on the basis of the actually available results of sprayers inspections activity carried out in some EU countries (Belgium, Germany, Italy), it is possible to estimate that about 35% of sprayers inspected will have to change their manometer, 20% the pressure regulation system, 15% the nozzles, 5% the filters, 5% the antidrip devices, 5% the pump membranes, and 2% the pump. It means that in the next seven years, about 6 million nozzles, 1 million pressure gauges, and 50000 sprayer pumps will need to be replaced, generating a new market for sprayer components of around 1 billion Euro.

In summary, due to the enforcement of the new EU Framework Directive on the Sustainable Use of Pesticides, it is expected to enhance the value of field crop and air-assisted sprayers market to about 1.3 billion Euro within the next seven years.

Current spraying equipment offer potential for improvements. Beside hi-tech installations, low-tech devices can be found on the same sprayers. Overall risk mitigation capacities of a sprayer only can be realised if all relevant components fit together consistently. Intensive communication between the experts in various disciplines (Plant Protection Science/Application Techniques) is necessary to find best solutions and bring them to market. Advisers and operators need to be made more aware of relevant criteria which determine the "environmental friendliness" of the application equipment and use that information in selecting and recommending sprayers. Crop protection should be considered as a process including the application techniques of PPPs as a main element. Mitigation measures should be optimised along the whole process chain because it could be more efficient and economical. Such approaches could help to reduce inconsistencies in the areas of technical offers, advice, and regulations. Techniques and infrastructures are also key elements in risk mitigation but the most important factor might be the correct behaviour of the operator.

References

[1] **Jourdier A.**, 1859. Le materiel agricole, Editions Hachette, Paris, p. 220.

[2] **Passelegue G.**, 1930. Enciclopedie des Connaissance Agricoles – Les Machines agricoles. Librairie Hachette, Paris.

[3] **Ballu** , 1933. Encyclopedie industrielle. J.-B. Bailliere – Machines Agricoles, Paris.

[4] **Balsari P.**, 2003.. Evoluzione dei mezzi di difesa fitosanitaria. La meccanizzazione – I Georgofili, Firenze, 305-330.

[5] **Bach M., Röpke B., Frede H-G.**, 2005. Pesticides in rivers – Assessment of source apportionment in the pesticides in rivers – Assessment of source apportionment in the context of WFD; European Water Management Online, Official Publication of the European Water Association (EWA).

[6] **Mason P.J., Foster I.D.L., Carter A.D., Walker S., Higginbotham S., Jones R.L., Hardy I.A.J.**, 1999. Relative importance of point source contamination of surface waters: River Cherwell catchment monitoring study. Proceedings of XI Symposium on Pesticide Chemistry, Cremona, Italy, 405-412.

[7] **Müller K., Bach M., Hartmann H., Spiteller M., Frede H.G.**, 2002. Point and non-point source pesticide contamination in the Zwester Ohm Catchment (Germany). Journal of Environmental Quality, **31**(1), 309-318.

[8] **Seel P., Knepper T.P., Gabriel S., Weber A., Haberer K.**, 1996. Kläranlagen als Haupteintragspfad von Pflanzenschutzmitteln in ein Fließgewässer – Bilanzierung der Einträge. Vom Wasser, **86**, 247-262.

[9] **Frahm J.**, 2007. Innovationen bei Pflanzenschutzmitteln, Wirkstoffen und in der Pflanzenschutztechnik. Tagungsband Dachverb, Agrarforschung, Frankfurt.

[10] **Balsari P., Marucco P., Nilsson E., Wehmann H. J., Ganzelmeier H.**, 2008. Assessment of the efficiency of systems and procedures for the internal cleaning of sprayers. Aspects of Applied Biology, **84**, 209-216.

[11] **Hoenderken, J.; Zevenbergen, G.**, 2009. Washing programmes of sprayers do their work correctly. Landbouwmechanisatie 2009, **60** (5), 12-14.

[12] **Ganzelmeier H.**, 2000. Drift, drift reducing sprayers and sprayer testing. Aspects of Applied Biology, **57**, 1-10.

[13] **Van de Zande J.C., Porskamp H.A.J., Michielsen J.M., Holterman H.J., Huijsmans J.F.**, 2000. Classification of spray applications for driftability, to protect surface water. Aspects of Applied Biology, **57**, 57-66.

[14] **Walklate P.J., Miller P.C.H.**, 2000. Drift classification of boom sprayers based on single nozzle measurements in a wind tunnel. Aspects of Applied Biology, **57**, 49-56.

[15] **Balsari P., Marucco P., Tamagnone M.**, 2007. A test bench for the classification of boom sprayers according to drift risk. Crop Protection, **26**, 1482-1489.

[16] **Miller P.C.H., Stafford J.V., Paice M.E.R.**, 1995. The patch spraying of herbicides in arable crops. Proceedings of Brighton Crop Protection Conference Weeds – BCPC, 1077-1086.

[17] **Balsari P.**, 1999. Le attuali tecnologie disponibili per l'agricoltura di precisione. Atti Convegno Nazionale AIIA "L'innovazione tecnologica per l'agricoltura di precisione e la qualità produttiva", Grugliasco 22-23 Giugno 1999, 3-22.

[18] **Sökefeld M., Gerhards R., Kübauch W.**, 2000. Teilschlags-spezifische Unkrautkontrolle – von der Unkrauterfassung bis zur Herbizidapplikation. Pflanzenkrankhschutz, **17**, 227-233.

[19] **Ganzelmeier H., Rautmann D., Zwerger P., Schiemann J.**, 1997. Verfahren zur optischen Detektion und Behandlung von Kulturpflanzen und nicht biologisch transformierte Kulturpflanze. Patentschrift, DE 196 42 439 C 1, Veröoffentlichung 20.11.1997.

[20] **Rosell J. R., Nogues A., Planas S.**, 1996. Development of an electronic selective orchard spraying system based on the control of the applied flow rate. AgEng paper 1996, Madrid.

[21] **Engelke B.**, 2000. Zur Regulierung von Geräten in der ganzflächigen mechanischen Unkrautbekämpfung. Landtechnik, **55** (2), 146-147.

[22] **Balsari P., Doruchowski G., Marucco P., Tamagnone M., Van de Zande J., Wenneker M.**, 2008. A System for Adjusting the Spray Application to the Target Characteristics. Agricultural Engineering International: the CIGR Ejournal. Manuscript ALNARP 08 002 Vol. X. May, 2008.

[23] **Godyn A., Holownicki R., Doruchowski G., Swiechowski W.**, 2008. Dual-fan Orchard Sprayer with Reversed Air-stream – Preliminary Trials. Agricultural Engineering International: the CIGR Ejournal. Manuscript ALNARP 08 007. Vol. X. May, 2008.

[24] **Castilla N., Hernandez J.,** 1995. Protected cultivation in the Mediterranean area. Plasticulture, **107**, 13-20.

[25] **Balsari P., Oggero G.**, 2001. Evaluation of human exposure of pesticides during spray application in greenhouse. Proceedings of AIIA International Workshop "Greenhouse design and crop engineering", Vieste (Italy), 11-14 September 2001.

[26] **Giles D. K., Blewett T. C., Saiz S., Welch A., Krieger R.**, 1992. Foliar and non-target deposition from conventional and reduced-volume pesticide application in greenhouses. International Conference on Agricultural Engineering, paper n° 9211-14.

[27] **Wygoda H. J., Rietz S., Shäfertöns J. H.**, 2000. Neue Applikationstechnik in Gewächshaus-Reihenkulturen. 52 Deutsche Pflanzenschutztagung in Freising-Weihenstephan, 9-12 Oktober

2000. Mitteilungen aus der Biologischen Bundesanstalt für Land und Forstwirtschaft, **376**, 414-415.

[28] **Belforte G., Deboli R., Gay P., Giglio A.**, 2003. Design and experimentation of robots for structured greenhouses. Proceedings of XXX CIOSTA Conference 2003, 279-287.

[29] **Balsari P., Oggero G.**, 2002. La sicurezza nell'impiego di prodotti fitoiatrici con irroratrici portate dall'operatore. Proceedings of national congress AIIA "La sicurezza delle macchine agricole e degli impianti agro-industriali", 57-63.

[30] **He Xiungkui**, 2010. The opportunity and challenge of pesticide application of agriculture and horticulture in China. Aspects of Applied Biology "International Advances in Pesticide Application 2010", in press.

Figure 1 - Advertising sheet of a knapsack sprayer for vineyards used in Italy in the XIX century.

Figure 2 - Example of spray lance equipped with a manual piston pump used in the second half of XIX century.

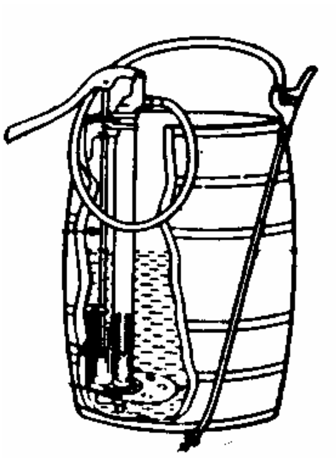

Figure 3 - Example of animals trailed motorised pump sprayer used in the 1920's.

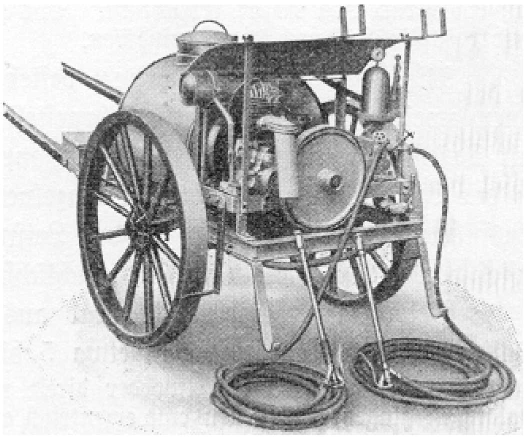

Figure 4 - Example of boom sprayer used in the 1960's. *Source: [www.senesac.com]*

Figure 5 - Scheme of the phases of the PPP management dealing with point sources water contamination. *Source: [TOPPS]*

Figure 6 - Scheme of the PPP dissipation paths occurring during pesticide application and of the phenomena that may lead to diffuse sources water contamination.

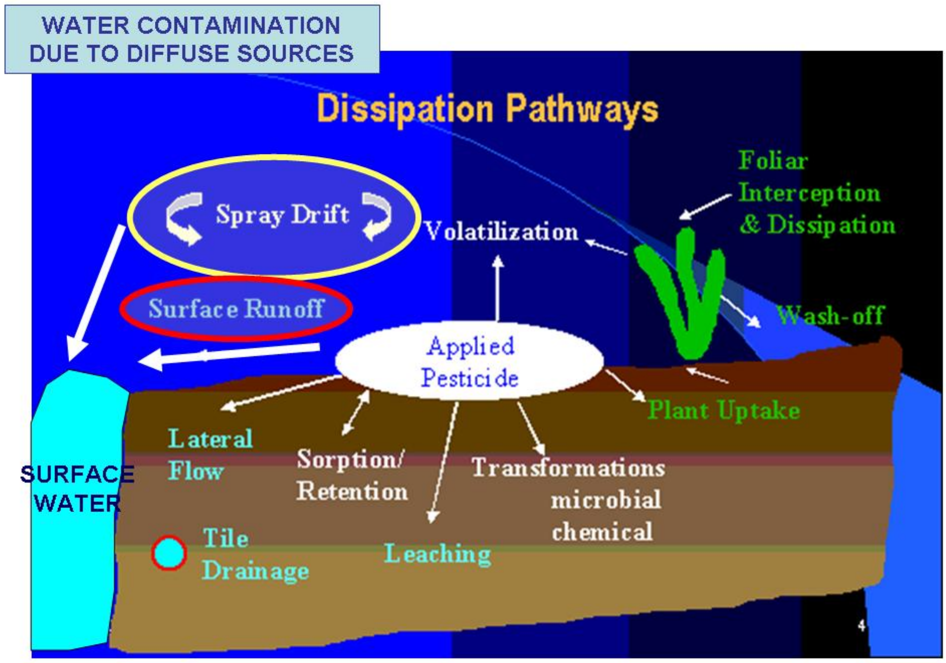

Figure 7 - Scheme of the EU legislative outline concerning pesticides.

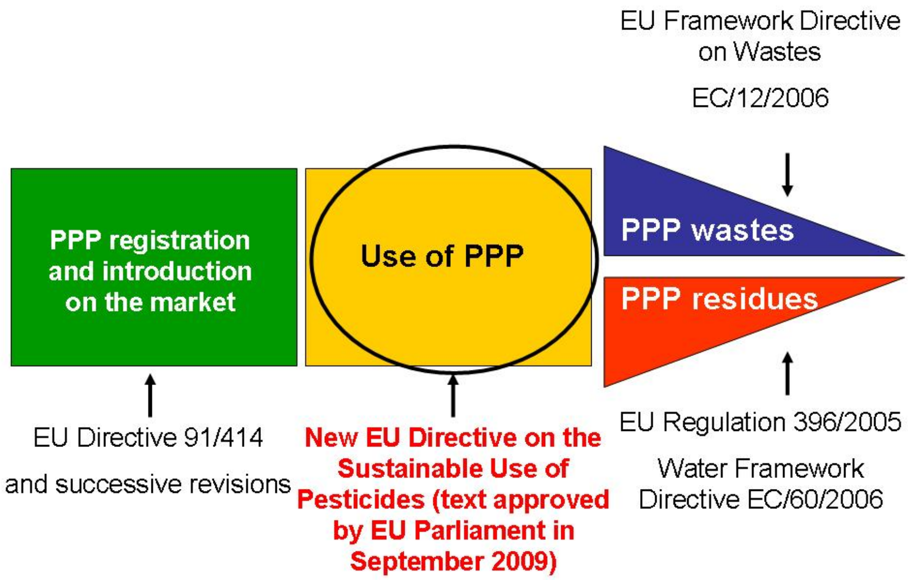

Figure 8 - Scheme of induction hoppers: independent from the sprayer and fed with tap water (on the left side) and attached to the machine (on the right side).

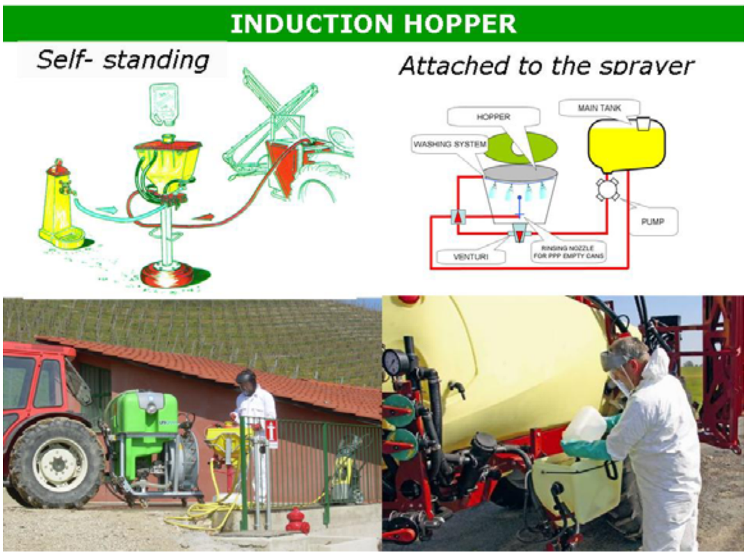

Figure 9 - Example of tank overfilling and consequent generation of point source phenomena.

Figure 10 - Programmable and automatic flow meter to be used for sprayers filling. *Source: [Polmac srl]*

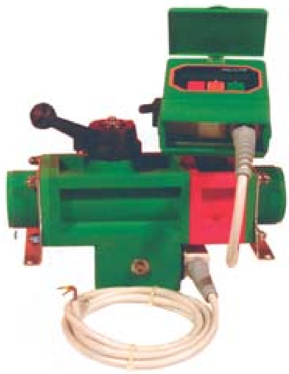

Figure 11 - Example of a PPP closed transfer system to introduce chemicals in the sprayer main tank.

Figure 12 - Scheme of a sprayer internal cleaning procedure: A) the pump sucks clean water from the auxiliary rinse water tank and feeds the tank rinsing nozzle, that washes the tank walls ad dilutes the PPP mixture residue in the tank; B) the diluted mixture is sprayed out through the nozzles; C) a further rinsing of the circuit, including back flow line, is made and the further diluted PPP spray mixture present in the tank is spayed out through the nozzles; D) a final rinsing of the circuit is carried out an the sprayer cleaning is completed; some clean water is saved to make external cleaning.

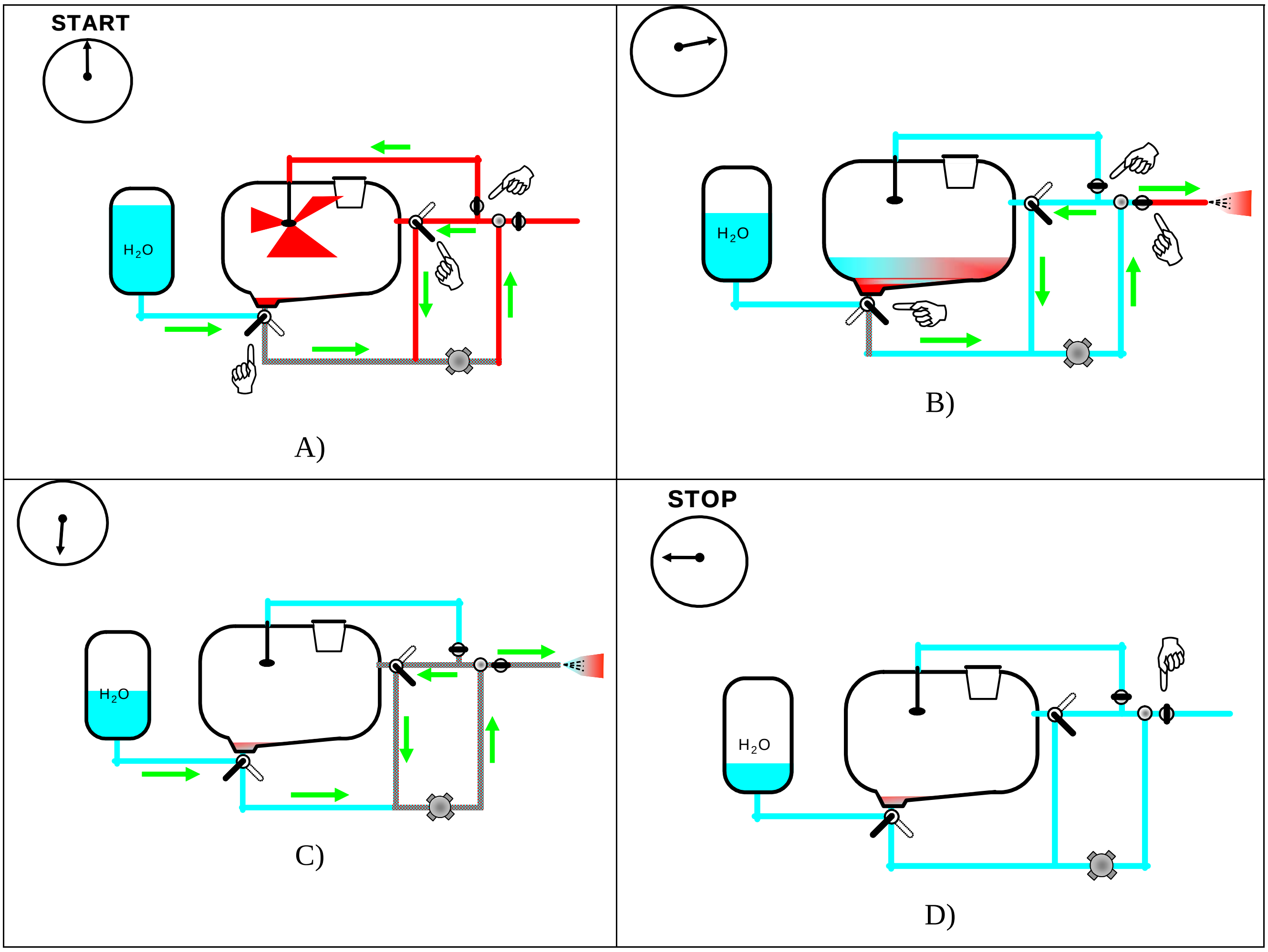

Figure 13 - Example of external cleaning of sprayer carried out using a spray lance. *Source: [TOPPS]*.

Figure 14 - Example of computer panel to check the actual applied volume. *Source: [Berthoud]*.

Figure 15 - Hardi Commander boom sprayer control panel equipped with the "Autowash" function enabling to manage automatically the complete internal sprayer cleaning.

Figure 16 - Example of new air induction flat fan nozzle (Teejet AIXR03) featured by a reduced production of very small droplets (the percentage of droplets < 200µm size is less than 1%; D10 = 290µm; D50 = 567µm; D90 = 842µm, operating at 3 bar pressure).

Figure 17 - Example of IR sensor used to detect the presence of weeds and to manage the spray application according to the infestation level detected.

Figure 18 - Example of optical sensor mounted on a boom sprayer to keep constant the working height.

Figure 19 - Example of closing system of the air outlet on one side of an air-assisted sprayer.

Figure 20 - Scheme of the components of a spraying system for patch weed control through the use of optical sensors.

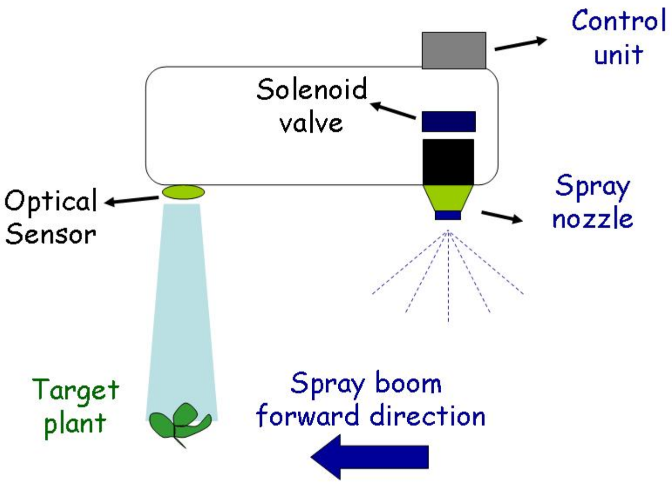

Figure 21 - Scheme of the components of a spraying system for site specific weed control through the use of geo referenced maps.

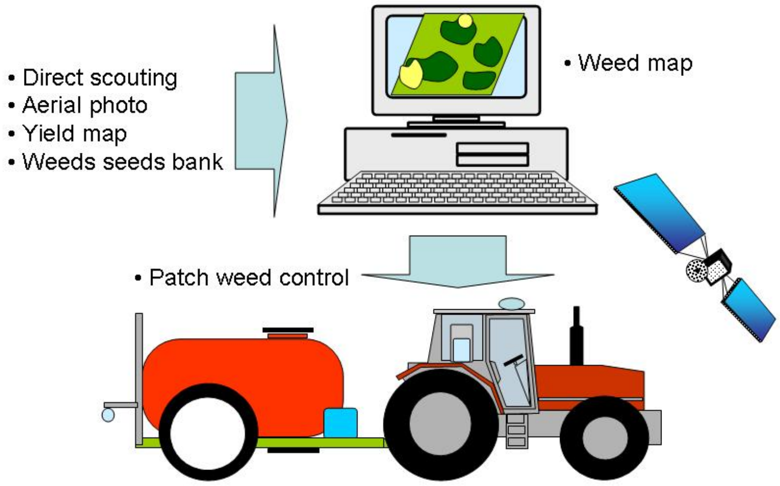

Figure 22 - CASA sprayer prototype realised in the ambit of ISAFRUIT European Project.

Figure 23 - Concept of the ISAFRUIT Crop Adapted Spray Application (CASA) system.

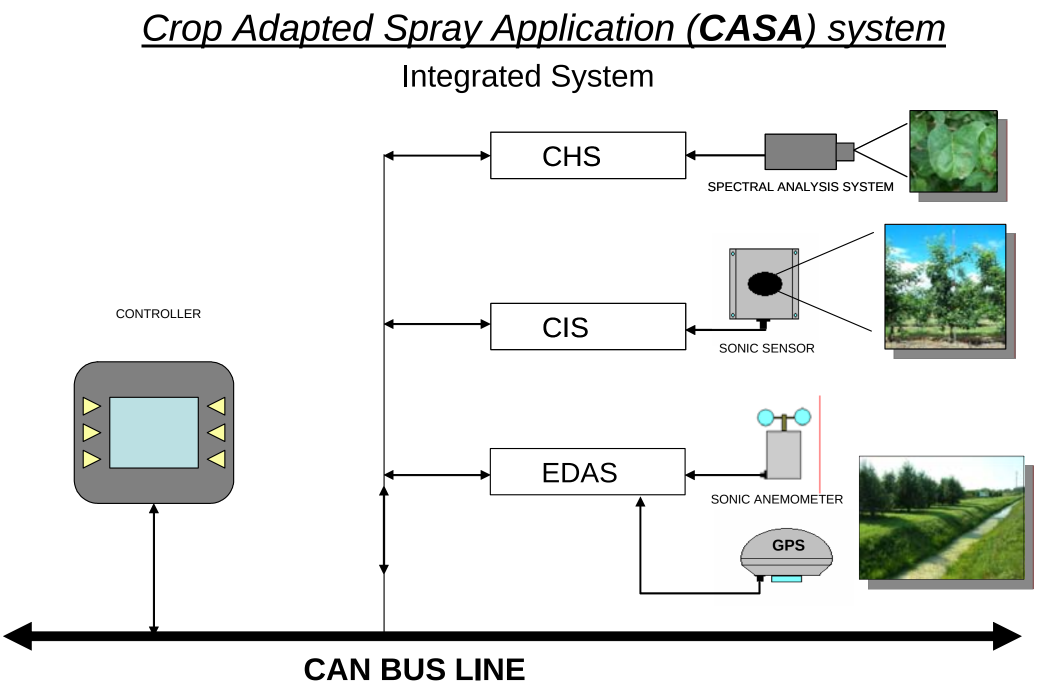

Figure 24 - Crop Health Sensor (CHS): the light reflectance spectrums obtained from a healthy and from an infected apple leaf present typical differences at certain wavelengths which enable to assess the health status through an optical sensor.

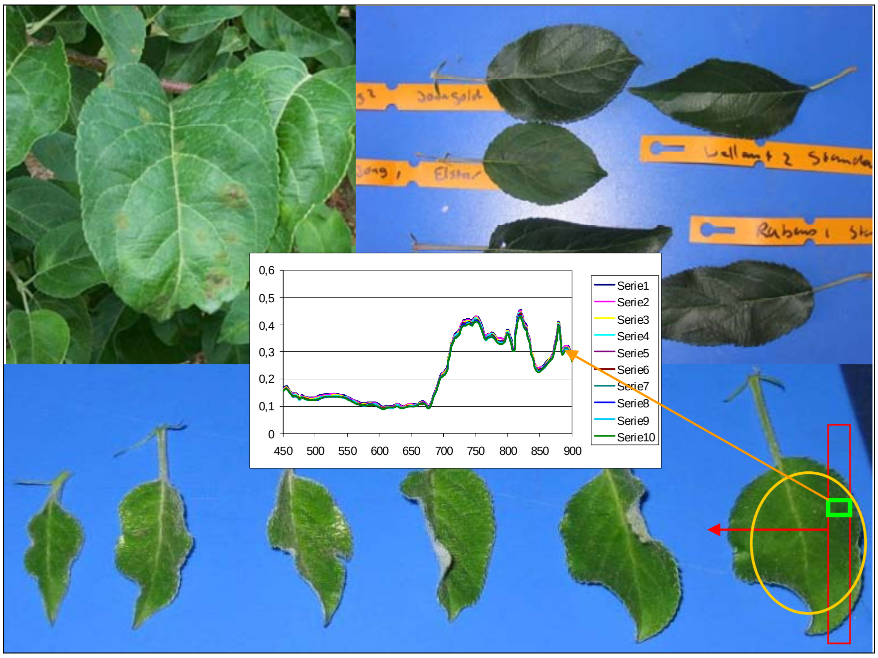

Figure 25 - Crop Identification System (CIS): the ultrasonic sensors positioned at three different heights have the task to detect the presence of the target in front of the sprayer and to provide information about canopy size and density.

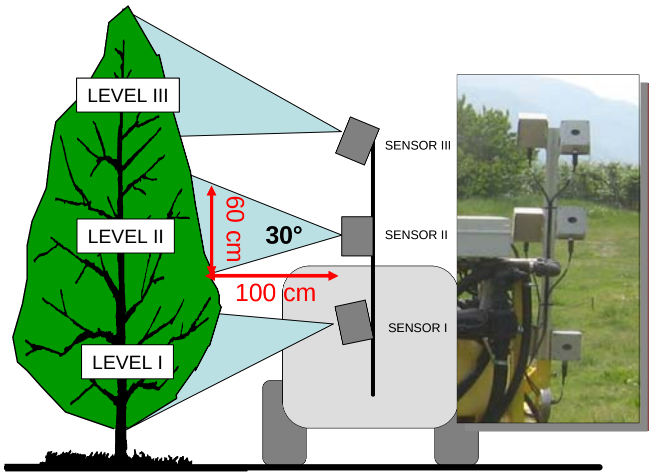

Figure 26 - Trend of volume application rates registered in three different orchards along the season employing the CIS sprayer and comparison with the conventional volume application rate of 850 l/ha. Using CIS PPP savings can reach 80%, assuming to operate at constant PPP concentration.

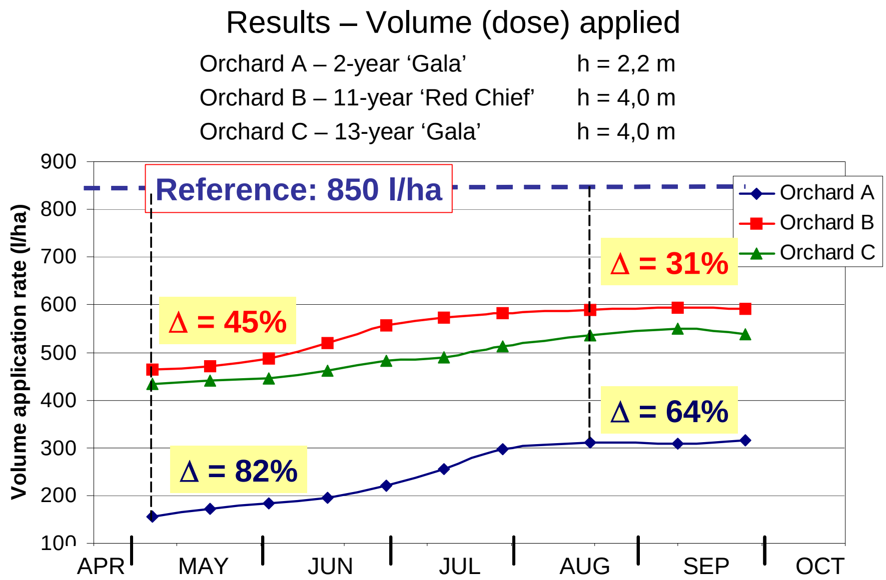

Figure 27 - Scheme of functioning of the EDAS system: according to the position of the sprayer in the orchard and to the wind conditions, conventional or anti-drift nozzles are automatically activated and air repartition between left and right side of the machine is conveniently managed to prevent spray drift.

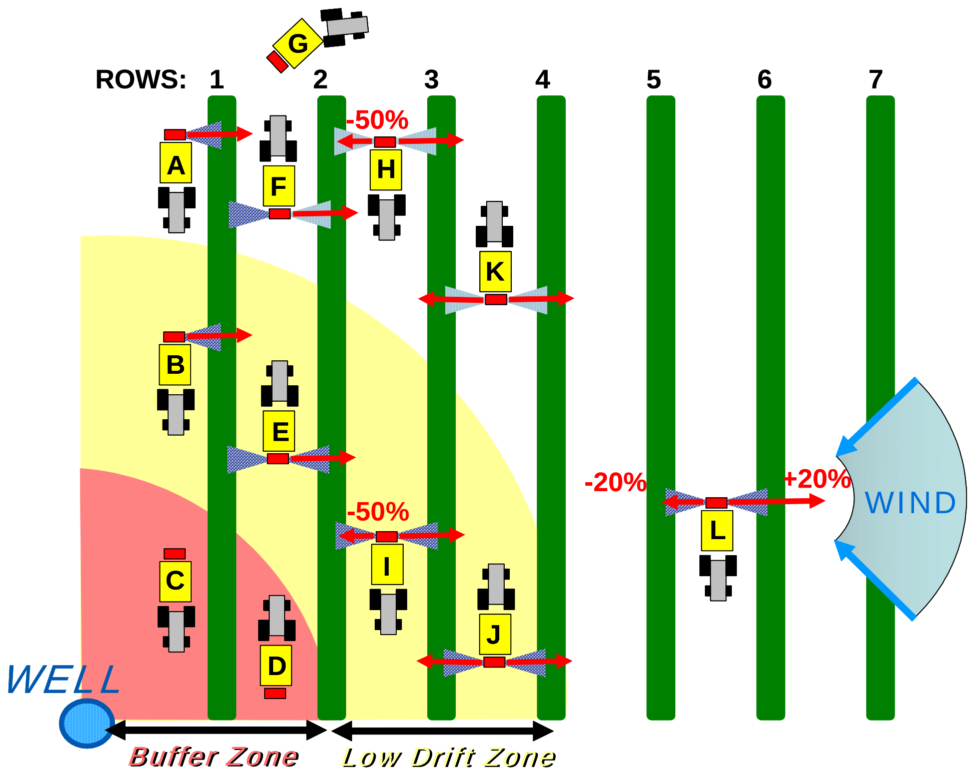

Figure 28 - Example of tunnel air-assisted sprayer used in vineyards and orchards.

Figure 29 - Prototype of robot for all operations in greenhouses developed at University of Torino.

Inserire foto robot Paolo Gay

Figure 30 - Prototype of automatic sprayer to be used in greenhouses developed at DEIAFA University of Torino.