RHEA AIRBLAST SPRAYER: DOSE CALIBRATION INDEXES RELATED TO CANOPY AND FOLIAGE CHARACTERISTICS

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Abstract. In recent years, the pest control treatments have become central stages of the agricultural production processes. The reasons are related to climate change, which are gradually varying the types of pathogens and parasites and their development trends, but also for the forthcoming rules imposed by Legislative Decree 150/2012 Italian transposition of Directive 2009/128/EC on sustainable use of agrochemicals. The sustainable use of PPP (Plant Protection Products) focus the designing of the EU FP7 RHEA Project (Robot fleets Highly for Effective Agriculture and forestry management). To this end, the research unit has designed and developed an innovative sprayer that allows a variable rate spraying. However, this technique requires studies to define the relationships between the characteristics of the target and the volume distributed. In fact, tree crops pesticide spraying three variables of GAP good agricultural practices need to be considered: the drops type, the unit dose, the air flow intensity. Based on these considerations, a study to assess the most appropriate dose in relation to the canopy features variation, was conducted. The tests were carried out in an experimental vineyard in central Italy (Arezzo) employing a tunnel sprayer in order to quantify the doses distributed/recovered during the green management stages. In so doing a geo-referenced measurement system for monitoring the level of mixture in the tank, made by ultrasonic sensor was built. The results showed percentages of recoverable doses from 17,8% to 30,6% during the green management. This study represents a first stage of the research, which is also focused on the assessment of the potential correlations between vigour (e.g. NDVI vigor index) and the required dose.

Keywords: environmental sustainability, precision viticulture, air-assisted sprayer; ultrasound, recovery spraying

1 Introduction

In last years, the pest control treatments have become main stages of the production process which have important consequences in order to obtain the product. The reasons are related to climate change, which is gradually varying the types of pathogens and pests and their development trends, but also for the forthcoming rules imposed by Legislative Decree 150/2012 Italian transposition of Directive 2009/128/EC on sustainable use of agrochemicals. A very complex and evolving framework that requires innovative management approaches i.e. the adoption of predictive models, the creation of monitoring networks for farms, the use of efficient

sprayers. In tree crops pesticide spraying, three variables of GAP Good Agricultural Practices need to be considered: the drops type, the unit dose, the air flow intensity.
In fact, in the viticulture's ordinary pest control steps it is estimated, an usual dispersion of 80% in the first treatments, 50% in those intermediates and around 30-20% in those in full canopy. Therefore, a proper implementation of pest control stages, cannot disregard to adjust the dose and the air flow, depending on the target characteristics and the phenological stage of the crop. One of the three RHEA's project (Robot fleets Highly for Effective Agriculture and forestry management NMP-CP-IP 245986-2 RHEA) objectives is related to the crop protection treatments. To this end, an innovative air blast sprayer coupled to the RHEA mobile ground unit, was developed. This equipment makes it possible a variable rate spraying on four separate horizontal bands, corresponding to four vertical zones of the canopy orchard. Variable rate spraying depends on certain variables: in vineyard is closely related to the phenological stage, while in olive growing it depends on the type and the age plant (traditional olive tree versus high and super high density olive trees), and by management practices. For which the right treatments management should provide a doses variation depending on the features of the target. Even the pesticide manufacturers, in recent years, have found that the dose has to be linked to the vegetable plant mass (i.e. leaf area, density, layers, leaves development stage, their shape, etc.). So they have defined for each crop (together with the concentration) the "normal dose" of mixture L ha^{-1} considering that it assumes the full canopy development, the ordinary atmospheric conditions, the usual losses, all this with a good safety factor. Therefore, the normal dose for the vineyard treatments is conventionally fixed in 1000 L ha^{-1} (10 hl), thus the concentration stated on the label must be multiplies by ten to obtain the phytoiatric effective quantity per hectare. However, 1000 L is an excessive volume in many contexts of production that results in a reduction of farms' efficiency due to an enhanced number of fills, high intervention times with a lower resulting controllable surfaces and higher costs. The timeliness increase, the controllable surface and the cost reduction may be obtained by reducing the dose. This is achievable by high pulverizations but this determines highly unstable drops at the temperature and to the aerodynamic drag, which evaporate quickly and are transported even by light breezes. The consequences are elevated dispersions and the phytoiatric effectiveness reduction. So with conventional air blast sprayer, in the first and intermediates treatments, where the vegetation is not totally developed, it needs to apply lower doses: in fact, it is estimated that in the first treatments there are average dispersions of 80%, 50% in those intermediate and 30-20% in full canopy (Ade *et al.*, 2005, Pergher *et al.*, 2009, Rimediotti *et al.*, 2011). To define the effective quantities sprayed on the target is necessary to employ tunnel sprayers that reduce the dispersions and recover the mixture otherwise lost. A further aspect of the research is the definition of systems that allow to perform a real-time canopy features monitoring in order to vary continuously the dose. In literature, there are some survey methods e.g. C.A.S. (Salgarollo et al., 2006), TRV Tree Row Volume (Sutton & Unrath, 1984), which however require multiple manual measurements of vegetative parameters. To this end, in this preliminary study the use of a foliar reflectance sensor (NDVI vigor index) as a potential solution to this objective, was evaluated.

2 Materials and methods

All field tests were performed in an experimental vineyard (cv: Sangiovese) in central Italy (Arezzo), trained to a horizontal spur-cordon (4-6 per spur), at 0.8 m height from the ground; planting distances were 2.65 m between the rows, and 0.9 m between the vines. The tests were conducted during the growing season (2013), however, the present work focuses on the analysis during the final seasonal stages and particularly in the run-up and subsequent to the green topping stages. A total of 15 rows, corresponding to an area of 3200 m^2, were monitored. The experimental methodology involved the use of a tunnel sprayer Bertoni Ltd. model L'Arcobaleno in order to quantify the doses distributed/recovered. It is made of two vertical interception shields with opposite concavity, supported by a portal frame, within which occurs the spraying, the mixture recovery[1] as well as the air flow generation. In the bottom part of these, there are two collectors connected to the mixture recirculation circuit of the main tank. The specific position of each shields is adjustable by an hydraulic system to better fit the canopy thickness and to improve work efficiency. Hydraulic actuators, managed by an electrical box, allows the shields closure. The air flow, realized with eight electrical fans, is designed to determine an air depression through the in vertical interceptors in order to collect the not retained mixture by the vegetation. The liquid flow is instead conveyed directly on the nozzle bars placed outside the air flow. This design determines an internal air circulation between the interception shields that optimizes the mixture distribution reducing the problems related to the wind presence and drift. The power consumption at the power take off of the entire equipment, including the pump of the sprayer, is about 11 kW and the empty mass is 800 Kg.
The tests were performed using seven nozzle per side, model Albuz ATR brown color, with the following settings:

Table 1. Operational parameters during trials.

	Operational Parameters
Nozzle serial number	Albuz ATR 75.1802.93
Colour	Brown
Pressure (bar)	8
Forward speed ($km \cdot h^{-1}$)	6
No. of active nozzles per side	7
Spray flow rate per nozzle ($L \cdot min^{-1}$)	0,60
Spray flow rate all nozzles ($L \cdot min^{-1}$)	8,4
Working width (m)	2,65
Reference application rate ($L \cdot ha^{-1}$)	266,7
PTO speed ($rev \cdot min^{-1}$)	540
Volumetric air flow rate ($m^3 \cdot h^{-1}$)	16000

2.1 Mixture monitoring system

In order to measure the actual doses, a measurement system was set up. It was made up of a double concentric plastic cylinder with external diameter of 100 mm and an internal of 50 mm included into a closure cap which replaces the original one. This was fixed on the bottom through a manual locking system and placed at the center of

[1] recovery: amount of mixture recovered by the sprayer

the tank. The latter, was characterized by a regular shape, similar to a cuboid (0,4 m W; 1 m ; 0,8 m H), and by a high agitation of the mixture. In order to make as linear as possible the level measurements, holes in the monitoring system, placed at right angles between them and with respect to the mixture flow inside the tank and near of the bottom side of the cap, to allow an easy air exchange, were made. Measurements were made with an ultrasonic sensor Banner mod. U-GAGE T30UXUA with an operating range of 10-100 mm located at the tip of the internal cylinder. The resulting values, expressed in mm, indicate the water column height variation compared to the initial one. These, through a serial link, were sent to an Arduino microcontroller. The latter, performed mediation in continuous of 500 values per second. Thus the final ones was sent to an acquisition, georeferencing and storage system made up of an on-board PC, equipped with a specific software (UNIFI SW), linked to a GPS receiver mod StarFire 3000 John Deere Company (precision accuracy SF2) with a sampling frequency of 0.1 m.

Fig. 1. Dose monitoring system

The canopy monitoring consisted of the Crop Circle™ ACS210 sensor by Holland Scientific. This sensor comprises eight ultrabright light-emitting diodes (LED's) that simultaneously emit light in both near infrared (650 nm) and red (880 nm) wavelength's, and a pair of photodetectors. Moreover, is equipped with its own active internal light source which to make measurements in all ambient light conditions. The device is pointed at canopy, the LED's are pulsed at a certain frequency and the photodetectors, measure the reflected signal of both LED's. The illumination footprint, in our sampling vineyard (inter-row 2,75 m), was approximately 0.3 m horizontal x 0.7 m vertical.

Fig. 2. on the left: Crop Circle™ ACS210 sensor mounted on the shield of the sprayer; right the on-board PC equipped with UNIFI software for data georeferencing and storing.

The tissues of plants invested by the beam absorb light in the visible portion of the spectrum (and reflect a small percentage from 2% to 10%) and reflect the light in the portion of Near Infrared (NIR variable from 35% to 60%) due to of the discontinuity in refractive indices between the walls of the cells and intercellular spaces of air. The interaction between the reflectance of the foliage in the portions of the spectrum of the visible and NIR can be exploited to non-invasively determine the status of plant biomass and other indices such as the PCD (plant cell density). When the light emitted by the sensor in the wavelengths of the visible and NIR enter the canopy, the portion not absorbed by the leaves is reflected towards the sensor itself. Data from the sensor were captured and georeferenced on the on-board PC equipped with the same software employed for doses monitoring trials. Reflectance data were collected at a sample output rate of 6 Hz (Holland Scientific, 2004).

2.2 The experimental arrangements

In order to properly configure the sprayer, a calibration to verify the real volume sprayed by adopting the standardized protocol, was made. Four trials respectively on June 12th and 27th , July 18th and August 2th were performed. In each one, 15 rows with a mixture of commercial formulations to control the grape downy mildew (Berk. et Curtis former. De Bary) and Uncinula necator (Schwein.) control, were sprayed. The sprayed-recovered doses quantification was conducted either with the measurement system set up either with manual measurements. The latter is gained by the difference between the initial dose, loaded accurately in the tank with graduated cylinders of 2 L up to the desired dose, and the final dose of the tank measured with the same tool. The doses measuring through the ultrasonic sensor, instead, were obtained by indirect method based on the millimetric height variation recorded by the system. Specifically, a preliminary sensor's calibration curve to correlate the registered height (mm) with the corresponding liters in the tank was made. Following the least squares method the straight line equation that regulates the decrease trend of the level tank was obtained. Then, this is used for the characterization of volume changes for each row. This allows to assess the real dose sprayed on the canopy. The effective sprayed doses were obtained by multiplying the flow rate to the nozzles for the actually spraying time needed to perform the row. The first is obtained by multiplying the nozzle flow rate to their number, while the timing by a real time monitoring (clockwise hh.mm.ss. Vs GPS position WGS84) through the acquisition system. Thus, for the difference between the effective sprayed doses and the value of the dose on target i.e. the volume decrease in the tank, the recovered mixture was defined. About the canopy characterization, manual measurements to the average LAI and volume (m^3) definition and via TRV method, were made. As regards the LAI assessment was used UTHSCSA Image Tool (UTHSCSA Image Tool, 2014) that uses the scanned images of leafs to automatically calculate the area. Moreover, in this work, we tryed to assess the Crop Circle response to canopy cross-sectional area, as measured from a combination of canopy height and width. To this end, a continuous monitoring of the canopy during spraying and manual measurements (average of the plot) for the development of the canopy were performed.

3 Results

The tests carried out provided information about the sprayed and retrieved doses by Bertoni's sprayer during the green management stages. Table 1 summarise the results in the four treatments.

Table 2. Doses Analisys

	management	sprayed[1] dose L	On target[2] Dose L	Recovered[3] Dose L	Recovered Dose %
06/12/2013	-	96,60	74,54	22,24	23
06/27/2013	topping	115,70	70,67	45,03	30,60
07/18/2013	-	112,20	96,21	15,99	14,20
08/02/2013	topping	102,50	84,15	18,33	18

[1] Sprayed dose: dose distributed on the 15 rows
[2] On target dose: dose actually distribued on the canopy
[3] Recovered dose: sprayed dose that not get to target and thus recovered from the sprayer

As showed in table 3, the reduction of the canopy volume due to the topping stage leads to an appreciable increase in the recovered dose see table 2. This trend is lower in the last stage of the growing season, as a result of the leaf layers increase. The final average value of recovered dose with bertoni's sprayer, was 21.45%.

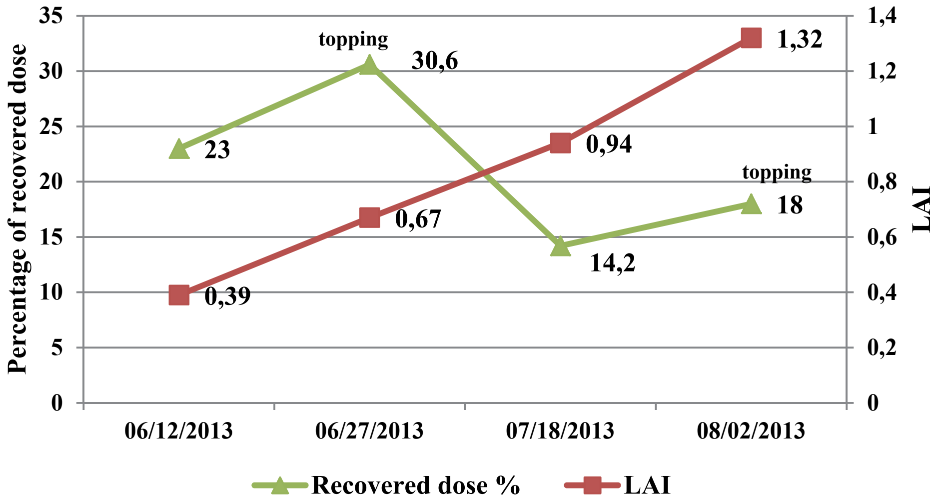


Fig.3. Chart of LAI evolution and its relationship with the recovered dose during the green management stages.

Table 3. evolution of the canopy development

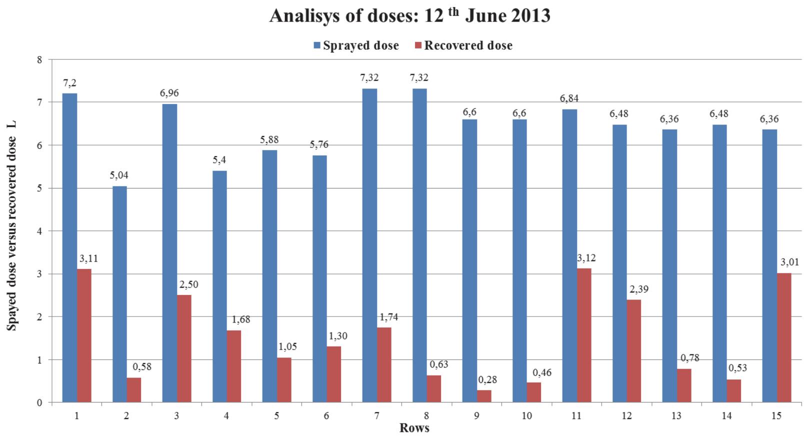
	Canopy surface m^2/ha	LAI	TRV m^3/ha
06/12/2013	3919	0,39	2172,20
06/27/2013	6695	0,67	1777,78
07/18/2013	9414	0,94	3408,00
08/02/2013	13240	1,32	2971,11

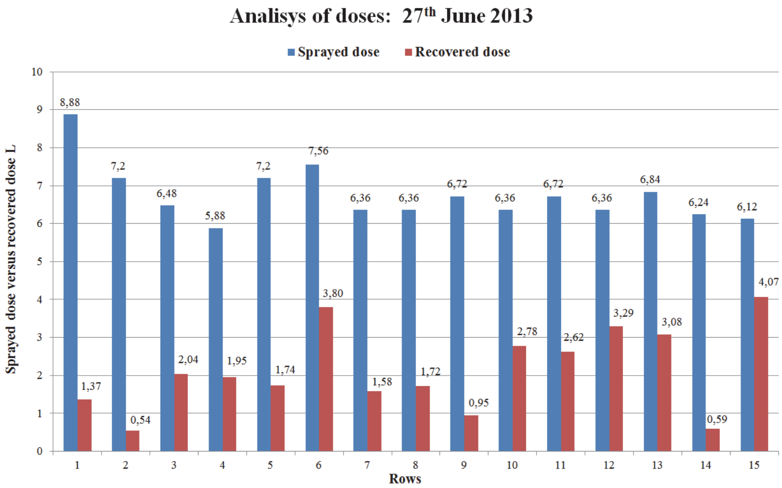
The use of ultrasonic sensor for pesticide mixture level measuring was suited to the objectives. The high accuracy and timeliness of the implemented system has allowed a continuous monitoring with a high level of reliability. Results showed see figure 4 significant amount of recovered mixture, which make it clear the high losses that occur during spraying. In some rows, in the stage of full vegetation, recovery rates varying between 50% and 60% were recorded. Therefore, from a sustainable management point of view, the sprayer should be set so as to minimize the mixture recovery.

About the employment of the crop circle sensor to the canopy features evaluation, it was not possible to identify statistically significant results. That can be explained either by the limited surface investigated either by the high uniformity of the vineyard see table 4. In fact, right from the earliest stages of development, the average values of vine's vigor were fairly uniform, until they become equal in the full canopy stage. This makes it impossible to identify areas with different vigor where to analyze a possible relationship between canopy volume and NDVI.

Table 4. NDVI data: average values of each rows

	NDVI Index				
Row	**06/12/2013**	**08/02/2013**	**Row**	**06/12/2013**	**08/02/2013**
1	0,63	0,71	9	0,48	0,68
2	0,47	0,75	10	0,56	0,77
3	0,61	0,75	11	0,61	0,73
4	0,59	0,72	12	0,62	0,72
5	0,58	0,75	13	0,62	0,74
6	0,55	0,73	14	0,60	0,75
7	0,63	0,76	15	0,58	0,75
8	0,52	0,72	**average**	**0,58**	**0,73**





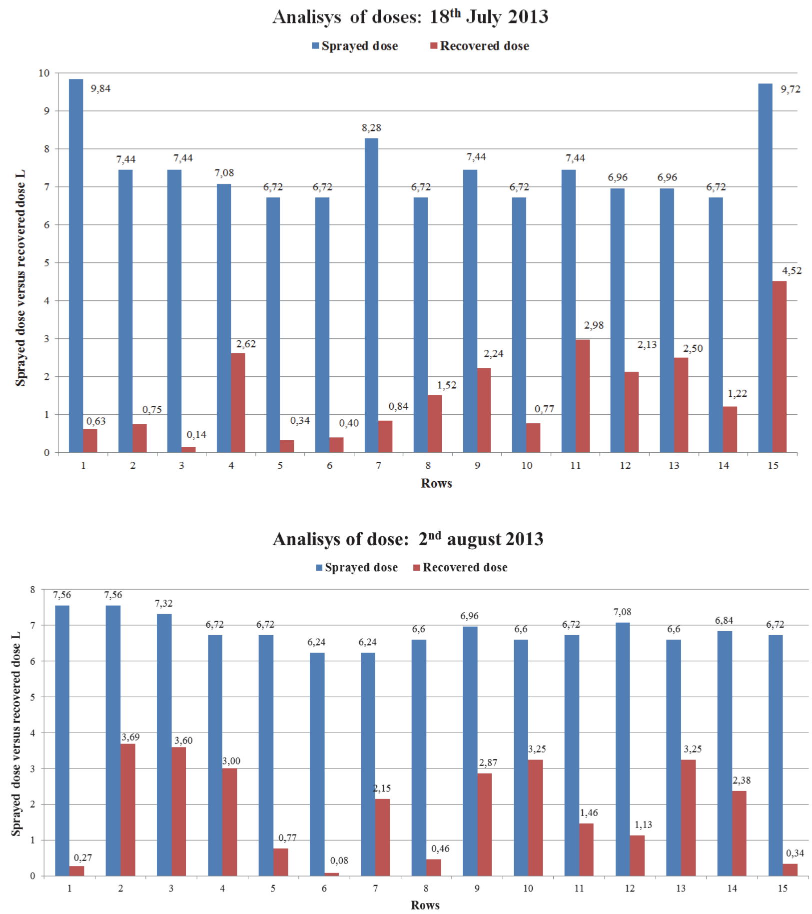


Fig.4. bar charts of sprayed and recovered dose monitored during the season

4 Conclusion

The pursuit of the objectives set by the European Directive 2009/128/EC on the sustainable use of plant protection products implies the implementation of solutions to optimize the pesticide employment. About this, the tunnel sprayers with opposing air-flow circulation and mixture recovery, are a valuable system to exceed the operating limits of conventional sprayers. Furthermore, the adoption of precision viticulture techniques represent an effective decision support tool. The system set up, allowed to quantify the recoverable pesticide with the use of these sprayers. This informations are either a useful tool to assess the work, either the basis for a database creation to verify and optimize the future planning of crop protection practices. The sprayer allowed to optimize the efficiency of distribution with a percentage of recovered dose in the seasonal stages analysed between 17.8% and 30.6%. The results confirm the necessary adjustment of doses distributed according to the target features that, which in turn, vary in relation to the development stage and by the crop management techniques (toppings and defoliation). In fact, in a sustainability perspective, the objective is the definition of the most probable dose that allows to make the treatment without residual mixture in the tank. However, this is an "annual objective" because of the high growth variability observed year by year. Therefore, the farms need to make all the necessary experiences on the grounds that among the varieties there is a different drops retention, shape of the leaves, amount of bloom and trichomes present on the upper and lower pagina. If on the one hand the Bertoni's sprayer optimizes the spraying, no less important are the achievable economic advantages: it is estimated an average savings respectively of € 5,000-10,000 / year on surfaces between 15 and 30 ha (Pergher *et al.*, 2009). The optimum employment of the tunnel sprayers should to assume the reaching of the minimum quantity of mixture recovered and at the same time the maintenance of the treatment efficacy. However, the mixture circulation results in a collection impurities that can be reduced up to inactivate the active substances. These aspects will be investigated in the future experiments.

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