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Suckers' Management Control

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Executive Summary

This document aims at proposing an estimation and control method of the hazelnut sucker emission attitude, to be applied in large-scale hazelnut orchards. An analysis of current best practices in hazelnut sucker control has been performed, followed by the proposed control solution.

The following aspects have been analysed:

1. State of the art analysis: identification of current techniques for sucker control.
2. Suckers estimation model: study and definition of an estimation model to detect suckers amount per plant.
3. Control model: definition of a simplified model for control purposes to perform sucker management.
4. Validation design: monitoring of sucker emission and development in selected trees to prepare the validation dataset for the estimation and control models.

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Abbreviations and Acronyms

AI	Active Ingredient
WSSA	Weed Science Society of America
PHI	Pre-Harvest Interval
NA	Not Applicable
GPA	Gallons Per Acre
NAA	l-naphthylacetic acid
UGV	Unmanned Ground Vehicle
Ad	Adult Tree
Yo	Young Tree
ID	Identification Code
NBI	Nitrogen Balance Index
CV	Cultivar
DoA	Description of Action

1 State of the art on hazelnut sucker emission and control

The European hazelnut is a species characterized by its high sucker emission aptitude, see Figure 1. The quantity of suckers emitted varies among the cultivars [1]. Starting from the second leaf, sucker control is an essential practice, given the fact that suckers compete with the tree itself for water and nutrients. During the juvenile phase of the plant, suckers are usually manually removed, while from the fourth year several control strategies are considered, ranging from manual or mechanical elimination, to chemical control that is performed spraying specific and authorized herbicides (i.e. active ingredients 'Carfentrazone ethyl' or 'Pyraflufen ethyl') or proper nitrogen and salt solutions (i.e. ammonium sulphate). To ensure the effectiveness of these chemical applications, suckers must be in the herbaceous stage, in other words their length should be shorter than 30 cm and their stems have to be not yet woody.

In small orchards with a limited number of plants and in organic farms, sucker management is generally performed by hand, using pruning shears. This enables the farmer to select a limited number of suckers to be left unpruned, to rejuvenate the plant in orchards where trees are grown as multi stemmed bushes. While this approach is environmentally friendly, it has the drawback of begin labour intensive and expensive [2]. Mechanical control is also carried out with cutters, repeating the operation several times during the season. Unfortunately, it does not remove suckers in the inner portion of the bush, and it has the potential risk of damaging the trunk.

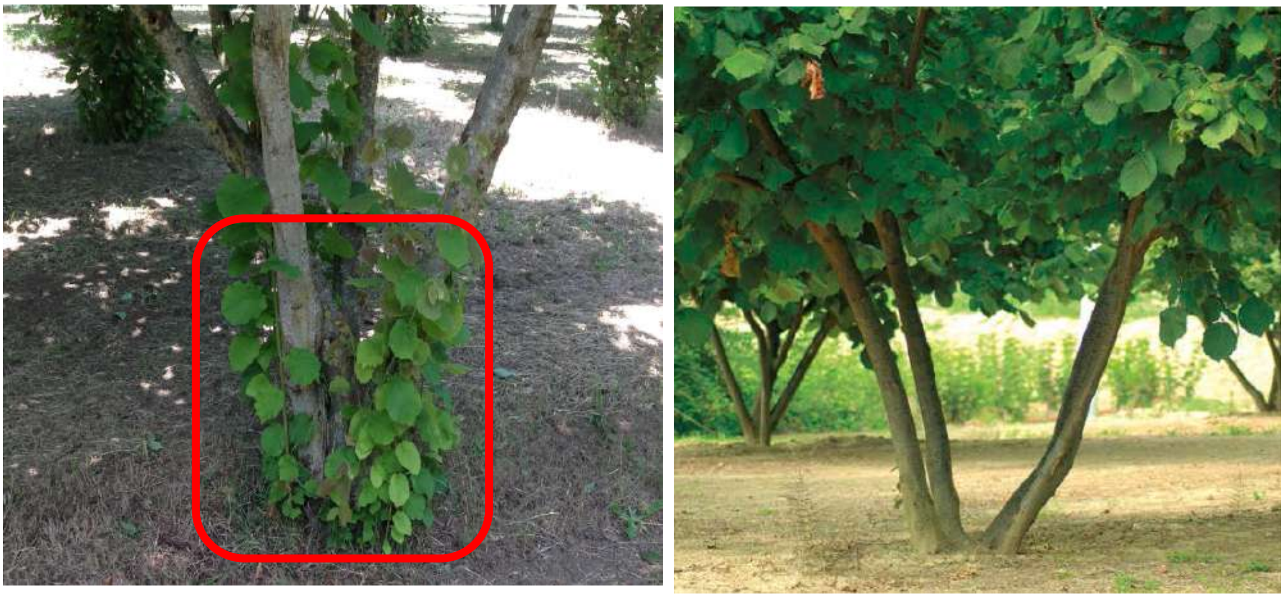

Figure 1 - Example of a hazelnut tree with suckers, in the red square, (left) and a hazelnut tree after suckers removal (right).

In larger orchards, manual and mechanical control result in an extremely expensive and time-consuming procedure. For these reasons, the most common method for sucker management in large plantation management today remains the application of herbicides. This is mainly carried out manually by field workers, who spray all plants in the orchard. For larger orchards, a tractor with a pump for herbicides is used. In both cases, there is no distinction between a plant that actually needs the treatment and a plant that does not require it. Additionally, a non-calibrated amount of herbicide is applied to all plants. In this framework, the scope of PANTHEON is to individually treat each tree according to its needs. The suckering control solution of PANTHEON is composed of two steps. In the first step, the characterization and estimation of sucker canopy dimensions of every plant is carried out. In the second place, tailor-made treatments are computed and applied, to allow the application of different rates of herbicide to each tree. This innovative solution is expected to reduce herbicide volumes and enhance plant health conditions.

1.1 Sucker Emission aptitude of European hazelnut

Table 1 reports the most important hazelnut cultivars classified in terms of their sucker emission aptitude, as described in Descriptors for Hazelnut [3]. Cultivars listed in bold are the most widespread in commercial orchards.

Sucker emission	code	Reference cultivars
Absent	0	Dundee, Newberg (Ibryds *C. avellana* x *C. colurna* used as clonal rootstocks)
Very weak	1	Butler, Tonda Bianca
Weak	3	Corabel, Cosford, Daviana, Ennis, Merveille de Bollwiller, San Giovanni
Medium	5	Pauetet, Segorbe, Tonda Gentile Romana
Strong	7	Fertile de Coutard *sinonym* Barcelona, Negret, Tonda di Giffoni, Tonda Gentile delle Langhe, Nocchione
Very strong	9	Imperiale de Trebizonde, Palaz, Tombul

Table 1 - Hazelnut cultivars classified in terms of sucker emission aptitude.

For a more in-depth knowledge of the cultivar influence on sucker emission aptitude, a three-year investigation has been recently carried out in a hazelnut field located in the Viterbo province (Italy), in the same area of the "PANTHEON experimental farm, with the aim to classify the sucker emission aptitude of additional cultivars [4] with respect to those classified by [3]. Forty-eight accessions were observed in the period 2008-2011 and their sucker emission aptitude was recorded and grouped as reported in Table 2. Furthermore, Annex 1 describes qualitatively the sucker emission aptitude of the 48 accessions by original pictures captured in the growing season 2018. We expect this information could be used during the experimental validation of the proposed detection and control algorithms for the tuning of the related parameters as it will be explained in Section 2.2.

Sucker Emission	Cultivar [Origin]
Very strong	Barcelona [France], Barrettona [Unknown], Camponica [Campania (IT)], Grifoll [Spain], Napoletanedda [Sicily (IT)], Riccia di Talanico [Campania (IT)], Tonda di Giffoni [Campania (IT)]
Strong	Annusa Racinante [Sicily (IT)], Avellana Speciale [Campania (IT)], Comen [Greece], Daviana

	[England], Grossal [Unknown], Karidaty [Turkey], Minnolara [Sicily (IT)], Morell [Spain], Negret [Spain], Nocchione [Latium (IT)], Piazza Armerina [Sicily (IT)], Racinante [Sicily (IT)], San Giovanni [Campania (IT)], Santa Maria del Gesù [Sicily (IT)], Sivri [Turkey], Tombul [Turkey], Tonda Bianca [Campania (IT)]
Medium-strong	Jean's [England], Nostrale [Sicily (IT)], Segorbe [France], Tonda Gentile delle Langhe [Piedmont (IT)], Vermellett [Unknwon], Vermellett SP [Unknwon]
Medium	Carrello [Sicily (IT)], Ennis [USA], Fructo Rubro [Unknwon], Gironell [Spain], Gunslebert [Germany], Merveille de Bollwiller [France], Tonda Gentile Romana [Latium (IT)]
Weak-medium	Apolda [Unknwon], Bearn [Unknwon], Comune di Sicilia [Sicily (IT)], Montebello [Sicily (IT)], Nociara [Sicily (IT)], Tonda Rossa [Campania (IT)]
Weak	Closca Molla [Spain], Hynich [Unknwon], Pallagrossa [Unknwon]

Table 2 - Origin and sucker emission attitude of the cultivars presents in the hazelnut field "Le Cese" (Viterbo province, Italy). The cultivar origin is reported in square brackets.

It has to be highlighted though, that sucker emission aptitude is not only driven by the genotype. Indeed, it can also be influenced by other factors such as growth system, planting pattern, seasonal weather conditions, alternate bearing (during off years, hazelnut trees tend to produce more suckers). Additionally, suckers emission attitude varies in relation to the specific cultivar and to the tree shape growth system (multi stemmed bush or single trunk). All these factors will be taken into account during the development of the numerical protocol for sucker dimension estimation. Indeed, the capability of SCADA system proposed within PANTHEON to collect historical data over time will prove extremely useful for the tuning of the parameters of the proposed estimation and control algorithms as well as to determine the phenotypical expression of each single tree.

1.2 Sucker control of European hazelnut

In the past, hazelnut suckers were considered as a useful by-product of the orchard because they were harvested to generate propagation material for new plantations. At the same time, suckers allow for the progressive renewal of the main branches of the plant that are trained as multi-stemmed bush, in case of diseases or damage.

In modern hazelnut farming, sucker removal is a standard practice. Annual suckers removal is performed because they are in competition with the plant for water and nutrients and also because they represent an obstacle to mechanized operations, mainly during the harvesting of nuts. From the second year, suckering is therefore an annual practice applied by the grower. During the juvenile phase of the plant, suckers are removed by hand. In plants grown as a multi-stemmed bush, care is taken to only eliminate suckers in excess and those that are poorly arranged, in order to favor the formation of the future bush arranged in 4-5 stems (Figure 2). From the fourth year onwards, several control strategies are considered, ranging from manual or mechanical elimination, to chemical control that is performed spraying specific and authorized herbicides. Manual elimination of suckers is usually performed in a single summer operation (Figure 3), as this operation is a costly and time consuming one. Manual sucker removal of an adult orchard, where trees are grown as bushes (density of 400 plants/ha), requires about 20-25 hours/ha of labor per year, resulting in more than 1/5 of the annual orchard management cost.

Mechanical control with the use of proper brush cutters (on suckers at the herbaceous stage), requires several seasonal repetitions. However, it does not allow the complete elimination of all suckers, mainly in the inner parts of the bush, and it may also cause damage to the plants. This technique is used in organic orchards or to eliminate suckers that have resisted chemical control.

Figure 2 - Young plant of European hazelnut grown as multi-stem bush. The shape of the growth system has been achieved by selecting four main suckers at the base of the bush.

Moving on to chemical sucker removal, the first studies on hazelnut started in 1960 in Italy and Oregon (USA). Among the active ingredients experimented over the years, chlorthiamid (2,6dichlorothiobenzamide), aminotriazole (IH-1,2,4-triazol-3-ylamine), bromacil (5-bromo3-sec-butyl-6-methyluracil), dichlobenil (2,6-dichlorobenzonitrile), paraquat (1,1 'dimethyl-4,4'-bipyridinium), dinoseb (2-sec-butyl-4,6-dinitrophenol) can be reported [5]. However, some of these active ingredients (AI) are no longer authorized, since they are considered not environmentally friendly. For example, the AI in 'Paraquat' was banned on January 2015 because of harmful effects on avifaunaand beneficial insects.

In more recent years in Italy, other chemical suckering controls have been tested, such as the use of esters of NAA (l -naphthylacetic acid), (2,4-dichlorophenoxyacetic acid) andgluphosinateammonium (4-[hydroxy(methyl) phosphinoyl] DL-homoalanine) [6]. The NAA esters (also called synthetic auxins) are plant growth regulators used in agriculture on various crops. They exert in plants many physiological effects including vegetative growth control action. Furthermore, they do not have a phytotoxic effect, however their sucker control action is not always fully effective. Gluphosinate ammonium was authorized as herbicide in the EU until 2018, after which it was banned for its possible reprotoxic activity. Currently chemical suckering control on hazelnut is permitted using other chemicals such as carfentrazone ethyl and pyraflufen ethyl (Table 3).

The chemical control strategy, based on the use of authorized herbicides with suckering action, is normally carried out in two or three applications throughout the season. This is a widespread practice, given the effectiveness of the action and the reduced application cost (Figure 4). Suckering treatments have to be carried out promptly, when suckers are at the herbaceous stage (normally shorten than 20-30 cm in high, considering medium vigor and sucker emission aptitude cultivars). Otherwise, removing them become more difficult as a result of their progressive lignification, which would result in the need of applications. In plants grown as single trunk (Figure 6), the use of trunk guards is recommended until the bark is well developed (two to three years).

Some practical indications on authorized herbicides and distribution methods are given in the following paragraph. Since the authorizations for the use of products and AI that can be used are constantly evolving, it is suggested to consult the European, national and regional databases and guidelines concerning approved herbicides and dosage limits for the use of chemical suckering. Limitations imposed by different regulations (e.g. organic agriculture), and the need to reduce the environmental impact of herbicides, together with the risks of chronic phytotoxicity on plants (in particular when the AI have a systemic action), point towards new control solutions, more sustainable from an economic and environmental standpoint.

Recently, the effectiveness of pyroweed control (Figure 6) has been evaluated in proper trials [7]: it resulted to be a non-sustainable strategy due to the current high costs and the temporary effect (sucker control limited to about 20 days from the application). The use of water vapor as weed killer on herbaceous suckers is also still limited to the experimental phase, due to both the complexity of the technique and the elevated water consumption.

A promising solution involves the use of no-sucker rootstocks, such as *Corylus colurna* seedlings (Turkish hazel) and hybrids of *C. colurna* x *C. avellana*, including Dundee and Newberg (hybrids released in Oregon in 1990), on which to graft cultivars of commercial interest. The use of no-sucker rootstocks allows avoiding the operations of suckering, but at the same time imposes innovations on the growth system of orchard, with plants trained as single trunk. Furthermore, the effects that rootstocks derived from *C. colurna*seedlings have on cultivars in terms of phenology, soil adaptation, productivity and plant vigor should also be assessed to guide future choices.


Figure 3 - Manual elimination of suckers, usually performed in a single summer operation (left bush before suckers removal; right: bush after suckers removal). Original pictures captured in a commercial orchard.

Figure 4 - Desiccant effect of the suckering herbicide a few days after treatment.

Figure 5 - Plant of European hazelnut grown as single trunk.

Figure 6 - Automatic "Orchard-Vineyard" pyroweed model (on the left) and automatic weeder field treatment tested on hazelnut (on the right).

1.3 Herbicides and active ingredients authorized for chemical suckering in European hazelnut

This paragraph describes some practical indications for the preparation and distribution of authorized suckering herbicides. The AIs and their relative trade names described in Table 3. are the most common suckering used in Italy as authorized herbicides for hazelnut. A rational approach in the use of these chemicals suggest alternating their use from year to year. Care in choosing the correct vegetative stage of the green suckers allows farmers to spray the herbicide two times per growing season, although occasionally three spraying could be necessary. As reported in Table 4, the recommended volume per hectare for each AI is normally diluted into 300 liters of water.

AI	Tradename	Volume (l/ha)	Time of application	NOTES
Carfentrazone ethyl	Affinity plus; Spotlight Plus	From 0.4 to 0.9 l/ha depending on the number of suckers	In the early stages of sucker growth at the herbaceous stage (10-15 cm)	Carry out at least 2 suckering operations per year in order to have a good containment of the shoots. Localize the treatment on the suckers using shielded bars in order to avoid that the drift of the solution reaches the

				vegetation not interested in the treatment. Use only anti-drift nozzles (absolutely avoid the use of turbulence-conical nozzles), with low operating pressures (1-2 bar), in order to produce very large and heavy drops and ensure complete wetting of the treated organ. Therefore, adequate volumes of water are recommended (recommended 300 l/ha). Intervene before the suckers have reached a maximum length of 20 cm, however before lignification.
Pyraflufene thyl	Evolution; Piramax EC	0.8 l/ha	In the early stages of sucker growth at the herbaceous stage (10-15 cm)	To be used as an alternative to Carfentrazone ethyl

Table 3 - Indications for chemical control of suckers in hazelnut orchards. The authorized AIs, volume and time of application are listed according to the indications valid on hazelnut orchards in Italy.

For what concerns Oregon (USA), AIs, trade name, volume and other information to be taken in consideration in suckers control, are reported in Table 4 [8].

Active ingredient [WSSA [1]] (trade name)	**Rate pounds AI/acre (product)**	**Max seasonal per acre per year (product)**	**Reapply (month)**	**Minimal Age (month)**	**Replant (month)**	**PHI (day)**
2,4-D [4] (Saber)	0.71–0.95 lb AI (1.5–2 pt)	1.9 lb AI (4 pt)	1	12	1	45
carfentrazone [14] (Aim EC)	0.03 lb AI (2 fl oz)	0.079 lb AI (7.9 fl oz)	0.5	0	0	3
glufosinate [10]	1.0 lb AI (56 fl oz)	4.5 lb AI (246 fl oz)	0.5	0	6	14

(Rely 280)						
paraquat [22] (Gramoxone SL)	0.625–1 lb AI (2.5–5 pt)	4 lb AI (20 pt)	0.5	0	0	1
pelargonic acid (Scythe)	5–7 % v/v	NA	NA	NA	NA	1
pyraflufen [14] (Venue)	0.002–0.005 lb AI (2–4 fl oz)	0.0085 lb AI (6.8 fl oz)	1	12	0	0

Table 4 - Indications for chemical control of suckers in hazelnut orchards. The authorized AIs, the volume and time of application are described referring to the indications valid on hazelnut orchards in Oregon (USA), under the auspices of Ore (lb = libra; fl oz = fluid once; pt = pint US dry).

[1] WSSA - Weed Science Society of America, herbicide site of action group number [n]. Trade names here reported are not a recommendation but are listed to facilitate interpretation of the table.

For what concerns the AIs listed in Table 4, in medium sucker canopies, 100 GPA of water are normally sufficient. On the other hand, in large canopies, 150 to 200 GPA of water are recommended, as this can improve coverage and treatment efficacy. In the following section, we describe in detail the characteristics of the suckering herbicide, Carfentrazone ethyl, chosen for our first-year experiments in the PANTHEON farm. The selection has been carried out following the restrictions of the Italian laws on the use of herbicides and also considering the most used AIs over the past years by the Italian hazelnut growers. Other environmentally friendly AI, as the authorized urban weed control acetic acid andammonium sulfate, are also discussed and evaluated to be used in second part of the experiment. Carfentrazone (trade name Spotlight Plus®) is an effective solution to manage both weed and suckers, producing low toxicological and environmental impact. The AI has an exclusive action of contact and need to be spread on photosynthetic organs. It is applied in doses of 0.35-0.40 l/hl or 1 l/ha depending on the vigor and suckers dimension. Compared to manual suckering, Spotlight Plus® offers significant time saving advantages, while avoiding the type of wounds produced by mechanical tools at the base of the trunk and reducing the phenomenon of suckers rejection. Spotlight Plus® is characterized by the innovative formulation in Water/Oil Emulsion that improves the distribution of the AI on the target to be destroyed and greatly reduces drifting during application. It is recommended to ensure complete wetting of the suckers by applying adequate volumes of water. The AI Carfentrazone ethyl needs light to be activated, thus the time of application is decisive for its activation. It is advisable to apply the product in the morning or at the latest three hours before sunset.

A more environmentally friendly AI to be tested in hazelnut sucker control as "organic AI" is acetic acid (82%), complexed by pongamy, disaccaricle, protein hydrolysate, polyclroxy acid and natural saponins. Its trade name is Urban Weed and it is in patent pending. Acetic acid reduces transpiration of the vegetative tissues that are in contact with it, reducing their vegetative growth. The product forms a semi-permeable film that limits leaves transpiration. The product must be used on dry vegetation, in broad daylight and with temperatures above 12 - 15 °C: in these conditions, the product forms a film on the weed vegetation and performs at its best. On particularly vigorous herbaceous organs, it is recommended to treat with temperatures higher than 18 °C and with maximum solar irradiation. The product is applicable with any type of equipment sprayer, taking care of using nozzles which allow the formation of fine droplets (150/300 µm diameter), fan-shaped for low vegetation and cone-shaped for high vegetation and thick. The quantity and concentration of the product need to be calibrated in hazelnut sucker control, and this environmentally friend solution could be highly suitable in young hazelnut orchards.

Similarly, and among the natural products of plant origin, pelargonic acid, is the only fatty acid with a herbicidal action. Chemically, it is a saturated aliphatic monocarboxylic acid with nine carbon atoms; the brute formula is $C_9H_{18}O_2$. Its name (pelargonic acid) is due because it was first isolated from the leaves of *Pelargonium roseum.* It exists in nature as an essential oil, contained in the form of an ester, but it can also be obtained from the oxidative demolition of oleic acid. It is a colourless liquid, not very soluble in water and with a strong smell of rancid. Its herbicidal action is carried out only in post-emergence of weeds or with contact activities at the leaf level. Pelergonic acid is active against a wide spectrum of annual and polyannual weeds, mono and dicotyledons, algae and mosses. The action of the product is revealed in a few hours with widespread leaf yellowing leading to the drying of the affected parts in one day after surgery. Pelargonic acid has no residual action so it does not pollute the soil and is very suitable in urban and periurban areas. Also, this AI will be taken under consideration for testing its effectiveness as environmentally friendly chemical suckering.

The ammoniun salt of sulfuric acid "ammonium sulfate**"** is also considered an AI for chemical suckering as it can wither green suckers thank to the caustic action of sulfate. It can also improve the nitrogen intake in the orchard. Itis not as efficient as the Carfentrazone ethyl, given that the released nitrogen in the soil can increase the development of new suckers in the following weeks after treatment. It will be taken under consideration in the second steps of the experiment.

1.4 Characterization of the herbicide sprayer

Recently, a private company named "Rometron", located in the Netherlands, has developed WEEDit [9], a new system for weed control. The system, carried by a tractor, can operate at 25km/h. Several sensors scan the soil, emitting red light to detect unwanted plant life. Driving the tractor across the field, sets of individual nozzles cover each one-meter section, while the ground surface is scanned at a rate of 40,000 times per second. The plant chlorophyll responds to the red light by absorbing it and emitting near infrared (NIR) light back onto the sensors. The WEEDit sensors pick up the NIR response and react by activating particular sets of spray nozzles. Each individual spray solenoid opens up in one millisecond, spraying the targeted weed with a pre-specified mix of herbicides.

On the PANTHEON project, we attempt to move one-step further with respect to the already available technology. More specifically, we aim not only at identifying suckers dimensions but also at applying different volumes of herbicide according to the sucker dimensions. It has to underline that WEEDit, for instance, does not take in consideration suckers in their lignification stages, because NIR can detect only the "green stage", which will be then be efficiently sprayed with the proper herbicide. Additionally, the quantity of the herbicide is not proportional to the volume or area of the “green spot”. Thus, we believe that for sucker estimation a more complex approach is needed. Such an approach should take into account other parameters, such as volume and area, together with the distribution of the suckers canopy. Our approach will be calibrated on the single plant, with its specific sucker response. In other words, a "field map" will be derived from the collected information to identify and map trees that need strong, medium, light or no treatment. Historical data of sucker management at the level of single tree will also be archived, to understand historical trend and to always be able to retrieve the last application date (and application characteristics) per single tree

In suckers' management control, the field application of the herbicide is going to be performed using a UGV (Figure 7) equipped with a tank and a spraying system. In this context, the objective, besides the detection of what plants to treat, includes the way the treatment is administrated (e.g. position of the UGV, nozzle type, application time of the herbicide). The distance at which the UGV and the position of the sprayer should be located, depends directly on the liquid spatial distribution given by the sprayer. Similarly, the application time for each tree will depend on the quantity of product that actually gets in contact with the suckers. In this respect, we initiated a research activity to characterize these variables, in order to determine the quantity of product provided to the plant depending on distance, angle and application time. Additionally, we plan to study how this distribution varies given different nozzles.

1.4.1 Experimental approach

Due to the relative lack of reliable physical models for herbicide application, we plan to obtain the product distribution through laboratory experiments. Given several experiments, we will try to establish a mathematical characterization of the amount of herbicide applied to a specific object.

1.4.2 Experimental setup

Since numerous variables of the sprayer setup (e.g. pressure) affect the herbicide distribution, we focus on reproducing the setup currently used by standard hazelnut producers. To do so, we have collected information from the Ferrero agronomists, which provided us with detailed information on the setup they generally use, as reported in (Figure 8). In order to determine how the herbicide is spatially distributed and how much quantity of product is lost based on the application distance and the shooting angle, we plan to use water and we decided to spray on absorbing surfaces at different distances and angles. On the basis of this test, we will better adjust the distribution.

Figure 7 - UGV equipped to perform targeted application of chemicals on suckers.

Figure 8 - Spray system setup. The trailed sprayer is activated by the tractor.

1.4.3 Expected Results

Based on these experiments, we expect to derive a simple mathematical model of the sprayer dynamics. This will be used to plan the trajectory of the UGV, in order to minimize the application time, while maximizing efficacy.

1.5 Nozzles types for herbicides

In order to obtain an efficient suckers control, it is important to accurately choose the type of nozzle. Considering that all herbicides used in sucker control are contact herbicides (they only kill the green plant parts touched by the chemical) complete coverage of the target is critical.

In weed control, spraying is carried out using nozzles fixed at a bar and the sprayers normally works in a continuous way. On the contrary, for suckering control, spraying is intermittent, and a high accuracy is required to provide the correct amount of herbicide to the suckers canopy, avoiding that the herbicide gets in contact with other parts of the main plant, while reducing AI dispersion in the environment.

The most suitable nozzles for suckering control are “low-drift nozzle”: they can be either eccentric or air induction (Figure 9, and Figure 10). An eccentric nozzle is characterized by an asymmetrical spray pattern via eccentric orifice and it is highly recommended for chemical suckering. It is the most used kind of nozzle in vineyard. Air induction nozzles produce larger droplets by introducing air into the water flow inside the nozzle mixing chamber (Venturi effect). Playing on the geometry of the nozzle creates a pressure variation that allows, through the two holes obtained laterally, to suck in external air that mixes with the fluid inside the nozzle giving rise to large and heavy drops full of air bubbles that precipitate quickly and explode in contact with plants or soil creating a large amount of fine droplets. Larger droplets provide better penetration, while those that explode provide excellent coverage, even at the back of the leaves. These nozzles allow for drift reduction of up to 70%.

The nozzle has to spray at an angle of 80°. Usually, the nozzles operate at low pressure (1-1.5 bar). Nozzles mounted on shielded equipment can contribute to reducing the risks of AI drift (Figure 11). They can be used both to manage weed along the row and also suckers. This approach is high herbicide consuming. It is recommended to avoid turbulence nozzles, such as conical types.

Figure 9 - Eccentric nozzle.

Figure 10 - Air induction nozzles.

Figure 11 - Nozzles mounted on shielded equipment.

2 Mathematical model for detecting and controlling suckers

In this section, we detail the approach for the detection of suckers entity per single plant, describing also the most appropriate sensors on board UGVs to be used for sucker characteristics estimation. We also report the development of an algorithm to determine and then apply the correct amount of herbicide per plant during suckering.

Considering that the authorized suckering AI act by contact on photosynthetic organs, accurate evaluations were conducted in 2018 at the PANTHEON experimental farm, through weekly observations on the development of suckers in both adult (fields 18 and 21) and young plants (field 16), to manually monitor the organs development and develop the best strategies for suckers characteristics estimation per plant. The most representative characteristics for the purpose of effective application and reduction of use of the suckering herbicide are:

1) the volume of the suckers' canopy at the base of the stump or trunk,
2) the spectral response of the suckers themselves.

These two characteristics are taken into account during the formulation of the mathematical model of sucker canopy estimation.

2.1 Sucker detection per plant

As stated above, the treatment of suckers at the individual plant level requires first to determine the suckers 3D structure and colour characteristics. As presented in Deliverable 4.1, based on the UGV sensor measurements, spatially enriched point clouds are computed. For this purpose, each tree is scanned with a laser scanner and two cameras from four positions to derive an all-around view of each tree. In principle, the camera images are projected to the laser scans. Thus, the image pixels are assigned to the 3D points and vice versa. In consequence, for each pixel the 3D information, as well as for each 3D point the spectral information is available (Figure 12).

In Task 4.3 – "Tree Geometry Reconstruction" it is planned to use state of the art image classification or object recognition approaches to identify suckers automatically. In particular, neural networks have been proven to outperform human experts in image classification and object detection tasks [10]. Spectral indices, like the NDVI might provide useful information to distinguish suckers from the soil, stem or branches (for the presence of bark). Since young suckers have a conspicuous light green colour, highly distinguishable from the bark, the sucker detection is expected to work well. To train the sucker detection, a supervised classification and a manual reference data collection is planned. Based on the detection results, the 3D point clouds will be reclassified.

Although 3D information of the detected suckers will be available, the derivation of a volume is challenging. There are several approaches imaginable to provide such a volume, but their particular use for the suckers treatment is not clear yet. To use the convex hull of the 3D points associated with suckers as the volume seems straightforward, but the volume might be overestimated, since gaps between leaves will also be covered by the hull. Alternatively, an alpha-concave hull could be derived, since it might provide a more realistic estimation of the suckers shape. The simplest solution would be to provide the number of 3D points representing the sucker only, since the number of points is already be correlated with the volume.

Next to the sucker's dimensions, additional features (like the number of suckers or the protective area) are planned to be provided, since these might be correlated with the amount of herbicide required. In consequence, different methods to represent the volume, as well as various features expected to be useful to calibrate the amount of herbicide will be provided. The final decision for the most suitable features will be made based on the calibration results.

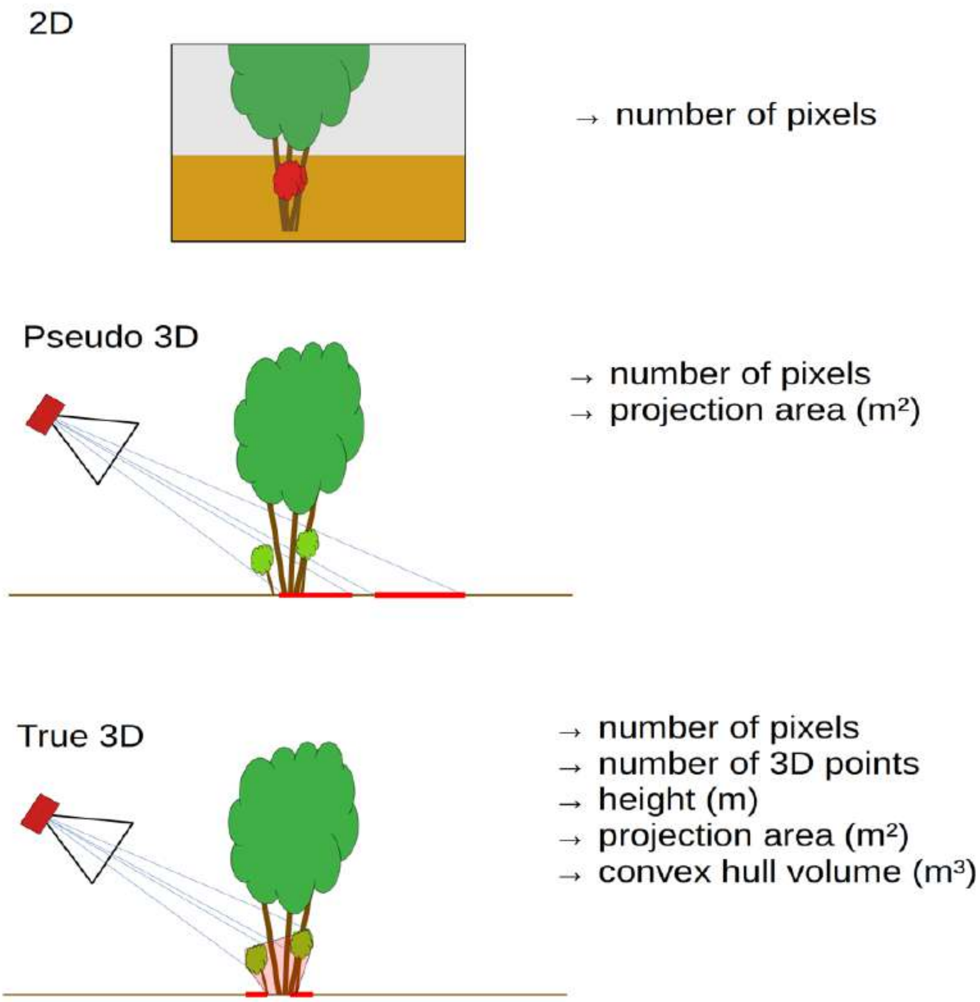

Figure 12 - Synoptic description of 2D and 3D image pixels. The 3D pixels are assigned to the 3D points and vice versa. For each pixel the 3D information is available.

2.2 Mathematical model for sucker canopy estimation and control

As anticipated, dimension (area/volume) and additional features (like spectral response) of the suckers represent the key variables that can be measured through the sensors on-board the UGV to determine the quantity of herbicide to be applied plant by plant.

The logic behind the following algorithm is here briefly described. According to the agronomists' expertise, 30 cm of height from the ground can be assumed as a reasonable threshold to distinguish between branches (on the upper part) and suckers (on the lower part). Therefore, the algorithm for sucker detection will only analyse the part of the point cloud below 30 cm from the ground level. In other words, we assume that no sucker is longer than 30 cm. This is also a precaution to avoid damaging branches of the tree. In the portion of volume comprised between the ground and 30 cm above it, the algorithm identifies what is green and leafy. The high reflectance in the band green and NIR should help characterize herbaceous suckers, assuming that no lignified sucker is present. For what concerns treatment, the volume of herbicide to be sprayed is assumed to be linearly proportional to the 3D volume (or 2D area) of the suckers detected. This is a first assumption that of course will need testing and possibly some future refinements. A coefficient of proportion is used to take into account a trial-and-error calibration phase, but also to be able to account for different AIs and different concentrations. Tuning of these parameters will be carried out over the years by exploiting the historical data collected by the SCADA system proposed within PANTHEON.

To develop an appropriate mathematical model for suckers canopy control at level of the single tree, we defined the following conceptual framework:

1. Assume to have a fixed concentration of the herbicide per litre of water, as described in the authorisations of the selected AI.
2. Perform a mapping between trees need and intensity of treatment (strong, medium, light, none). It will be computed with respect to the parameters extracted by the sensors on-board the UGV.
3. Perform a mapping between type of treatment and amount of herbicide: expressed in how many seconds of spray as a function of the selected nozzles and suckers characteristics in order to define the volume of herbicide required for a single tree.
4. Compute the overall amount of herbicide required per block/field by summing up the requirements of all trees in the block/field.

2.2.1 Determination of the quantity of herbicide for each plant

The kind of information that will be used to decide the amount of treatment for each plant can be roughly classified in three groups:

1) Knowledge *a priori* on the plant and on the herbicide;
2) Estimation of the size of the suckers;
3) History of the treatment

By **knowledge *a priori*** on the plant we intend all available datasets that provide information on the suckering attitude of each plant. As already discussed, the most important factors are CV, age, and geometry (multi-stem, single trunk, etc.) of the plant as well as the plantation layout. This knowledge *a priori* can be uses to tune the “aggressiveness” of the sucker removal treatment. The other knowledge *a priori* that we have concerns herbicide characteristics, its concentration, time of action, and the safety prescriptions linked to it (amount of herbicide per hectare per amount of time).

The main online information useful for sucker's treatment is the estimation of the **size** of the suckers. In line of principle, many different measures of the size of the suckers can be used, including: the estimation of the volume of the suckers envelope, the estimation of the exposed surface of the volume of the sucker, the estimation of the sucker's leaves surfaces, the estimation of the total biomass of the suckers, etc. At the current stage, it is still unclear which of these is the most convenient measure to tune the sucker's treatment. The strategy we propose in this section is agnostic with respect to the specific measure of the sucker. We will denote as $X_{sucker,i}$ $X_{sucker,i}$ the measure of the i-th sucker.

By **history of the treatment** we mean the information collected, on the database, on the amount of herbicide already sprayed on the plant and the dates in which this was applied. This information is fundamental to avoid treating a plant that has been treated too recently (for which the herbicide has still not started its effect), and to ensure that there is no violation of the safety prescription of the herbicide.

Based on these pieces of information, Table 5 provides the pseudocode describing the general idea of the proposed control numerical protocol to determine the quantity of herbicide to be administrated to every tree.

Algorithm – Quantity of herbicide for each plant
1 From the database, recall the treatment data
1.1 If a treatment has been administered in the last $X_{sucker,i}$ days, do nothing
1.2 On the basis of the total amount of herbicide administered in the last t_{window} days and on the basis of the legal prescription, determine the maximal quantity of herbicide that can be administered to the i-th plant, $h_{max,i}$
2 Estimate the parameter $X_{sucker,i}$
3 Determine the amount of herbicide to be applied as $$h_i = \min\{\alpha_i(X_{sucker,i}), h_{max,i}\}$$
where $\alpha_i(\cdot)$ is a suitable monotonically nondecreasing function.

Table 5 - Pseudocode description of the proposed numerical protocol.

Some explanation is in order:

1) $X_{sucker,i}$ is the windows in which the herbicide has an effect. For most herbicide this is in the order of 1 week.
2) In line of principle, with respect to the point 1.2 of the algorithm given in Table 5, the limitations on the amount of herbicide depends on the national laws and on the herbicide itself. In this algorithm, we considered the amount of herbicide/plant/unit of time, given that most of prescriptions can be reformulated in these terms (usually the prescriptions are given as amount of herbicide/hectare/unit of time, which can be easily converted in prescription per plant).
3) For the determination of the amount of herbicide, in the general algorithm we have considered a generic nondecreasing function $\alpha_i(\cdot)$ for each i-th plant. Indeed, for the moment, while it is clear

that "the bigger the sucker, the more the herbicide", there are no indications on which is the most convenient for such law. Accordingly, we will start with a simple affine control law in the form of:

$$\alpha_i(X_{sucket,i}) = k_{P,i}\, X_{sucket,i} + c_i$$

where $k_{P,i}$ is a proportional term needed to remove the current sucker, and c_i is a constant amount of herbicide sprayed independently on the dimension of the sucker. This it to ensure that, even in case of absence of suckers at the present moment, the plant is still protected in the next window $X_{sucker,i}$.

Another possible option is to opt for quadratic functions in the form:

$$\alpha_i(X_{sucket,i}) = k_{P,i}\, X_{sucket,i}^2 + c_i$$

or for whatever other nonincreasing function. In the remainder of the project we will focus on the affine case.

2.2.2 Determination of the parameters of the control law

The main difficulty in the definition of the above sucker's control algorithm is the tuning of the parameters $k_{p,i}, c_i$ of the functions $\alpha_i(\cdot)$.

On the basis of the discussion in the previous sections it has been shown that the sucker's emission attitude (which highly influences the amount of herbicide to be used) depends on a very large number of aspects. It has been remarked that the main ones are:

1) Cultivars: certain cultivar have a sensibly higher suckers' emission attitude than others;
2) The larger the layout of the plantation, the higher the suckers' emission attitude;
3) The more the plant is similar to a single trunk tree, the higher the emission attitude.

In line of principle, we should determine the parameters $k_{p,i}, c_i$ of the function $\alpha_i(\cdot)$ for each tree of the plantation.

Clearly this is, at least in the first years of use of an automatic method, not realistic. As a consequence, the idea is to use these 3 factors to determine the parameters for "categories" of plants.

To do so, we will rely on the experience of the agronomists within PANTHEON. In particular, we will consider the two cultivars available (Tonda Gentile Romana and Nocchione), and the specific layouts and tree geometries present in our experimental field, and a number of real case studies of different volumes. For each of them the agronomists will spray (with a hand sprayer) the amount they believe is appropriate for the suckers. The data on the amount of herbicide sprayed will be recorded and the parameter $k_{p,i}, c_i$ will be identified by interpolation.

In a second phase we count to improve these parameters using the data collected in the orchard and using an adaptive algorithm.

If these protocols are as successful as expected, a further scientific work, to be carried out after the end of the project, will be to generate tables of $k_{p,i}, c_i$ for the major cultivars and the most frequent layouts and geometries.

2.2.3 Low level spraying policy of the herbicide and trajectory planning of the robots

It is also assumed that the atomizer works at constant pressure. Accordingly, the amount of herbicide sprayed by the atomizer for the i-th tree can be approximated as a linear function of the time, i.e.:

$$h_{sprayed,i} = r_v \, t_i$$

Where r_v is the liter/second spraying rate of the atomizer. It must be remarked that the amount of herbicide sprayed and the quantity of herbicide that actually reaches the plant are different values, given than in any atomization there is a certain percentage that is lost in the atmosphere or that reaches the ground. Accordingly,

$$h_i = (1 - l_a) h_{sprayed,i}$$

where l_a is the percentage of herbicide that does not reach the plant. This quantity depends on the shape of the nozzle, on the pressure of the pump, on the specific spraying trajectory used to spray the plant, and on the wind. Using the above formulas, it results that the application time can be derived as:

$$t_i = \frac{1}{r_v(1 - l_a)} h_i$$

An important aspect, currently under investigation, is the determination of the optimal trajectory of the ground robot and of its robotic arm for the application of the herbicide. The requirement for the generation of a “good” trajectory are:

1) The herbicide is sprayed sufficiently uniformly on the sucker;
2) The loss factor l_a si minimized;
3) The total time to carry out the spraying of a sequence of trees is minimized.

In the first part of the project, the solution we are currently using is the one of mimicking what done by a tractor: the robot moves at a constant speed, parallel to the lines. The arm of the robot points at the tree from different angles and sprays for the needed time.

However, preliminary analysis on very simplified model (where we assume that the robot has to reach 4 spraying points around the plant) have shown that this kind of approach is not necessarily the most effective. In particular, this simple analysis showed that travelling around one tree (see Figure 13) could be a more efficient approach, depending on the distance between lines.

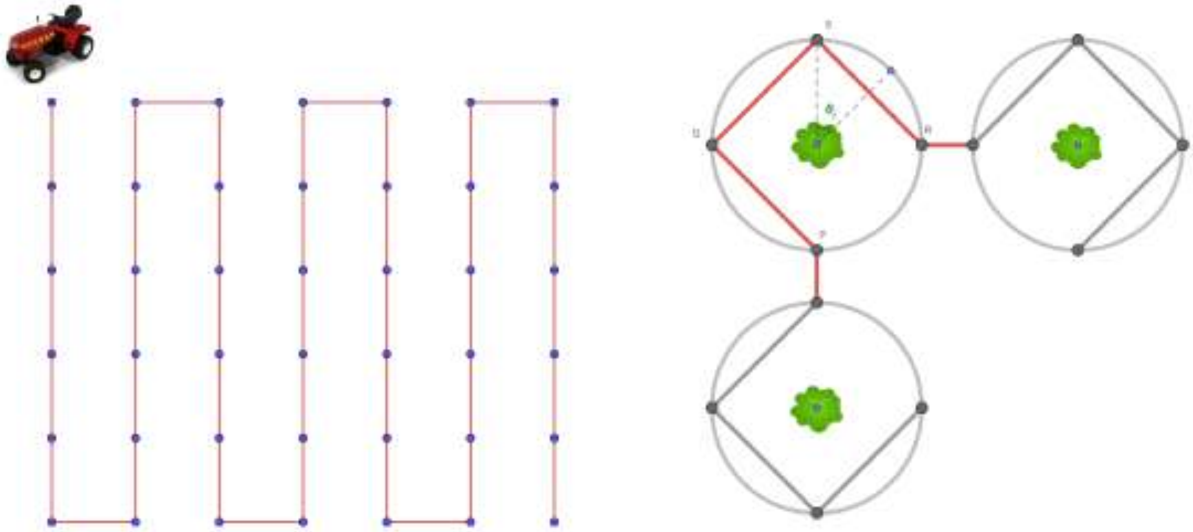

Figure 13 - Trajectories for spraying assuming 4 points of spraying, classical visit per line against visit per tree.

At the current stage, we are developing a complete model (implemented in Gazebo) including the robotized sprayer, see Figure 14.

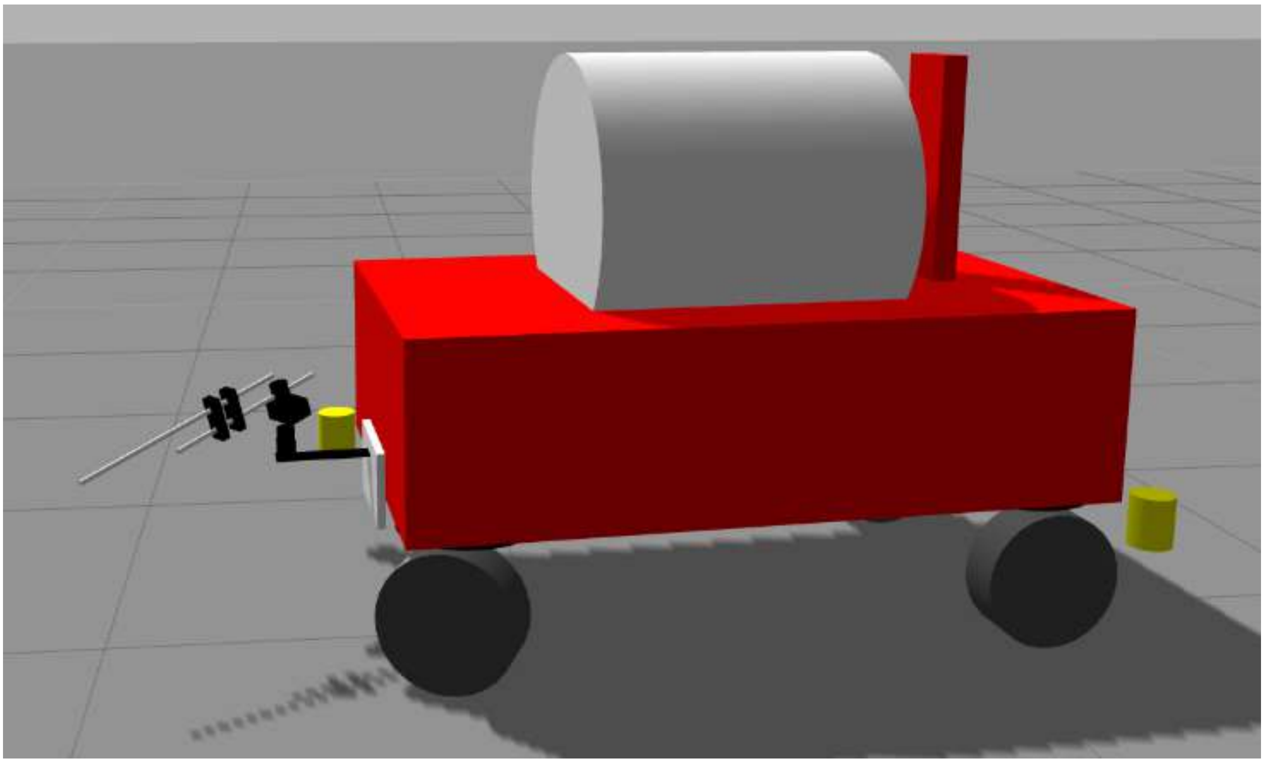

Figure 14 - Gazebo model of the robot and of the robotic arm with the atomizer.

The model we are developing also include a simplified representation of the sprayer, able to predict the amount of herbicide that reaches a given surface (Figure 15).

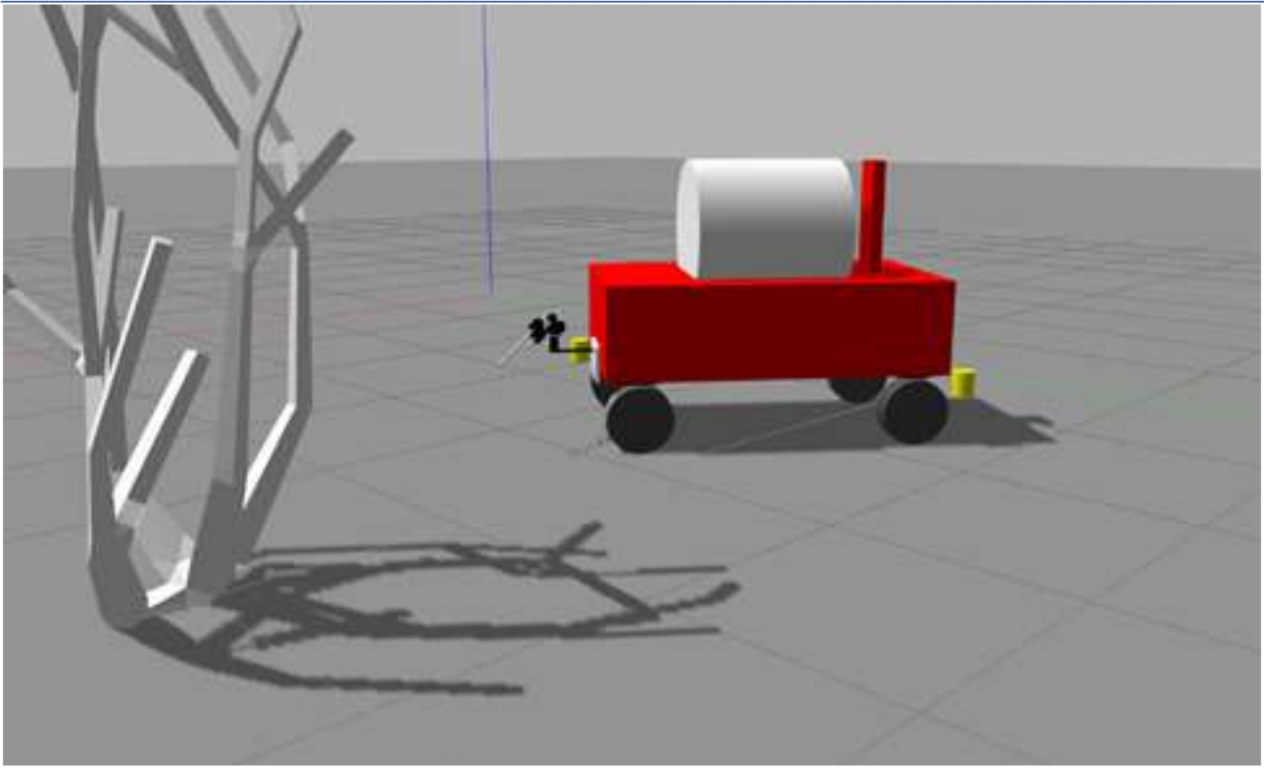

Figure 15 - Gazebo model of the robot in the orchard.

This model and simulation tools are currently being used to find better trajectories for the spraying process, to try and reduce the total execution time of the operation and the losses, while increasing the uniformity of the herbicide coverage on the plant sucker.

2.2.4 Loading of the herbicide for the mission

An important parameter to avoid waste of herbicide is to load the robot with the right amount of herbicide to be used: indeed, the quantity of herbicide left unused at the end of the day is to be considered a loss. In this subsection we want to remark that, in a framework where sensing and action are independent, a good way to reduce waste is to consider the amount of herbicide loaded on the robot as one of the variables in the mission planning. In other words, given a set Π of plants to be treated in this mission, one should compute the total amount of herbicide to be used $H_{total} = l_a(\sum_{\{i \in \Pi\}} h_i)$ and to load exactly this quantity on the tank. This ensures, on average, a saving that corresponds to half a tank at the end of each day.

3 Description of fields and trials for mathematical model validation

In this section we explain the trials we performed to validate the mathematical model for suckers canopy detection and control at level of single tree. Figure 16 shows the overview of all the selected trees in the experimental farm to calibrate/validate all tasks planned in the project, where Figure 17 depicts a zoom-in on the trees selected for sucker monitoring and removal. The trees identified for sucker detection and control are located within the polygons with a green border. Ten trees were selected in early January 2019, both in the adult and the young orchards. The adult trees, about thirty years old, were selected in field 18, where the cultivar Tonda Gentile Romana is cultivated and the orchard, equipped with a subirrigation system, is spaced at 5 x 5 m. Ten additional trees have been selected in an adjacent row as control. In these trees chemical suckering control will be carried out with traditional applications (denoted in the following also as "traditional spray"). The same scheme has been established also in field 16 to test the model on young trees (orchard four-year-old, cultivated with Nocchione, spaced 4.5 x 3 m). Both adult and young trees are grown as multi-stemmed bushes (see for example the trees depicted in Figure 19, Figure 20, Figure 21, Figure 22, Figure 23, and Figure 24). All selected trees have been assigned an ID code as they represents the samples for the validation of sucker detection and control (their coordinates are listed in Table 7).

We selected trees of different ages because, it is well known in the literature that trees of diverse ages are differently influenced by several factors, such as light penetration into the canopy, different translocation of photosynthetic substances, dissimilar vegetative growing aptitude and entity of fructification [11]. The above concept is also reinforced by the ecophysiological measures carried out during the growing season 2018 on mature leaves of suckers in comparison with those of sprouts of branches on the same trees. As shown inTable 6, chlorophyll, flavonoid, anthocyanin contents and the NBI varied significantly. Furthermore, the NBI observed in the leaves of suckers significantly decreased from late June to late July, as the nitrogen substances were moved in the stem during its progressive lignification. For these reasons, the trials consider both adult and young orchards, as they are characterized by a different suckers development, in terms of both rate of growth and abundance.

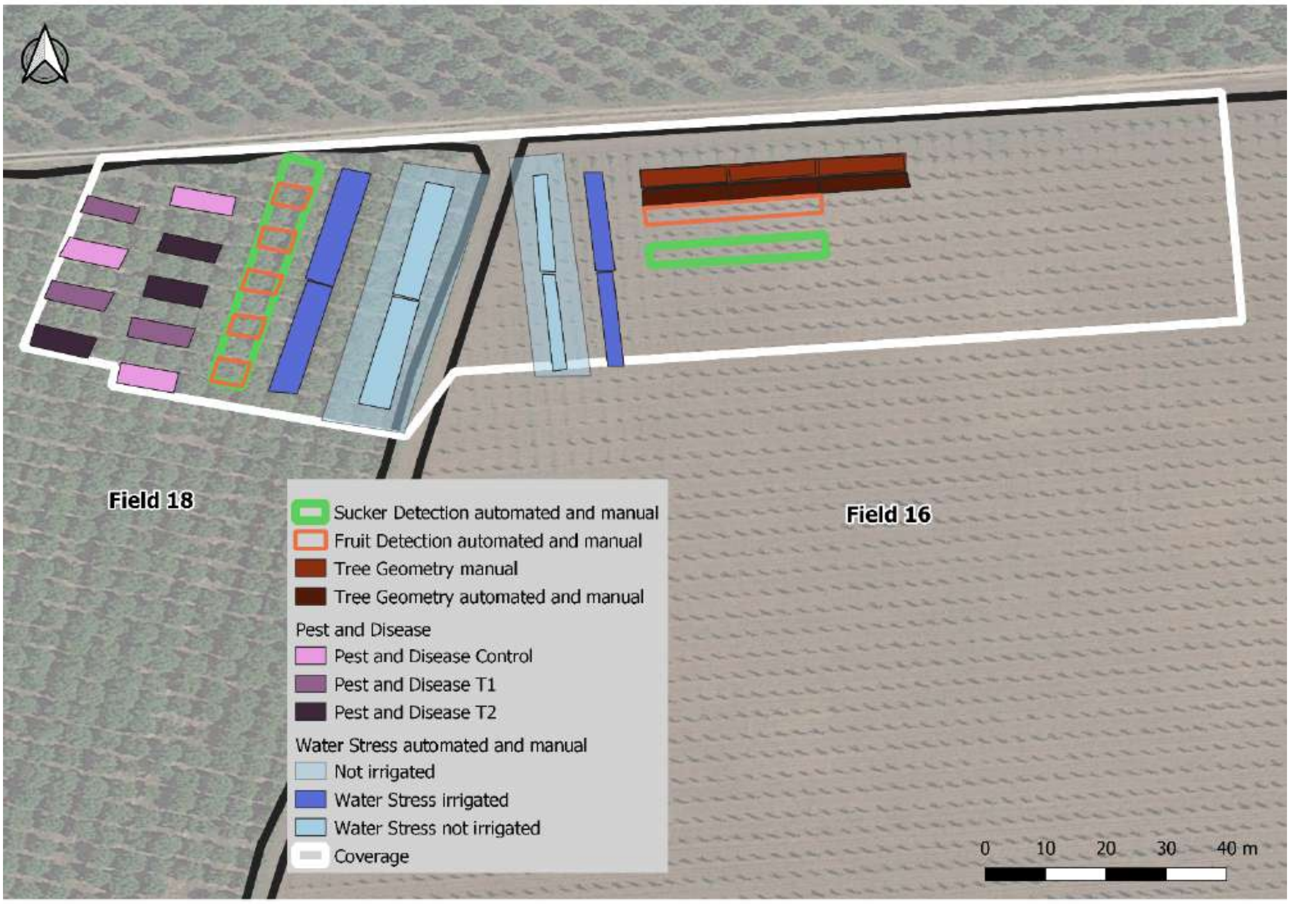

Figure 16 - Overview of trials performed in PANTHEON Project. Trees for sucker detection have been selected both in an adult orchard and a young orchard.

Figure 17 – As Figure 16, but with a zoom in on the trees selected for sucked detection and control.

		Chlorophyll (µ cm^{-2})	Flavonoid (µ cm^{-2})	Anthocyanins (µ cm^{-2})	NBI
26 June 2018	***Shoot***	42.07 ± 3.86	1.67 ± 0.23	0.05 ± 0.02	25.59 ± 3.60
	Sucker	35.14 ± 6.97	1.17± 0.35	0.05 ± 0.02	31.05 ± 5.81
27 July 2018	***Shoot***	41.02 ± 3.97	1.65 ± 0.17	0.07 ± 0.03	25.00 ± 3.10
	Sucker	32.70 ± 6.96	1.33 ± 0.26	0.09 ± 0.03	25.31 ± 6.24

Table 6 - Chlorophyll, flavonoid, anthocyanins and Nitrogen Balance Index (NBI) measured in the adult leaves of suckers compared with adult leaves of shoots of the same trees. These measurements were carried out randomly selecting ten trees of cultivar Nocchione in field 16.

Tables 6 report coordinates and ID of each selected trees.

Plant Code	Latitude N	Longitude E
Ad S1	42°16’47.20908”	12°17’52.5750”
Ad S2	42°16’47.14104”	12°17’52.46052”
Ad S3	42°16’46.9992”	12°17’52.37124”
Ad S4	42°16’46.89444”	12°17’52.39608”
Ad S5	42°16’46.61164”	12°17’52.40148”
Ad S6	42°16’46.50384”	12°17’52.22112”
Ad S7	42°16’46.1874”	12°17’52.03032”
Ad S8	42°16’46.22556”	12°17’52.1448”
Ad S9	42°16’46.03872”	12°17’52.0602”
Ad S10	42°16’46.00452”	12°17’52.0656”
Yo S1	42°16’46.76484”	12°17’55.365”
Yo S2	42°16’46.7562”	12°17’55.47732”
Yo S3	42°16’46.73856”	12°17’55.59252”
Yo S4	42°16’46.75872”	12°17’55.67712”
Yo S5	42°16’46.79472”	12°17’55.78692”
Yo S6	42°16’46.83144”	12°17’55.9212”
Yo S7	42°16’46.81308”	12°17’56.13864”
Yo S8	42°16’476.8282”	12°17’56.2308”
Yo S9	42°16’46.84764”	12°17’56.3694”
Yo S10	42°16’46.86024”	12°17’56.41188”

Table 7 - Geographic coordinates (WGS84) of the selected trees for sucker detection and control.

As already previously mentioned, during the year 2018 an accurate evaluation of sucker canopy development and farmer standards in term of suckers control has been carried out in pre-selected and representative rows randomly selected the orchards (field 18 and field 16), both for adult and young trees. These observations, carried out on a weekly basis, have contributed to determine the best strategies to estimate the number of suckers per plant. Such observations are briefly described below and a synoptic panel of the suckers development and control is reported in Annex 2. Starting at end of March 2018 the suckers emission attitude in fields 16 (young orchard, CV Nocchione, orchard design 4.5m x 3m) and 18 (adult orchard, CV Tonda Gentile

Romana, orchard design 5m x 5m) were recorded and photographed, without interfering with the ordinary farmer orchard management.

Figure 18 - Manual cutting and weighing operations of suckers in the young hazelnut trees of field 16.

Here below we report in a synthetic way the most important monitoring activities performed in the 2 fields.

Field 18 ("Tonda Gentile Romana", medium suckering attitude CV):

30 March 2018 - In early spring no suckers were detected: the farmer had applied herbicide at the beginning of March for grass control among the rows, which postponed spring suckers emission.

13, 20 April 2018 - On 13 April, suckers started to develop and then during the last week of April they showed an average growth of 15 cm in height (ready to be treated with a herbicide).

27 April 2018 - Suckers reached an average height of about 30 cm, and the farmer applied a proper herbicide for their control.

3, 11, 18 25 May 2018 - Suckers halted their growth (3 May 2018) and progressively showed desiccation, because of the herbicide treatment.

1 June 2018 - New suckers emission began.

8, 15 June 2018 - A second treatment was performed by the farmer, to control the new suckers emission.

22, 29 June; 6, 13, 20, 27July; 3 August 2018 - No suckers emission was detected during late June and July.

10, 17, 24, 31 August 2018; 7, 14, 21 September 2018 - In August, a few new suckers started to develop, showing a small vigor and a non-uniform crown. After a month, the suckers control properties decreased drastically, mainly caused by the low vegetative growth of the trees in late summer, but less by the herbicides. These suckers did not bother harvesting processes and continued to slowly grow during September.

28 September 2018; 5, 12, 19, 26 October 2018; 2 November 2018 - No more suckers development was observed, both in terms of number and vigor. The stems of the few remaining suckers progressively lignified.

Field 16 ("Nocchione", medium-strong suckering CV):

30 March, 6; 13 April 2018 - In this period no suckers were detected, since in late February the farmer manually performed a "training pruning" (to set up the structure of young trees), cutting also all suckers emitted by the trees.

20, 27 April; 3, 11, 18, 25 May 2018 - During the second half of April and May, suckers started to develop with high vigor, covering the entire basal crown of the young trees.

June, July, August 2018 - At beginning of June, the developmental stage of suckers did not allow for chemical

control. In spring-summer 2018, the farmer applied suckers control, to harvest new self-rooted suckers in the subsequent autumn. With a height greater than 50 cm, these suckers start to compete for nutrients and water with the young tree, affecting negatively the seasonal growth of the trees, as confirmed by the portable DUALEX measurements, carried out in late June and late July. In particular, in late June the measurements confirmed a higher Nitrogen Balance Index (NBI), assessed in the adult leaves of the suckers, compared to the shoots of the same trees.

September; October 2018 - During these months, suckers stopped their growth and the lignification phenomenon began. Also, external suckers penetrating the trees crowns resulted in a reduced crown development.

The decision of the farmer to avoid suckers control of the young trees - in order to harvest self-rooted suckers to establish new plantations - negatively influenced the seasonal growth of the trees. Starting in the second year, suckers control will be required to reach the project's objectives. Furthermore, the biometrical growth of selected suckers will be recorded, in order to monitor the growth of the suckers.

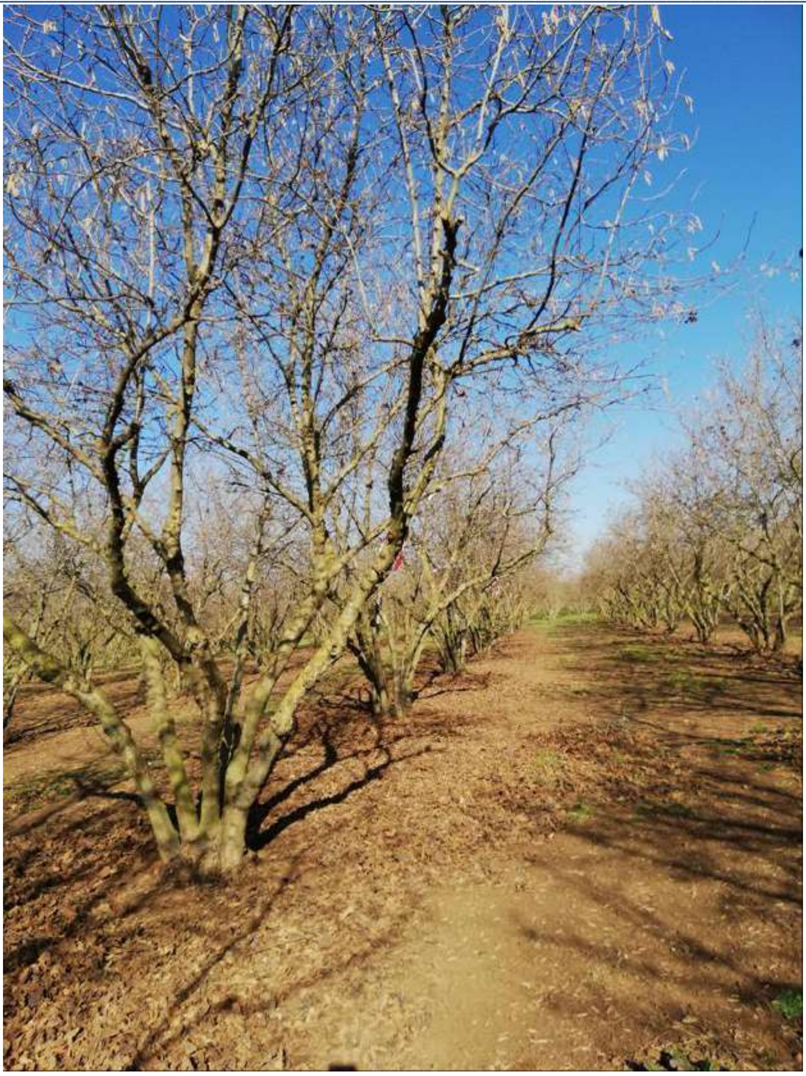

Figure 19 - Row overview of the selected mature trees (field 18, CV Tonda Gentile Romana) after manual suckers cutting performed in middle January 2019.

Additionally, at the beginning of 2019 a manual sucker cutting has been performed on selected trees (Figure 18, Figure 19, and Figure 20), both in mature and young orchards, and the new suckers development is under investigation, without any influence (Figure 21 and Figure 22) from the farmer. For the young trees, a heavy cutting of suckers has been carried out, given that the grower did not perform suckers during the growing season 2018. In Table 8 we list the weight of suckers removed from each young tree, and the quantity of wood recorded (on average 2.5 kg per plant). This highlights the importance of sucker control also in young trees, as the wood development of the suckers would have removed carbohydrates from the main branches.

Figure 20 - Row overview of the selected young trees (field 16, CV Nocchione) after manual suckers cutting performed in mid-January 2019

Plant Code	Weight of woody suckers per plant (kg)
Yo S1	0.58
Yo S2	0.66
Yo S3	2.62
Yo S4	2.59
Yo S5	0.99
Yo S6	0.92
Yo S7	3.83
Yo S8	4.40
Yo S9	4.68
Yo S10	3.30
Average	2.45

Table 8 - Weight of woody suckers in the young trees of field 16 at mid-January 2019.

Figure 21 – View of the new sucker emission in one of the selected mature trees (plant Ad S1, CV Tonda Gentile Romana, field 18) observed in the first week of april 2019.

Figure 22 – View of the new sucker emission in one of the selected young trees (plant Yo S1, CV Nocchione, field 16) observed in the first week of april 2019.

4 Validation of the control protocol effectiveness

Here we propose activities for the experimental validation of the proposed estimation and control algorithms of hazelnut suckers emission attitude, to be applied in large-scale hazelnut orchards. In particular, we plan to monitor suckers emission and development in selected trees, as described in the previous sections. The developed numerical protocol will be used to decide whether a plant needs sucker treatment or not and the amount of herbicide to be sprayed based on the indicators defined in Objective 2.1 of the DoA.

The calibration of the amount of herbicide based on the available numerical indicators will be fine-tuned through experiments and measurements in the test field. During the first year, a fundamental activity to both develop the numerical control protocol and to design the validation one has been the monitoring of suckers emission entity in the experimental orchard, managed with the ordinary practices adopted by the farmer. Notably, starting with the growing season in 2019, suckers development in the selected trees (innovative management and traditional one) will be both manually and automatically monitored.

Figure 23 details the sucker growth stage recorded in two different trees, selected for the monitoring and validation protocol, observed in late April 2019. As shown in the pictures, the suckers are in "green stage", the stems are not yet elongated and very hydrated and more in general all suckers present are in the herbaceous stage. This sucker development stage is agronomically considered the best period for the first seasonal suckering application, both to obtain high efficiency of treatment and save quantity of herbicide [2].

Figure 23 - Sucker development at "green stage" observed on 29th April 2019 in the young orchard (field 16; CV Nocchione). On the left it is reported the suckers development of plant Yo S1, while on the right it is reported the suckers development of the control plant.

4.1 Activities for the experimental validation

The following activities will be taken into account for the validation of the numerical control protocol:

1. Quantification of the amount of herbicide to be sprayed in the selected trees;

2. Monitoring of the changes in terms of effectiveness for sucker drying, between the two approaches of application (traditional vs automated);

3. Monitoring of the interval between two consecutive treatments (in case of suckers regrowth) and if and how this is influenced by the two approaches.

In the following a brief description for each of these activities is provided.

4.1.1 Quantification of the amount of herbicide to be sprayed in the selected trees

We expect the model to provide the amount of herbicide to be sprayed per tree. This dataset will be used to prepare the right amount of herbicide to be used to treat the selected trees. Similarly, a "standard amount of herbicide" calculated following the indications on the label of the commercial product (0.4 to 0.9 l on 300 l of water per hectare), will be prepared and used to treat the "control trees". This approach will be adopted both for mature and young trees. This will allow to understand if, by means of the proposed numerical protocol, a more environmental-friendly management of the orchard can be achieved.

4.1.2 Monitoring of the changes in terms of effectiveness for sucker drying, between the two approaches of application (traditional vs automated)

To evaluate and quantify the effectiveness of the automated protocol with respect to the traditional one, time of suckers drying will be monitored. This evaluation will be made not only with visual checks, i.e., considering the most appropriate approach as described in Figure 24, but also measuring over time ecophysiological parameters, such as the index of chlorophyll presence and NBI in selected leaves of treated suckers, applying non-destructive approaches. This will allow to understand if, by means of the proposed numerical protocol, a more effective management of the orchard can be achieved.

4.1.3 Monitoring of the interval between two consecutive treatments (in case of suckers regrowth) and if and how this is influenced by the two approaches

This monitoring activity will be performed counting over time the entity and the time of suckers regrowth in the stumps. Similar to the previous activity, this will be very useful to discriminate if, the proposed numerical protocol, is more effective and is capable of saving herbicide application during the suckers growing season.

Figure 24 - Stump of a mature tree subjected to traditional suckering treatment (unselected tree in field 21, CV Tonda Gentile Romana). In red box is highlighted the apical portion of dried, meanwhile in the white box are highlighted suckers in light green color.

4.2 Benchmarks and Possible Additional Outcomes

In this section, we briefly recall the benchmarks introduced in the deliverable D2.1 “Requirements, Specifications and Benchmark” that will be considered for the validation of the numerical protocol that has been described in Section 2:

1) automated detection of presence/absence of suckers with an omission error below 20% and with a commission error below 20% for suckers longer than 5 cm;
2) automated detection of presence/absence of suckers with an omission error below 25% and commission error below 25% for suckers shorter than 5 cm;
3) discrepancies between the automatic sucker treatment decision and the decision that would have been taken by an expert human in less than the 15% of the cases.

In the following, we briefly discuss possible additional outcomes of the validation activities.

Notably, as a by-product of the validation activities we expect to produce also an “application calendar”, capable to define the most suitable temporal windows of application for suckers treatments where better results can achieved by minimizing the amount of herbicides required to control suckers.

In addition, during the validation operations, we will consider also the possibility of replacing the chosen AI (Carfentrazone ethyl) with an organic one (i.e., Trade name: Urban Weed). This would allow to evaluate the effectiveness of the proposed numerical protocol in the "biological control" of suckers, thus paving the way for an even more environmental-friendly orchard management.

Furthermore, another potential by-product of the validation activities will be to investigate the effectiveness of the suckers detection algorithm with respect to some of the single-trunk plants in the young orchard (Field 16, CV Nocchione), selected for tree geometry reconstruction. This will allow to evaluate whether a different training growth strategy may result more amenable for automatic sucker estimation and control. Figure 25 depicts a different sucker canopy shape and entity with respect to the traditional tree grown as bush which is used in the farm.

Figure 25 - View of whole plant (left) and of the base of its trunk (right) performed at beginning of 2019 for tree geometry reconstruction (plant Yo B7; field 16; CV Nocchione). Note the different way in which the sucker crown develops compared to those of plan

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D5.2 - Annex 1

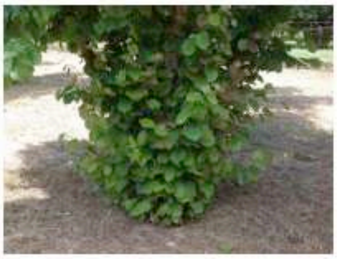
Sucker emission aptitude of Corylus avellana L. reported by Koksal A.I., Gunes N.T., 2008. Descriptors for hazelnut (Corylus avellana L.). Bioversity International, Rome, Italy; Food and Agriculture Organization of the United Nations, Rome, Italy; International Centre for Advanced Mediterranean Agronomic Studies, Zaragoza, Spain. ISBN: 978-92-9043-762-8. Pp. 56.

0 (Absent)
Reference cultivar:
Dundee
Vigour: hight
Growth habit: arboreus

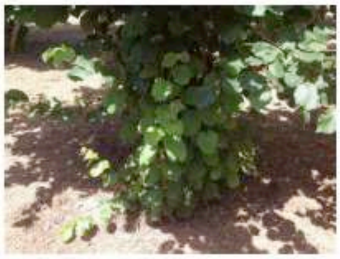
1 (Very weak)
Reference cultivar:
Pallagrossa
Vigour: high
Growth habit: upright

3 (Weak)
Reference cultivar:
Ennis
Vigour: intermediate - high
Growth habit: spreading

5 (Medium)
Reference cultivar:
Tonda Gentile Romana
Vigour: low - intermediate
Growth habit: upright



7 (Strong)
Refernce cultivar:
Tonda Gentile delle Langhe
Vigour: intermediate - high
Growth habit: intermediate



9 (Very strong)
Reference cultivar:
Tombul
Vigour: weak
Growth habit: very spreading

The intermediate codes includes two classes of sucker emission as follows: code 2 = Very weak-Weak; code 4 = Weak - Medium; code 6 = Medium - Strong; code 8 = Strong - Very Strong

Sucker emission aptitude of 48 hazelnut cultivars revealed in middle June 2018 (Collection field "Le Cese", Viterbo province, Italy)

Annusa Racinante

Apolda

Avellana Speciale

Barcelona

Barrettona

Bearn

Camponica

Carrello

Closca Molla

Comen

Comune di Sicilia

Cosford

Daviana

Ennis

Fructo Rubro

Gironell

Grifoll

Grossal

Gunslebert

Hynich

Jean’s

Karidaty

Longue d'Espagne

Merveille de Bollwiller

Minnolara

Montebello

Morell

Napoletanedda

Negret

Nocchione

Nociara

Nostrale

Pallagrossa

Piazza Armerina

Racinante

Riccia di Talanico

San Giovanni

Santa Maria del Gesù

Segorbe

Sivri “A”

Tombul

Tonda Bianca

Tonda di Giffoni

Tonda Gentile delle Langhe

Tonda Gentile Romana

Tonda Rossa

Vermellet

Vermellet SP

D5.2 - Annex 2

Monitoring of suckers' development in farm "Azienda Agricola Vignola" - Growing season 2018

Field 18

(cv Tonda Gentile Romana)

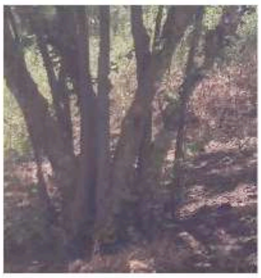
Adult orchard (about 30 year old)
Orchard design 5m x 5m
Growing system (multi-stemmed bush)

Brief cultivar description:

The nuts are medium sized (2.5 g), with a kernel/nut ratio of about 45%, spherical shape, low pellicle removal, and good taste and aroma. The cultivar is characterized by a medium to high productivity, intermediate vigour, late bud break and medium to late ripening. The alleles of incompatibility are $S_{\underline{10}}S_{\underline{20}}$.

30 march 2018

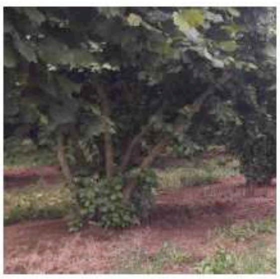
6 april 2018



13 april 2018

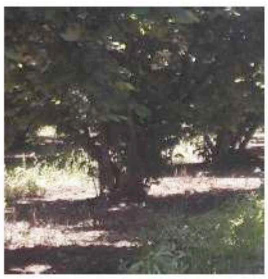
20 april 2018

27 april 2018

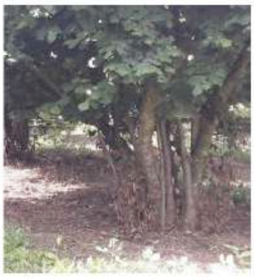


3 may 2018

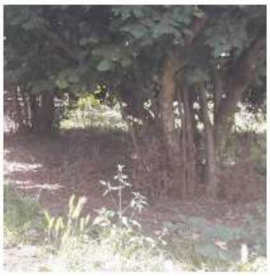
11 may 2018



18 may 2018

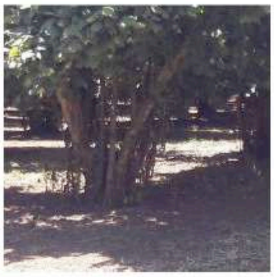


25 may 2018



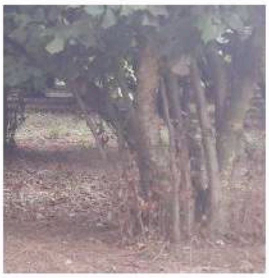
1 june 2018

8 june 2018



15 june 2018

22 june 2018

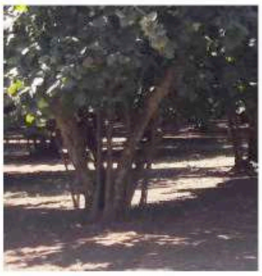


29 june 2018

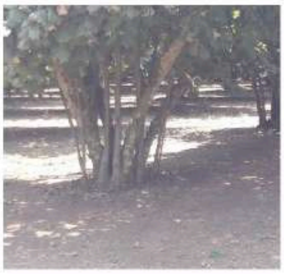
6 july 2018

13 july 2018

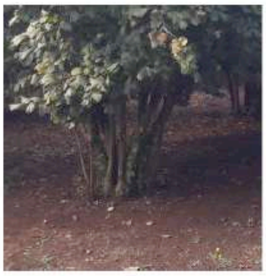
20 july 2018



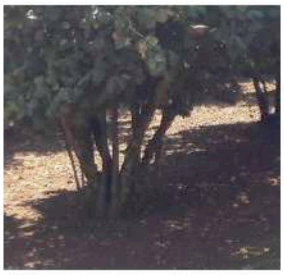
27 july 2018



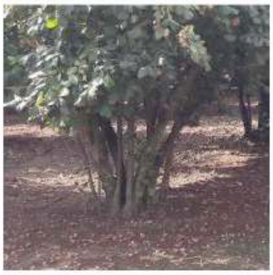
3 august 2018



10 august 2018

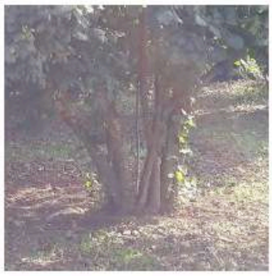


17 august 2018



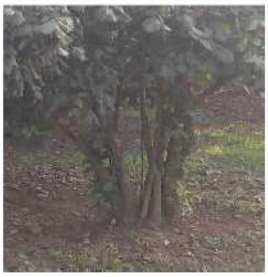
24 august 2018

31 august 2018



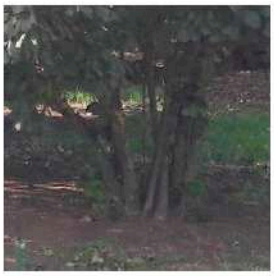
7 september 2018

14 september 2018

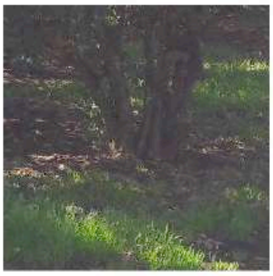


21 september 2018

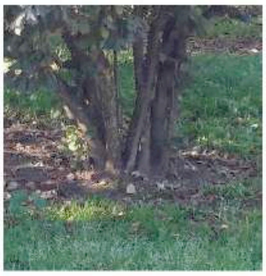
28 september 2018



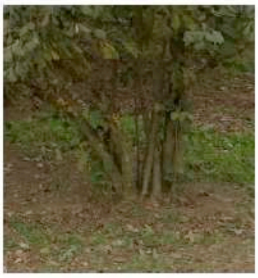
5 october 2018



12 october 2018



19 october 2018



26 october 2018

2 november 2018

Field 16

(cv Nocchione)

Young orchard (3 year old)
Orchard design 4.5m x 3m
Growing system (multi-stemmed bush)

Brief cultivar description:

The nuts are of medium to large size (3 g), with a low kernel per cent (38%), spherical shape, good pellicle removal, and excellent taste and aroma. This cultivar displays high productivity, intermediate to high vigour, early bud break, early to intermediate ripening and good adaptability to different environments. The alleles of incompatibility are S_1S_2.

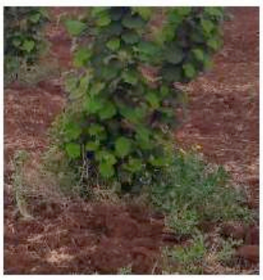
30 march

6 april 2018

13 april 2018

20 april 2018

27 april 2018

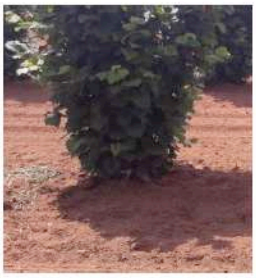


3 may 2018

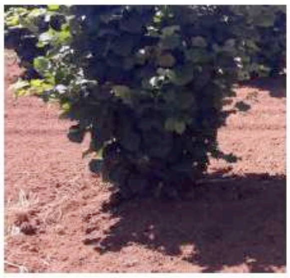
11 may 2018

18 may 2018


25 may 2018


1 june 2018


8 june 2018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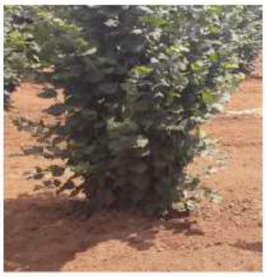
22 june 2018


29 june 2018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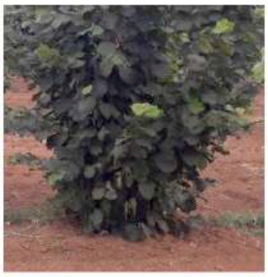
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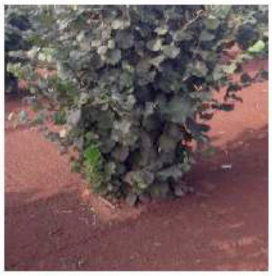
27 july 2018


3 august 2018


10 august 2018

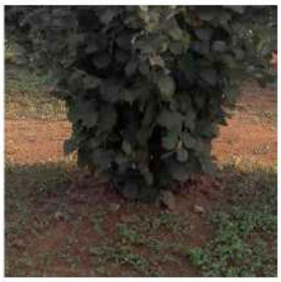

17 august 2018

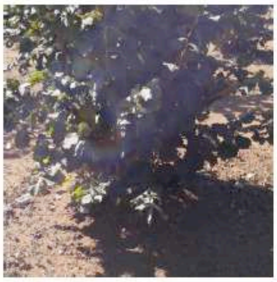

24 august 2018


31 august 2018


7 september 2018


14 september 2018


21 september 2018


28 september 2018


5 october 2018


12 october 2018


19 october 2018


26 october 2018


2 november 2018