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## Real-world (1:1 scale) hazelnut orchard for final demo

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**Executive Summary**

This document comprises a detailed description of the dimensioning of a real-word (1:1) hazelnut orchard, which will be used for the experimental validation of the SCADA concept proposed within the project PANTHEON. Furthermore, this document describes the farming operations to be considered for the final demo. The following aspects are considered:

1. Size of the orchard: Identification of the fields to be used for the experiments and the final demo.
2. Frequency of the monitoring activities: Identification of the monitoring activities, both automated and manual, of their temporal resolution and of the locations where to be performed.
3. Frequency of the agronomic interventions: Identification of appropriate agronomic activities, of their temporal resolution and of the requirements for the management of a typical large-scale hazelnut orchard.

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**Abbreviations and Acronyms**

| | |
|---|---|
| ha | hectares |
| LAI | Leaf Area Index |
| UAV | Unmanned Aerial Vehicle |
| UGV | Unmanned Ground Vehicle |
| BBCH | Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie |
| Lidar | Light Detecion and Ranging |

# 1 Size of the orchard

Modern hazelnut farming is generally carried out in well-structured orchards with a regular planting pattern. Typically, plants are organized in a planting scheme of X (distance between rows) x Y (distance between trees), with X x Y being one of the following possibilities, in meters: 5x3, 5x4, 5x5, 6x5, 6x4, 6x3. The use of regular layouts allows the mechanization of many field operations, which are carried out through orchard tractors and agricultural machinery.

The main drawback of current hazelnuts farming procedures is that, for large plantations (i.e. >10 ha), performing a per-plant monitoring and responding to the needs of each single plant is particularly challenging. In current best practices, decisions are made by assessing the status of a few plants, considered representative of the orchard, and extending the treatment to the entire sector where these plants are located, which in the case of the larger plantations may mean an area of up to 50 ha.

In the management of large orchards, the following 5 activities are among the most time consuming and labor-intensive ones that involve extrapolating the status of the entire field from a few representative trees: **irrigation, pruning, sucker detection and removal, pest and disease detection and harvest estimation**.

**Irrigation** is meant to compensate for water stress. It is usually carried out through fixed equipment and may consist of drippers, or sprinklers, or a mix of both. Typically, for plantations bigger than 50 ha, water treatment is the same for homogeneous portions of 5-10 ha, depending on irrigation water availability, wells and reservoirs. Water needs are usually regulated through remotely controlled valves. Fertilization is performed also through the irrigation system, which results in a uniform input being applied to the same portions of 5-10 ha. Currently, both irrigation needs and treatments are decided by the agronomist based on a qualitative evaluation and on quite scarcely sampled quantitative measurements that are performed on some representative trees for each homogenous portion of 5-10 ha.

The hazelnut tree is a suckering plant and its natural growth habit is the bush. To encourage the growth as a tree or as a vase-shaped plant, pruning and suckers' management are fundamental activities. **Pruning** has the following main objectives: obtaining early bearing through the development of tree structure (training), regulating vegetative and reproductive growth and, as a consequence, sustaining constant bearing of high-quality fruits. Pruning also facilitates orchard operations, like the use of machinery within the plantation. Young plants (and mature ones too in smaller orchards) are usually pruned manually by qualified workers. For what concerns large plantations of mature plants, pruning is carried out mechanically every 3-4 years, using vertical saws towed by tractors which cut all the plants in alternate rows, without trying to obtain a specific shape.

The most common method for **suckers' control** for large plantations is the administration of herbicides. This is mainly manually performed by field workers, who walk around the orchard spraying all plants. The herbicide is usually sprayed two times per growing season when suckers are still herbaceous (height of <20 cm). Sometimes, for the largest 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, and a non-calibrated and uniform amount of herbicide is applied to all plants; whereas it is well known that sucker emission attitude varies in relation to the specific cultivar, plantation density and to the tree shape growing system.

**Pest and disease control** are traditionally performed by spraying chemical products on the canopy of the trees, using atomizers carried by tractors. To detect the right moment to treat and avoid useless treatments, the various parts of the orchards are inspected regularly by agronomists, who decide whether and when to perform the treatments (again typically for homogeneous areas from 5 ha up to 50 ha).

Finally, especially for large orchards, the **production estimation** with a consistent lead time is a crucial piece of business intelligence information for the plantation manager. The current procedure requires walking in the field, counting the number of fruits on a branch of a "representative plant", and extending the result to a homogenous portion of the orchard (up to 50 ha). This procedure is time consuming, tedious and may lack of accuracy and objectivity.

The goal of this project is to take advantage of recent advances in the fields of robotics and remote sensing to allow for the collection of data at the level of each single tree, in order to automatize, render more productive and more environmentally friendly the 5 activities described above.

To test the proposed idea, 3 fields were selected within the "Azienda Agricola Vignola", a farm located in the municipality of Caprarola, in the province of Viterbo: they are displayed in Fig. 1 and their characteristics are listed in Tab. 1.

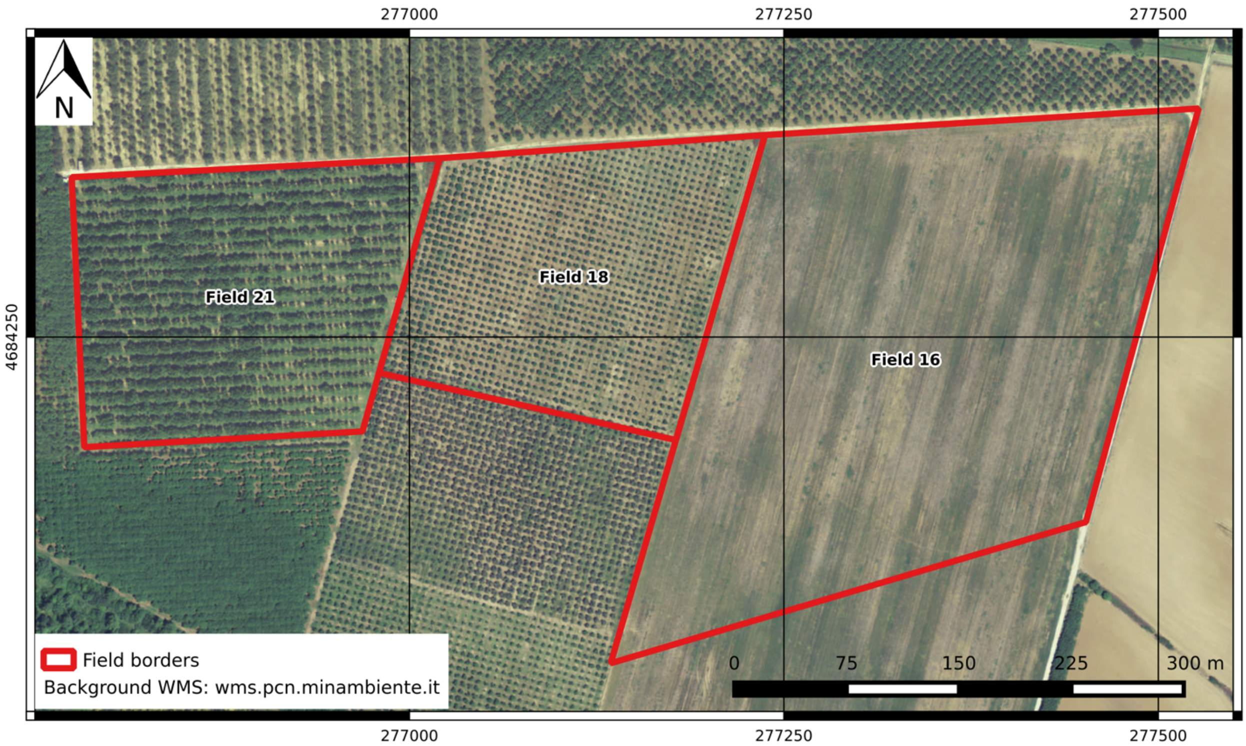


**Fig. 1:** Selected fields for the Pantheon project.

**Tab. 1:** Selected fields for the Pantheon project and their characteristics.

| Name | Area (ha) | Variety (-) | Density (m) | Age (year) | Irrigation (-) |
|---|---|---|---|---|---|
| Field 16 | 9.1 | Nocchione | 4.5x3.0 | Young: third leaf in the field | Underground drip irrigation: double line between the rows, 0.8m from the tree lines |
| Field 18 | 3.1 | Tonda Gentile Romana (Nocchione as pollinizers) | 5.0x5.0 | Adult: 30 | Underground drip irrigation: 1 line between the rows |
| Field 21 | 3.8 | Tonda Gentile Romana (Nocchione as pollinizers) | 8.0x4.0 | Old: >40 | Underground drip irrigation: 1 line between the rows |

The shapefiles (see Fig. 1) of the 3 selected fields have been shared with the partners, in order to plan field activities and decide where to perform different experiments, both for automated and manual sampling activities. To carry out the different tests foreseen in the proposal, the experiment design is composed of a certain number of selected trees, as is illustrated in Fig. 2 and Fig. 3. In particular, the tentative locations of different trees have been individuated in all the 3 fields.

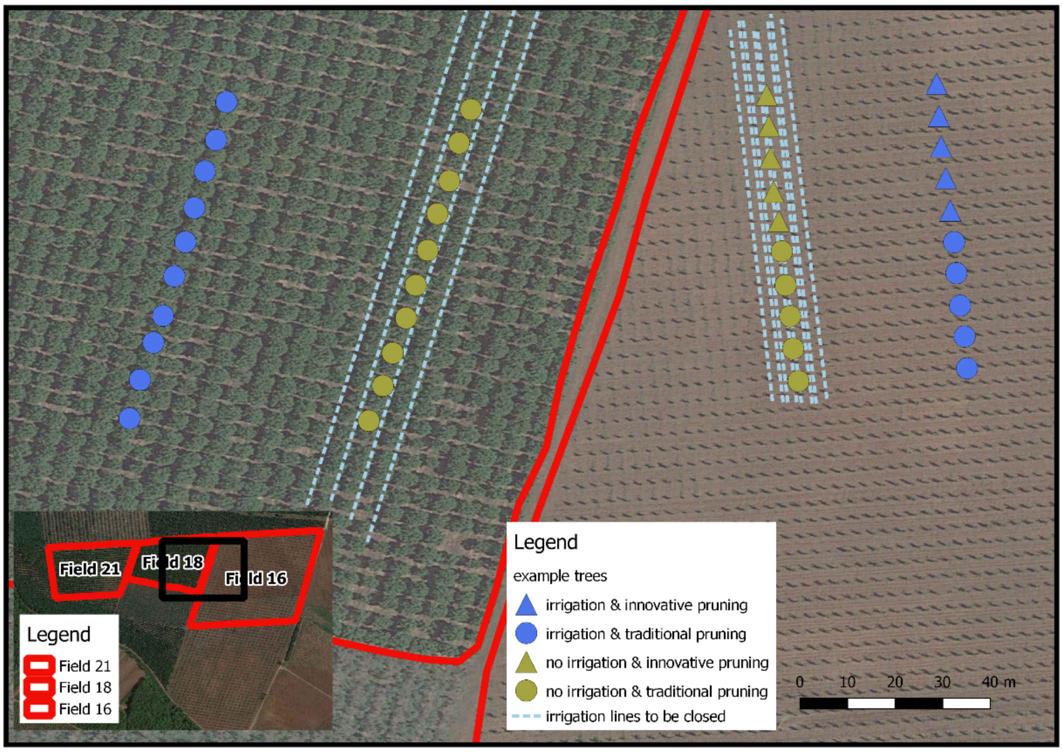


**Fig. 2:** Tentative selected trees and fields for the Pantheon project: irrigation and pruning tests. Harvest estimation will be performed on ~10 of the trees selected in Field 16.


**Fig. 3:** Tentative selected trees and fields for the Pantheon project: pest and disease tests.

For a reasonable planning of orchard management activities, a certain pre-defined number of trees will be selected in each field. An example of tree selection has been proposed in Fig. 2 and Fig. 3, according to the following guidelines in terms of number of trees, fields in which to select such trees and experiments to be attributed to each group of trees:

- Water stress: on ~10 trees selected in field 18 and ~10 trees selected in field 16;
- Sucker detection and control: on ~10 trees in field 18;
- Fruit detection: on ~10 of the trees selected in field 16;
- Tree geometry reconstruction: on ~10 trees selected in field 16, with half of the trees chosen for traditional pruning and the remaining half for innovative pruning;
- Pest and disease detection: on ~15 trees selected in field 21, with 5 of these trees chosen for "infestation T0", 5 as "infestation T1" and the remaining 5 chosen as control (protected against infestation).

The reasons for proposing these guidelines are here reported. For water stress, a significant number of trees have to be selected in a certain field; however, the number of trees has to be compatible with both the manual and the automated monitoring activities and the time availabilities of the consortium. Field 16 was selected to investigate water stress in young plants, while field 18 will provide insights on the behavior of adult plants under stress/no-stress conditions. Given the similarities between field 18 and field 21, we opted for field 18, given its proximity to field 16. In each of the selected fields (16 and 18), half of the total number of selected plants will be routinely irrigated, according to the standard irrigation regime of the farm manager, while the other half will be subject to no irrigation. The reason for selecting all these trees in rows is to limit the number of irrigation lines to be closed. Of course, more than 2 irrigation lines (one to the right to the selected row and one to its left), will need to be closed to make sure to induce water stress on the plants.

For sucker detection, a number of trees will be selected in field 18, which is composed of adult trees. On the other hand, fruit detection will be performed on trees in field 16, which has younger trees that should be faster to automatically image, at the same time simplifying the manual collection of hazelnuts for validation purposes.



Innovative pruning consists in pruning the shoots in the upper part of the crown of a young tree during its growth phase, in order to allow more light reaching the inner portion of the crown and to promote flower induction during the production phase. Field 16 was selected for tree geometry reconstruction given the young age of the trees that allows an easier approach in pruning and training of such trees to the desired pruning strategy. In order to compare differences between traditional and innovative pruning, half of the trees chosen for tree geometry reconstruction will be pruned in a traditional manner and the rest with innovative pruning strategies.

Eventually, pest and disease detection will be performed in field 21. The number of trees will be a multiple of 3, in order to have 1/3 of the trees with an earlier infestation time, 1/3 of the trees with a later infestation time and the remaining third with no infestation, so to be used as control.

By the end of 2018, this tentative plan will be converted into a defined selection of specific trees. Following the above guidelines, a precise number of specific trees will be selected in each field and every single tree will be geolocated, attributed a tree-ID with all metadata of interest (coordinates, age, variety, …), and assigned specific tests (i.e. no_irrigation, irrigation, pest_n1, no_pest, …).

Concerning pest and disease monitoring, for all plants of field 21, the five agronomically most important branches will be selected. Such branches will be chosen with the additional condition that they must also be visible vertically to the Unmanned Aerial Vehicles (UAVs) and possibly laterally to the Unmanned Ground Vehicles (UGVs). All these branches will be protected by handmade cages at T0 time (at the beginning of the trials). These cages are composed of a net bag that encloses the apical part of the branch. The net bags of the plants named "infestation T0" will be artificial infested adding true bugs at time T0 (~May), while the plants named "infestation T1" will be infested at time T1 (~June). The remaining "no infestation" plants will not be infested and will be used as control. Both "infestation T0" and "infestation T1" plants will be infected with the main representative true bug pests of the area. Such true bugs are those capable of causing the two most impacting different kernel damages. If the insects infest the newly developed fruits (May and June), they cause kernel abortion and the plant drops the infested fruit (damage detectable on the "infestation T0" plants). If the true bugs infest the growing fruit (from the end of June to the beginning of August), they cause kernel malformation and an unpleasant nut flavors named "cimiciato" (damage detectable on the "infestation T1" plants).

All the selected trees will be regularly monitored both manually and automatically, i.e. with UAVs/UGVs and the on-board sensors, following the procedures described in Section 2.1 for manual monitoring performed by experts and Section 2.2 for monitoring conducted with automated procedures.

# 2 Frequency of the monitoring activities

As anticipated, all selected trees will be subject to both manual and automated monitoring activities. Manual monitoring activities replicate standard agricultural practices in orchard management, with the added value that in this case the scientific partners will monitor at a higher temporal and spatial sampling rate all the selected trees. The dataset outcome of manual monitoring will represent the calibration and validation database for the automated monitoring activities. Indeed, automated monitoring is the main objective of the project and it will be developed on the selected trees.

## 2.1 Manual monitoring activities

Manual monitoring activities will be carried out by the scientists of the PANTHEON consortium partner UNITUS on a ten days basis all year round, in order to obtain a strong calibration and validation dataset, which is of paramount importance for this study. Every ten days all trees will be monitored by experts for:

- Phenology phases: according to the reported example of phenology report (see Tab. 2).
- Pest and disease monitoring: according to the reported example of pest and disease report (see Tab. 3).
- Additional biometric variables: including presence and geometry of suckers (see Tab. 4).

Phenology is the study of seasonal changes in the trees, such as flowering, leaf emergence, fruiting, etc., and their relationship with weather and climate.

In case of extreme events like snowfall and strong wind, manual monitoring will be suspended.

Additionally, two yearly activities will be performed by UNITUS:

- For the trees selected in field 16 for innovative pruning, such type of pruning will be done in the period of January – February: the outcome will be compared with the remaining trees selected in the same field for traditional pruning.
- For all trees on which automated fruit monitoring will be carried out, manual or vacuum collection of production per tree, at harvest time (end of August for Nocchione, first 15 days of September for Tonda Gentile Romana) will be performed.

According to the example of phenology report provided in Tab. 2, all trees will be monitored every 10 days.

To fill out the three last columns of Tab. 2, we consider a total of 24 phenological phases, including 10 vegetative phases, 5 male flower phases and 9 female flower phases as reported below:

- Vegetative phases: V01, V02, V03, V04, V05, V06, V07, V08, V09, V10.
- Male flower phases (catkins): M01, M02, M03, M04, M05.
- Female flower phases (clusters of stigmas): F01, F02, F03, F04, F05, F06, F07, F08, F09.

The meaning and description of each phase will be detailed in a technical report using appropriate pictures. In addition, a simulation model for hazelnut according to the “Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie” (BBCH) scale will be developed.

**Tab. 2:** Example of phenology report.

| Field | Tree-ID | Monitoring date | Male Phase | Female Phase | Vegetative Phase |
|---|---|---|---|---|---|
| 16 | 18_1 | DD/MM/YYYY | | | |
| 16 | 18_2 | DD/MM/YYYY | | | |
| 16 | … | … | | | |
| … | | | | | |
| 18 | 18_1 | DD/MM/YYYY | | | |
| 18 | 18_2 | DD/MM/YYYY | | | |
| 18 | … | … | | | |
| … | | | | | |
| 21 | 21_1 | DD/MM/YYYY | | | |
| 21 | 21_2 | DD/MM/YYYY | | | |
| 21 | … | … | | | |
| … | … | … | | | |

For what concerns pest and disease monitoring (see list on Pag. 10), the example of pest and disease report provided in Tab. 3 foresees 10-day monitoring activities of all the selected trees.

**Tab. 3:** Example of pest and disease report.

| Field | Tree-ID | Monitoring date | Pest/Disease | Severity | Fraction of tree affected (%) | Collected samples for lab test |
|---|---|---|---|---|---|---|
| 16 | 16_1 | DD/MM/YYYY | Yes | High | 20 | 10 leaves, 7 male flowers |
| 16 | 16_2 | DD/MM/YYYY | No | | | |
| 16 | … | | | | | |
| … | | | | | | |
| 18 | 18_1 | DD/MM/YYYY | | | | |
| 18 | 18_1 | DD/MM/YYYY | | | | |
| 18 | … | | | | | |
| … | | | | | | |
| 21 | 21_1 | DD/MM/YYYY | | | | |
| 21 | 21_2 | DD/MM/YYYY | | | | |
| 21 | … | | | | | |
| … | … | … | | | | |

Every 10 days a pest and disease expert will do an evaluation tree by tree based on symptoms visible to the naked eye. Bacterial and fungal diseases are difficult to identify from a simple observation of the tissues, therefore, in case it is necessary, samples will be taken and analyzed in the UNITUS laboratories, running specific tests to identify the type of pest or disease affecting the plant. Right before harvesting, all the hazelnuts that were developed in the branches enveloped into the net bags (T0, T1 and control or "no infestation") will be brought to the UNITUS laboratories to detect the infestation level, with the following categories: healthy nut, kernel abortion, kernel malformations, black or white kernel spots, and "cimiciato".

We reiterate that the manual monitoring activity performed every 10 days and the outputs of the lab tests are fundamental to identify pests and diseases that may be already present the day of the UAV/UGV monitoring (and that hopefully will be identifiable in the non-visible portion of the spectrum, making them detectable using dedicated image processing techniques) but which are not yet symptomatic, i.e. visible to the human eye of the pest and disease expert or the agronomist. When this is the case, the pest or disease will only become apparent, with visible symptoms, in the days following the one of the automated monitoring.

Eventually, additional biometric variables such as trunk cross sectional area and canopy diameter, will be measured to collect auxiliary calibration/validation datasets. For biometric variable monitoring, Tab. 4 presents an example of the variables that will be observed and registered at significant periods of the growing season.

**Tab. 4:** Example of biometric variable report.

| **Field** | **Tree-ID** | **Monitoring date** | **Trunk cross sectional area ($m^2$)** | **Canopy diameter and canopy ground projection (m)** | **Height (m)** | **Sucker: number (-) and height (m) for each of them** | **Production: nuts per cluster (-), clusters per branch (-)** | **Flowers: female and male flowers (-) per branch** |
|---|---|---|---|---|---|---|---|---|
| 16 | 16_1 | DD/MM/YYYY | | | | | | |
| 16 | 16_2 | DD/MM/YYYY | | | | | | |
| 16 | … | | | | | | | |
| … | | | | | | | | |
| 18 | 18_1 | DD/MM/YYYY | | | | | | |
| 18 | 18_1 | DD/MM/YYYY | | | | | | |
| 18 | … | | | | | | | |
| … | | | | | | | | |
| 21 | 21_1 | DD/MM/YYYY | | | | | | |
| 21 | 21_2 | DD/MM/YYYY | | | | | | |
| 21 | … | | | | | | | |
| … | … | … | | | | | | |

For example, trunk cross sectional area will be calculated with a circumference measurement at 30 cm height from the ground, at the same marked point of the selected woody stems and trunks, at the beginning and at the end of each growing season. In case of bush trees, all woody stems will be identified and measured in terms of cross-sectional area at the defined distance from the ground of 30 cm. Similarly, canopy diameter and ground projection, as well as height of each single tree, will be measured at the beginning and at the end of each growing season. Production of all selected trees will be monitored considering representative branches of the trees themselves: the numbers of clusters and the nuts per cluster will be counted every ten days starting in June until harvest time. Fruit set incidence will be performed on representative branches of the trees: we will count the number of female inflorescences every ten days during the female bloom period (starting in winter 2018-19) and then compare it with the nuts produced in the following growing season.

Pruning with innovative pruning strategies will be performed by UNITUS in the period January – February on half of the trees selected in field 16. The biomass removed during pruning with both the traditional and innovative techniques will be weighed. Pictures of the tree shape in front of a white panel will be collected every ten days using a digital camera, to monitor the development of the crown in the following growing seasons, in relation to the different pruning methods.

For validation purposes of automated fruit detection, manual harvest of the trees selected in field 16 will be performed by UNITUS, either hand picking the nuts fallen to the ground or with vacuum collection, harvesting all nut fallen to the ground in the rectangular area depicted in Fig. 4. In other words, given a X x Y m rectangular plot (function of the planting scheme) centered on the tree itself, all nuts that fall in this rectangular shape of Fig. 4 are considered to belong to that tree. Care will be taken in choosing trees without too much canopy overlap.

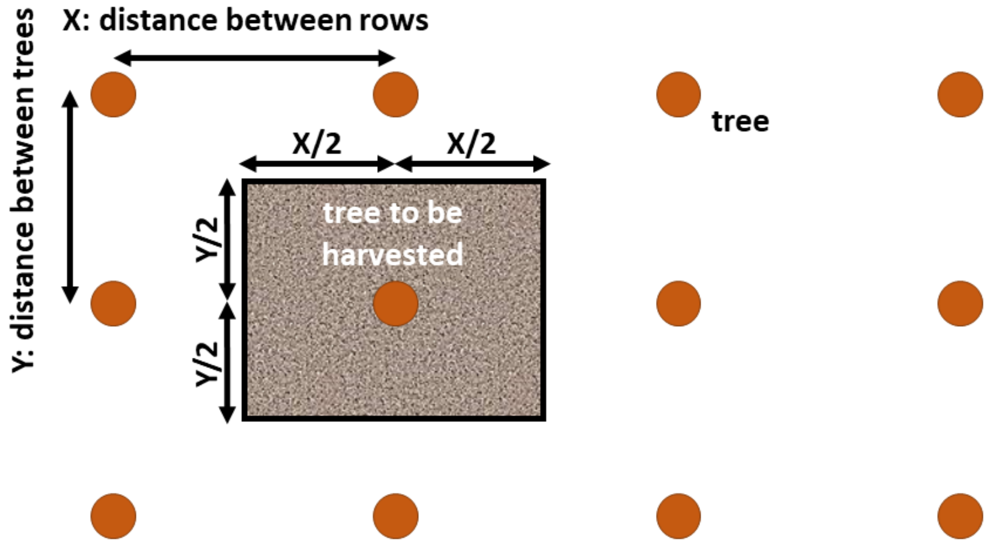


**Fig. 4:** All nuts fallen on the gray-shaded area are assumed to belong to the tree to be harvested.

This type of harvest will be executed after all nuts of a given tree have fallen to the ground, which most likely will happen by the end of August for Nocchione cultivar and during the first 15 days of September for Tonda Gentile Romana cultivar.

Production of each field will also be monitored every year, beginning from the harvesting season of 2019 (September 2019).

### 2.1.1 Calendar of the manual sampling activities

Tab. 5 reports the list of manual sampling activities, with a foreseen timeline, which may be slightly adapted in case of adverse weather conditions.

**Tab. 5:** Example of calendar of manual sampling activities (dates are subject to changes depending on weather conditions and technical problems).

| Date | Activity | Field / Trees |
|---|---|---|
| 15 Jan – 15 Feb | Innovative pruning | Field 16 (10 trees) |
| Every 10 days, through the year | Phenology + Pest and Disease detection + Sucker detection + Biometric variables | All selected trees in Fields 16, 18 and 21 |
| 2 times a year: beginning and end of growing season | Biometric variables | All selected trees |
| End Aug (Nocchione) - first 15 days of September (Tonda Gentile Romana) | Harvest (per tree and per rows) | Field 16 (10 trees) |

## 2.2 UAV/UGV monitoring activities

The same trees selected for manual monitoring will be also monitored automatically with the sensor equipment mounted on the UAVs and UGVs.

### 2.2.1 Water stress detection

From the literature, July appears to be the key month, in the Northern Hemisphere, to understand water use and the needs of the plants. Therefore, in the period from June to August, in conditions of clear sky, UAVs carrying thermal and multispectral cameras will collect data. Specifically, data will be collected from the selected trees of field 18 and of field 16, where we reiterate that half of the selected trees will have irrigation and the remaining will not receive water. A reasonable experiment design includes 6 scans a year. During every second scan, of the 6 foreseen, we will perform more than a single image collection during the day, at different times of the day, over the same trees, in order to monitor the daily evolution of water stress in a given plant. The rationale behind this is to identify the best time of the day to observe water stress, also characterizing times in which water stress may not be evident or detectable and therefore lead to misleading conclusions.

### 2.2.2 Sucker detection and control

During the so-called vegetative growth period, sucker detection will be carried out from April to August. During year 1 of the monitoring activities, only sucker monitoring will be performed, while from the following year, also tests on automated sucker removal, in the period from mid-May to July, will be started. In case of automated detection, the height of each group of suckers will be computed. This is fundamental to correctly define the type and dose of herbicide.

### 2.2.3 Fruit detection

From the end of June to the end of August, 3 scans will be performed to estimate the production per tree, on all the trees selected in field 16. Both the visible clusters and the total quantity of hazelnut per tree will be computed.

### 2.2.4 Tree geometry reconstruction

Tree geometry reconstruction will be performed 3 times a year: 2 times with bare leaf trees, 1 before and 1 after pruning, and a third time during the vegetative period. This activity will have to be strongly coordinated with the standard activities of the farm "Azienda Agricola Vignola": in other words, for the trees of field 16 selected for traditional pruning, the farm manager will communicate to the Pantheon team when they are planning to perform pruning. For the trees chosen innovative pruning, this will be carried out by one of the consortium members, UNITUS. The instrument used for tree geometry reconstruction is a Lidar mounted on a UGV. We consider the possibility of taking advantage of the combined use of Lidar and multispectral camera: depending on the results obtained during the first scan, this may be continued in the following years.

Reconstructing not only the tree structure, which can be done in winter time in bare leaf conditions, but also the tree structure when leaves are fully developed, allows for estimating the Leaf Area Index (LAI), which is a key parameter for pruning and expected production. In other words, having both the naked structure and the one with leaves will allow simulating how LAI varies when removing different branches of the tree, to obtain the optimum LAI value that should maximize production.

### 2.2.5 Pest and disease detection

In the planned experiment design, automated pest and disease detection will be carried out approximately 7 times per year, in the period May to August, using both UAVs and possibly UGVs. The cages placed on the selected trees in field 21 will be carefully removed by the pest and disease experts of UNITUS before each scanning activity and replaced right after it.

### 2.2.6 Calendar of monitoring activities

Tab. 6 reports the planned date ranges for automated monitoring activities. In case of delays due to, for example, adverse weather conditions or malfunctioning of the instruments, as well as in case of changes in the evolution of the growing season itself, the date ranges reported in Tab. 6 will be adjusted accordingly.

**Tab. 6:** Example of calendar of automated sampling activities (date ranges are subject to changes depending on weather conditions, pilots availability and evolution of the growing season).

| Date range | Scan | Sensors | Field / Trees |
|---|---|---|---|
| 15 Nov -15 Jan | Pre-pruning **Tree Geometry reconstruction** (no leaves) | UGV: Lidar | Field 16 (~10 trees: half to be pruned in standard way, half to be pruned in innovative way) |
| 15 Feb - 15 Mar | Post-pruning **Tree Geometry reconstruction** (no leaves) | UGV: Lidar | Field 16 (~10 trees: half to be pruned in standard way, half to be pruned in innovative way) |
| 20 Apr -30 Apr | Sucker detection | UGV: Lidar + all cameras | Field 18 (~10 trees) |
| 1 May -15 May | **Tree Geometry reconstruction** (with leaves) | UGV: Lidar | Field 16 (~10 trees: half to be pruned in standard way, half to be pruned in innovative way) |
| 20 May - 30 May | Sucker detection + Pest and Disease detection | UAV: thermal and multispectral camera<br>UGV: Lidar + all cameras | Field 18 (~10 trees)<br>Field 21 (~15 trees) |
| 10 Jun - 20 Jun | Pest and Disease detection + Water stress detection (multiple scans during the day) | UAV: thermal and multispectral camera (UGV: Lidar + all cameras) | Field 16 (~10 trees)<br>Field 18 (~10 trees)<br>Field 21 (~15 trees) |
| 20 Jun -30 Jun | Sucker detection + Pest and Disease detection + Water stress detection + Fruit detection (scaling) | UAV: thermal and multispectral camera<br>UGV: Lidar + all cameras | Field 16 (~10 trees)<br>Field 18 (~10 trees)<br>Field 21 (~15 trees) |
| 10 Jun – 20 Jul | Pest and Disease detection + Water stress detection (multiple scans during the day) | UAV: thermal and multispectral camera (UGV: Lidar + all cameras) | Field 16 (~10 trees)<br>Field 18 (~10 trees)<br>Field 21 (~15 trees) |
| 20 Jul - 30 Jul | Sucker detection + Pest and Disease detection + Water stress detection + Fruit detection (scaling) | UAV: thermal and multispectral camera<br>UGV: Lidar + all cameras | Field 16 (~10 trees)<br>Field 18 (~10 trees)<br>Field 21 (~15 trees) |
| 10 Aug -20 Aug | Pest and Disease detection + Water stress detection (multiple scans during the day) | UAV: thermal and multispectral camera (UGV: Lidar + all cameras) | Field 16 (~10 trees)<br>Field 18 (~10 trees)<br>Field 21 (~15 trees) |
| 20 Aug -30 Aug | Sucker detection + Pest and Disease detection + Water stress detection + Fruit detection (scaling) | UAV: thermal and multispectral camera<br>UGV: Lidar + all cameras | Field 16 (~10 trees)<br>Field 18 (~10 trees)<br>Field 21 (~15 trees) |

# 3 Frequency of the agronomic interventions

In the management of large hazelnut orchards, a number of farming procedures and agronomic annual interventions are traditionally carried out. Fig. 5 illustrates an example of agronomic activities and their timing throughout the year for the Northern Hemisphere, together with their recurrences.

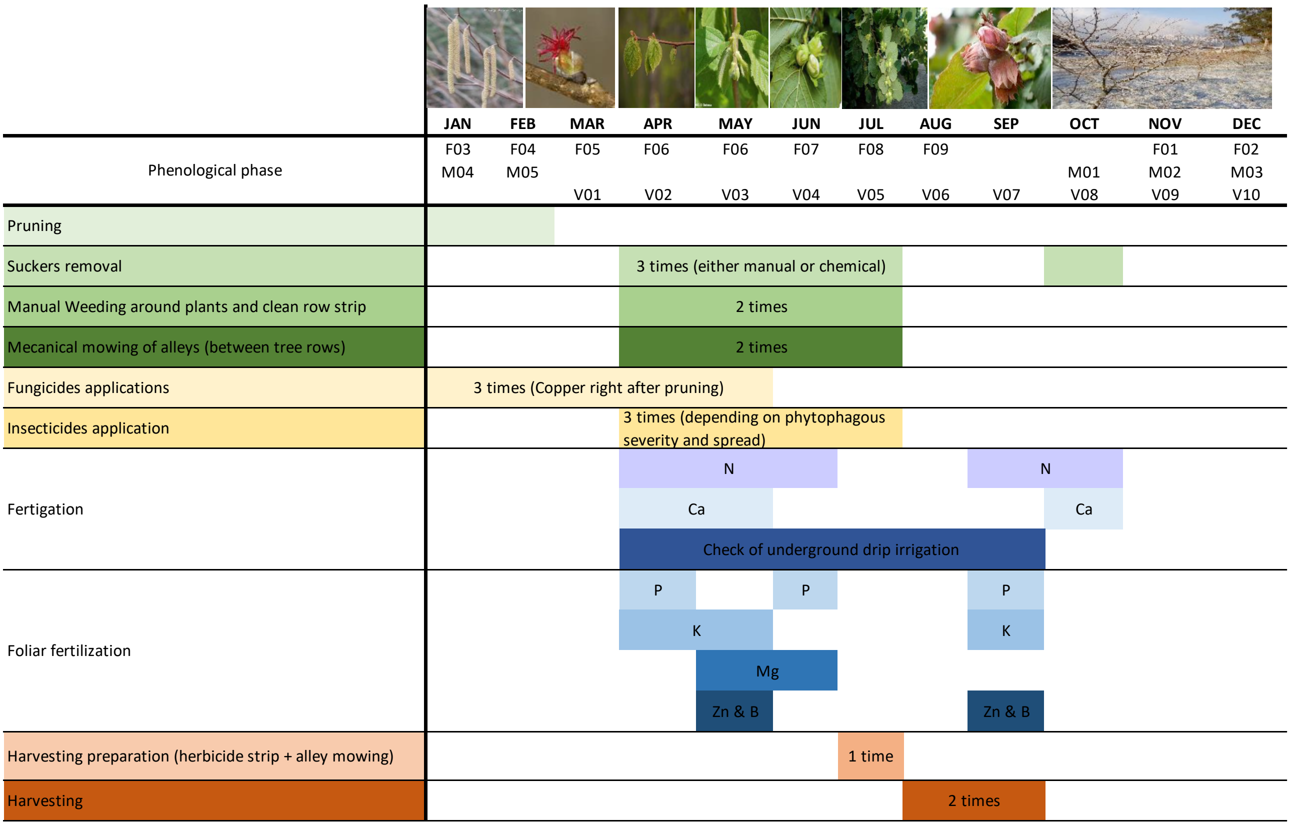


**Fig. 5:** Example of a calendar of main agronomic interventions in a standard large hazelnut orchard in the Northern Hemisphere.

Such agronomic activities might interact with the response and the behaviour of the trees selected for automated monitoring. As a consequence, all agronomic interventions will be monitored and recorded. In particular, such interventions include, but are not limited to, fertigation, pruning, weeding and sucker removal and phytosanitary treatments. The farm manager will be asked to record in a field diary all the manual and mechanical agronomic activities carried out in fields 16, 18, 21. An example of a possible template for a field diary is reported in Tab. 7.

The idea behind the collection of such activities is to monitor cost, time and effectiveness of the activities generally performed in the management of large orchards. For example, information on the total number of equivalent man-hour to complete sucker removal in a certain field will allow comparing the cost of the traditional activities with the one automatically performed by UGVs. Monitoring the phytosanitary treatments will permit comparisons between fields and plants in similar conditions, to avoid bias in the final analysis.

**Tab. 7:** Example of a possible template to record field operations and agronomic interventions.

| **Date** | **Field** | **Tree-ID** | **Activity** | **Notes** | **N of equivalent man-hour (-)** | **Prescription: active ingredients (-), doses (ml/hl), wetting (l/ha)** | **Tractor type** | **Machine type** |
|---|---|---|---|---|---|---|---|---|
| DD/MM/YYYY | 16 | 18_2 | Manual sucker removal | | 20 | - | - | Manual |
| DD/MM/YYYY | 16 | Entire field | Manual weeding | | - | - | - | Manual |
| DD/MM/YYYY | 18 | … | Fertigation | | - | | | |
| DD/MM/YYYY | 21 | | Phytosanitary treatments | Big mite treatment | 5 | clofentezine + mineral oil, 40+1000 ml/hl, 1000 l/ha | Landini 50 HP | Piave Eurocompact Atomizer Sprayer |
| … | | | | | | | | |

## 3.1 Fertigation

To monitor soil moisture, 9 probes to record humidity and temperature data of the soil will be installed in the 3 fields. The probes located in field 16 and 18, where the water stress experiment will take place, will allow a continuous monitoring of the irrigation. For the experiment on water stress, a coordinated activity between the management of the "Azienda Agricola Vignola" and the project consortium will regard the selection of the irrigation lines to be closed/opened and the appropriate timing of these actions. Continuous communication with the management of the "Azienda Agricola Vignola" will ensure that the partners are aware of timing and quantity of water distribution to the plants.

Additionally, for the water stress detection trials in field 16 and 18, it is important to consider the reduction of nutrients for all plants subject to water reduction. For such plants, an option to compensate the decrease in nutrients will be the use of granular fertilizers.

## 3.2 Pruning

With the exception of the selected trees in field 16 that will be pruned by UNITUS with innovative strategies, in all other trees traditional pruning will be carried out under the farm manager supervision. For both sets of trees (innovative pruning and traditional pruning), details on pruning activities, such as quantity of removed biomass will be promptly communicated to the project members.

Pruning decisions (how many branches to prune, what branches to prune) made on the basis of the datasets collected during automated monitoring activities and provided as inputs to the developed algorithms will be validated according to the following procedure. The result of the automated procedure will be compared against the decision that an expert would have made, on the basis of the same inputs, i.e. dataset(s) or image(s) that have been used as input to the algorithm. Comparisons will be made on the number of branches selected for pruning by the expert and what identified for pruning by the developed algorithm, also assessing the overlap of the pruning scheme suggested by the expert and the pruning scheme derived from the algorithm. In particular, as already stated in deliverable D2.1, the benchmark proposed is to limit substantial differences between the outputs of the automatic pruning protocol and the pruning suggestions of the expert to less than the 30% of the cases.



## 3.3 Weeding and sucker removal

Weed management is a standard agriculture practice in orchard management that becomes crucial when attempting automated monitoring. An orchard free of weeds will facilitate the automated detection of suckers, pest and diseases, etc. Therefore, the 3 fields need to be regularly weeded around the plants and along the tree rows, leaving all year long a clean strip along the tree rows. The team members will coordinate with the farm manager to ensure appropriate weed management, to reduce all external disturbing factors.

In order to facilitate sucker detection and control, it is important to keep the weeds/grass of the alleys (between rows) mowed, especially in field 16, where the younger trees can compete with weeds for water and nutrients. Any time the automated sucker detection is performed, an agronomist will be present in the field to manually check, for the same trees automatically monitored, the sucker characteristics: number, height, etc.

In case of using chemical sucker control, care will be taken to avoid lignification of the suckers, in order to guarantee a better efficiency of the active ingredients. Therefore, in the framework of standard activities in a large plantation, chemical control will be applied when the suckers are shorter than 10-20 cm in height.

## 3.4 Pathogens and phytophagus

In a case a pest or disease would be observed, either by a project member of by the personnel of the "Azienda Agricola Vignola " farm, in any other tree different from those selected for infestation in field 21, depending on the severity and spread of the agent, appropriate measures will be taken and immediately communicated to the project members. Such information will be reported in Tab. 7 for what concerns tree-ID, active ingredients, doses and wetting.

## 3.5 Fruit harvest

Besides harvesting the selected trees in field 16 according to the procedure reported in Par. 2.1, the production per every field in each year of the project will be recorded. Additionally, if possible, the farm manager will provide information on all available data in terms of production and quality/defects for the 3 fields in the past years. This will help understanding the trend in harvest results w.r.t. different varieties and alternate bearing, i.e. the tendency of crop trees to produce a greater than average crop one year, and a lower than average crop the following year.