Wildland-Urban Interface Virtual Essays Workbench

WUIVIEW

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Deliverable D2.1.
Report on real scale experiments

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Abstract	This deliverable describes the procedures and execution of the experimental tests on natural fuels, performed in ADAI's Forest Fire Research Laboratory, in Lousã, Portugal

(1) Draft / Final
(2) Public / Restricted / Internal

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1. Introduction

The study carried out by ADAI in the sequence of the Large Fire Event of Pedrógão Grande (Portugal) started on June 17th, 2017, evidenced how relevant was the proper arrangement of natural fuels around the more than 1400 houses visited (Viegas et al., 2017). Besides the relevance of the fuel management, i.e. maintenance of a correct vegetation load and assurance of fuel discontinuity, an appropriate organisation/design of the fuels around the house is essential to mitigate the fire risk.

Frequently, the high fire risk level of many houses results from a careless maintenance of the natural fuels in the surrounding that can be seen in the uncontrolled growth of herbaceous and shrubs, among other evidences. Other times, despite a great care in the maintenance of the gardens, an inadequate design and improper practices result in a higher fire risk. For example, in preliminary studies that we performed, we could observe that some typical gardening activities such as the trimming of bushes/trees hedges increases the fire risk as more dead material is produced in the interior of the hedge as a consequence of an extra shadowing caused by the sprouting of the ends of the branches that have been cut (Figure 1c and Figure 1f).

Figure 1 – Two vegetation hedges: images a, b and c with vegetation hedge pruned; images d, e and f with natural vegetation hedge (not pruned). Images a and d: general view; images b and e: zoom image outside the hedge; images c and f: zoom images in the interior of the hedge.

Several natural fuels, with different forms and shapes, can be found near and around the houses. The commonly found vegetation hedges can greatly increase the fire risk, not only due its frequent presence in the gardens but also due the great fuel load and the potential fire intensity associated with its combustion.

Tracking the general objective of the WUIVIEW Project that intends to design and test a virtual workbench service for the analysis of fire hazards and buildings vulnerabilities at different European Wildland Urban Interface (WUI) realities, several laboratory real-scale experiments with vegetation hedges were performed. Four typical species were selected for analysis taking into consideration their presence not only in Mediterranean countries, but also in northern European countries. Moreover, the selection of species considered the higher and lower expected combustibility.

The tests were carried out by ADAI and UPC in the Forest Fire Research Laboratory (LEIF) of ADAI, in Lousã (Portugal). Data were gathered with the primary aim of obtaining relevant burning dynamics variables, which are essential to run simulations on fire behaviour in WUI scenarios.

The Deliverable D2.1 summarizes the information concerning the mentioned real-scale experiments, giving details on the methodology used and the data monitored and providing discussion and conclusions as a consequence of the results obtained. A scientific analysis of the results is expected to be disseminated among the scientific and the fire practitioners' communities through a scientific paper that will be submitted to an indexed international journal. Besides, the main results of this study were already presented in the 1st WUIVIEW International Workshop (17th January, 2020), held in Coimbra, Portugal.

2. Objectives

The main objective of this study is the provision of data related to the burning characteristics of vegetation commonly used in green hedges surrounding houses, in what was identified as the WUI microscale. Four different species with expected different combustibility were analysed. This data will be updated in the WUIVIEW database (WP2) and will be essential to perform the simulations in order to test the survivability and sheltering conditions (WP6) of the scenarios designed in WP5.

The parameters requested, to accomplish the main objective previously described, are related to characteristics such as the flames temperatures, flames geometry (height, depth and volume), burning rate expressed as the fuel mass variation, flame emissive power, infrared videos and RGB images and videos. The fire spread by mechanisms other than the direct heat transfer is not a part of the WUIVIEW scope, however this data will enrich the WUIVIEW database.

Besides the burning tests, the characterisation of the vegetation used in the experiments was performed. This entails the mass distribution of the vegetation components divided in four groups – foliage, green branches, roundwood and dead materials – that were subdivided according the dimensions, namely the diameter - ∅<3mm, 3<∅<6mm, 6<∅<10mm, ∅>10mm. The fuel moisture content of each subgroup was determined. This analysis was important to perceive why some species burn faster than the others, which is very much related to the fraction of dead material and to the fuel moisture content.

Considering the combustibility as very dependent on the degree of dehydration of the vegetation, three sets of experiments were performed with the four previously identified species: S1- trees well hydrated; S2- trees not watered during 28 to 32 days; S3- trees not watered during 100 days. Both the burning experiments and the vegetation characterization analysis were carried out for the three mentioned sets of tests.

In this deliverable, only a general description of the main findings will be presented since a scientific analysis is out of the scope of this document. A publication with the scientific results is intended to be submitted to an international journal of the expertise. Nonetheless, besides the reporting of the activities performed, the contents of this deliverable can be a good support to define best practices in the selection, design and management of the vegetation hedge in the houses' surroundings.

3. Experimental setup

3.1. Laboratory Facilities

As previously reported, the experiments hereby presented were carried out in the Forest Fire Research Laboratory (Figure 2), in Lousã (Central Portugal). The LEIF is an infrastructure owned by ADAI, with the support of the University of Coimbra and the Municipality of Lousã. It is specifically designed to support experimental research on forest fires, namely on fire spread properties. The major part of the work performed here is comprised of laboratory scale experiments, where we can collect valid, reliable and controlled data about the tested phenomena during all the year, in any season, simulating the conditions observed in the real scenarios. In laboratory, it is possible to fix the values of several parameters such as fuel load, bulk density, wind and slope and choose one of them, for instance the geometry of the fire front to change. This way it is easier to understand the effect of the chosen parameters. The laboratory is equipped with several test rigs and equipment that are described in WUIVIEW Technical Note 2.1.

Figure 2 – Aerial view of ADAI's Forest Fire Research Laboratory (LEIF)

3.2. The test rig

One of the basic and fundamental parameters to be acquired during the tests was the mass loss rate of the fuels during the combustion. For this reason, the tests needed to be performed using a combustion table equipped with load cells. ADAI has such a device in LEIF, named "Platform of tree combustion" (see *Technical Note 2.1 Facilities & Equipment ADAI/CEIF*), but some adaptations needed to be done, as described next.

3.2.1. Structure development

The "Platform of tree combustion" consists of a square platform, approximately 1.5m wide, with a diagonal of 2.19m (Figure 3). This platform stands on 3 load cells (AEP C3S transducers), with a resolution of 0.0 5 kg each, that are connected to a laptop with an acquisition software capable of registering mass at approximately 1 second intervals.

Figure 3 – ADAI's Tree Combustion Platform, with dimensions.

In order to proceed with the tests designed for this task, two adaptations needed to be done to this platform:

i) A structure allowing to support either 1 or 3 trees at the same time, maintaining the ability to measure the mass loss rate of the trees in combustion.

ii) A structure allowing to support the ignition trays, independent from the main structure, i.e., not interfering with the load cells.

For this purpose, two small structures were designed, built and coupled to the main platform.

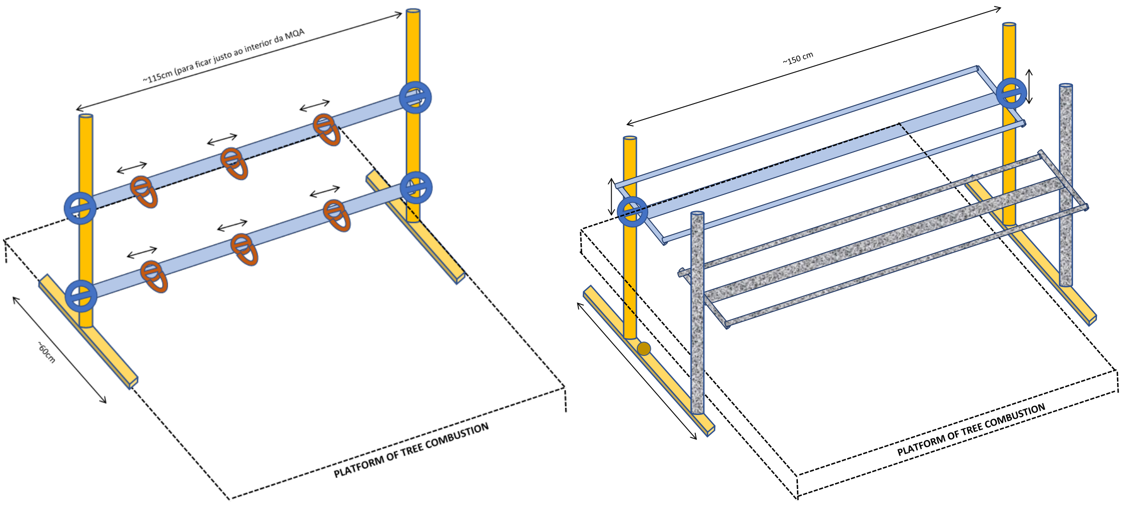


Figure 4 – Original design of the support devices for the combustion table. On the left the bars to hold the trees. On the right the ignition trays' supports

The original design was slightly changed, in order to maximise the useful area of the combustion table. Instead of placing the structures on both sides of the square platform, they were designed to be located in the corners, as seen in Figure 5.

Figure 5 – View of the 2 support devices built for the combustion table.

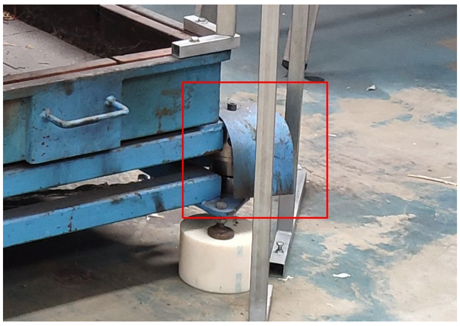
It is possible to see that the structure supporting the ignition trays is fixed outside the platform, while the device to hold the trees is fixed to the corners of the same platform. This configuration allows us to account for the weight of the structure supporting the trees, eliminating it when we reset the load cells prior to each test. At the same time, the mass loss rate of the ignition trays is not interfering with the tests. Figure 6 shows the setup of one of the tests with 3 trees, using the described platform with the support structures.

Figure 6 – View of the platform with the final setup for one of the tests, with 3 trees fixed to it.

3.2.2. Structure instrumentation and specifications

The experimental data acquisition consisted of several acquisition instruments, listed below in Table 1, in order to capture all the different characteristics previously identified.

Table 1 – Data acquisition systems used

	**Load cells**, supporting the entire combustion platform. These load cells are connected to a laptop for data acquisition. 
	Two **IR cameras** and two **visible cameras** placed in pairs, one perpendicular to the trees and another one parallel. 
	Various photographic and smartphone **cameras.** 
	Three **thermocouples** (type K), one placed at the level of the ignition trays (0.62m), another at mid-height of the trees (picture to the left) and the last one above the trees (3.75m) capturing the convection from the combustion. The thermocouples are connected to a laptop for data acquisition. 

One ***Pitot* tube** placed above the trees (3.75m), capturing the convection from the combustion. The pitot is connected to a laptop for data acquisition.

One **radiometer** placed perpendicular to the trees (1m). The radiometer is connected to a laptop for data acquisition.

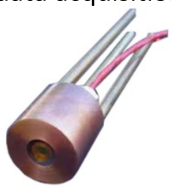


Figure 7, obtained from the Technical Note 2.4 (*TN 2.4 - Fuel sampling, tree ignition and burning tests in ADAI facilities*), schematically shows the distribution of the sensors and acquisition systems.

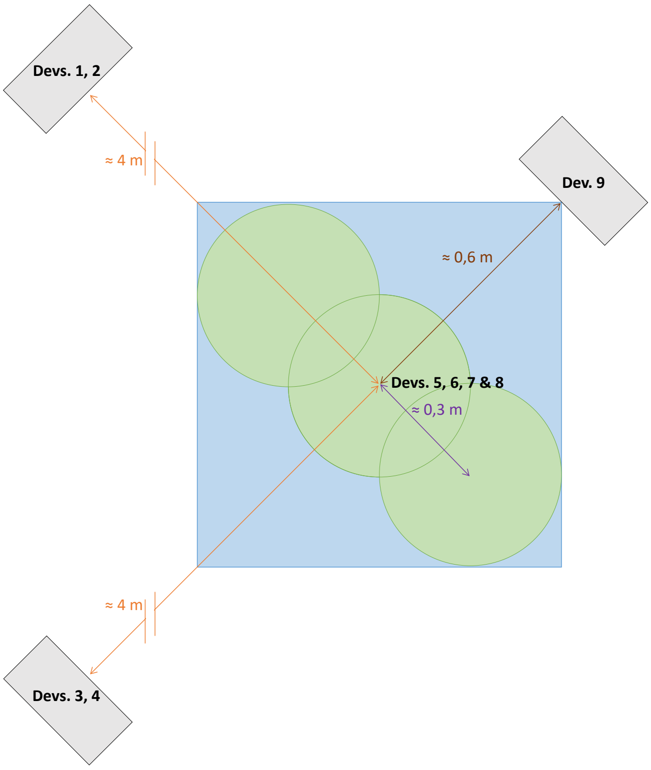


Figure 7 – Top view scheme of the experimental setup. Load cell module coloured in blue, trees in green and devices in grey with black bold letters. Dev(s) = device(s). z = height above the ground of the load cell. Dev. 1: RGB camera Sony FDR-AX53 (z ≈ 1.5 m); Dev. 2: IR camera FLIR SC660 (z ≈ 1.5 m); Dev. 3: RGB camera Sony HXR-NX30E (z ≈ 1.5 m); Dev. 4: IR camera OPTRIS PI 640 (z ≈ 1.5 m); Dev. 5: pitot tube (z = 3.75 m); Dev. 6: thermocouple (z = 0.62 m); Dev. 7: thermocouple (z variable); Dev. 8: thermocouple (z = 3.75 m); Dev. 9: radiometer (z ≈ 1 m).

3.3. Fuels characterization

When describing vegetation in terms of fire behaviour, the term “fuel” is used, to refer to the natural particle or groups of particles forming the living and/or dead vegetation, that “burn” or are the “fuel” to the combustion. In other words, wildland fuels can be defined as the living and dead vegetative matter that contribute to wildland fire and are often arranged into distinct categories including trees, shrubs, grasses, wood, litter, and duff (Ottmar, 2020).

3.3.1. Species selection

To couple with the predefined objectives of studying green hedges, four species were selected to be tested in this experimental campaign:

- *Cupressocyparis leylandii* (Figure 8-a)
- *Cupressus arizonica* (Figure 8-b)
- *Prunus laurocerasus* (Figure 8-c)
- *Thuja occidentalis* (Figure 8-d)

These species are frequently present in the European WUI. Its most frequent configuration is forming hedgerows inside or delimiting plots but can also be found as independent individuals.

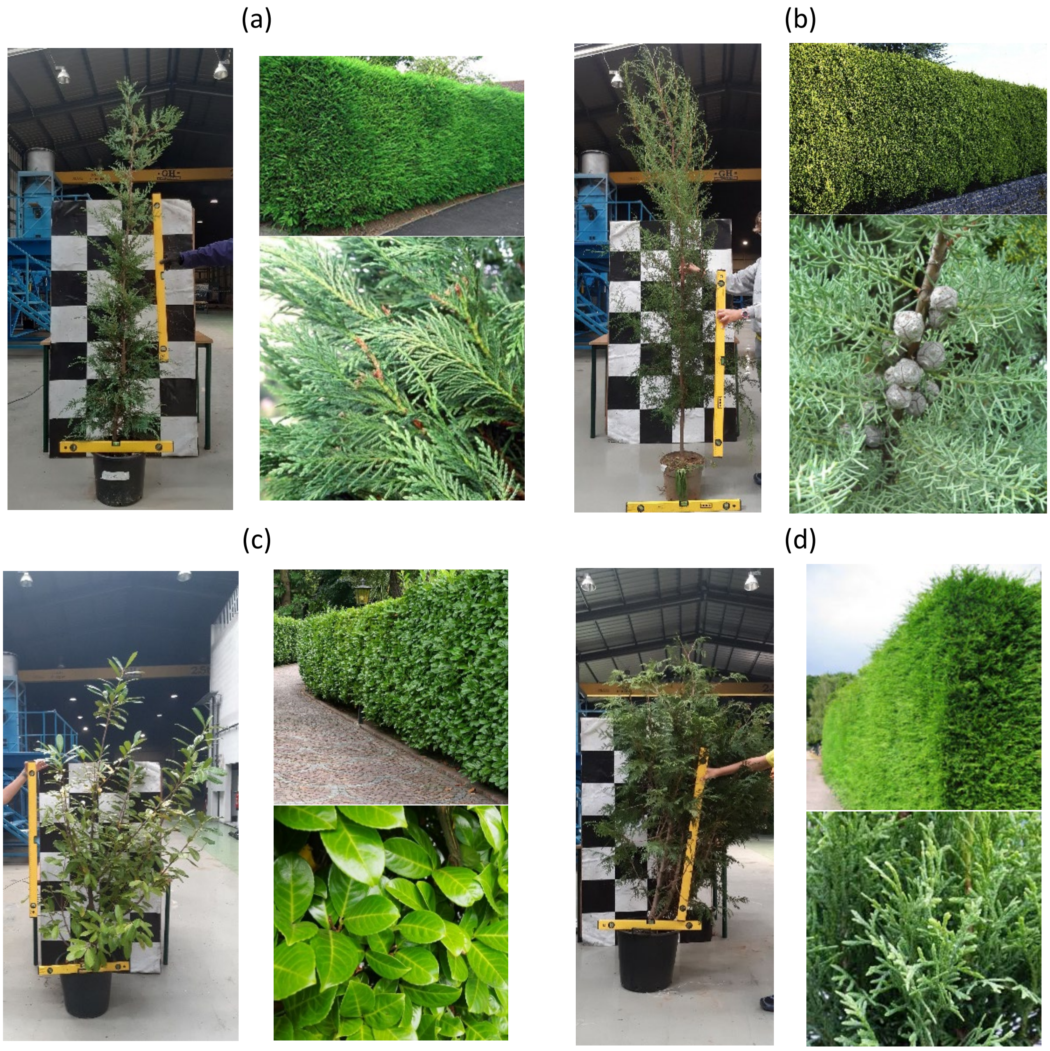


Figure 8 – Species selected to be tested in the experimental campaign. a) Cupressocyparis leylandii; b) Cupressus arizonica; c) Prunus laurocerasus; d) Thuja occidentalis.

To form the hedgerows commonly seen in house gardens, it takes years of growing and frequent pruning, to obtain the geometric shapes visible in the photos. As we were not able to obtain adult individuals from real gardens, we bought the trees for the tests in forest nurseries, choosing specimens as old as possible. We tried to acquire trees that were of the same age and geometry, inside each species.

3.3.2. Fuel sampling

All four species were fully characterized in terms of fuel load and its distribution along the tree, based on destructive sampling. The full process is described in detail in Technical Note 2.4 but is also briefly transcribed here.

To estimate the most important geometrical features of the sampled trees, pictures from two perpendicular directions were taken (front and lateral view). To allow the post-processing of the images, a chessboard pattern was positioned behind the specimen to be used as reference. Vertical and horizontal rules were also used to allow image-based distance measurements (Figure 9).

Figure 9 – Front view of a Cupressocyparis leylandii (left) and a Prunus laurocerasus (right) specimens. The horizontal rule is 0.6 m long; the vertical rule is 1 m long. The side of the chessboard reference square is 0.25 m long.

The canopy was divided (cut) in three sections of the same length along its longitudinal axis. These cuts were performed following parallel layers with the ground. If a branch belonged to more than one section, it was cut and separated among its subsequent sections. If the canopy base was not in contact with the ground of the pot, the bare stem between the ground and the canopy was removed and measured separately. The bottom section was named as the first section, the middle section as the second section and the upper one as the third section. The fuel in each section was classified into several subgroups regarding the criteria set in Table 2.

Table 2 – Criteria and subsequent subgroups used to classify fuels.

Criteria	Subgroups
Species	*Cupressocyparis leylandii* *Cupressus arizonica* *Prunus laurocerasus* *Thuja occidentalis*
Section	1st section 2nd section 3rd section
State	Living fuels Dead fuels
Physiology	Foliage Green branches Roundwood
Diameter	Ø < 3mm 3≤Ø< 6mm 6≤Ø<10mm Ø≥10mm

Note that not all the subgroups existed in each specimen (e.g. a tree may not have a dead woody stem with a diameter larger than 10 mm in its upper part). The fuels were classified, weighted (wet weight), dried and weighted again, in order to obtain the dry weight. Samples were then dried for 24 hours in ovens at approximately 95°C. If there was a lack of space inside the ovens, an aliquot part greater than 10% of the wet weight of the bulkier samples was used to estimate the moisture of the whole sample.

Figure 10 – Scenes from the fuel sampling and characterization process

The tested specimens had different degrees of dehydration, as will be seen in the presented analysis. The trees were received in different periods, and were left without watering for i) 5 days, ii) 28 to 32 days and iii) 100-101 days until the tests were performed.

3.4. Experimental protocol description

3.4.1. Experimental procedure

Two kinds of fuel configurations were tested: (i) 1-tree (Figure 11a) or (ii) a set of 3-trees (Figure 11b). In configuration (ii) the tree stems had a separation between them of about 30 cm and the crowns were imbricated.

(a) (b)

Figure 11 – Tests configuration: (a) 1-tree configuration, (b) 3-trees configuration

The ignition of these fuel configurations was achieved using trays filled with alcohol. Four trays (31.5× 18cm^2, each one) – two on the back and two on the front – with 300mL of alcohol were used to ignite the 1-tree setups, and 9 trays with 250L of alcohol were used in the 3-trees setups (4 trays of 31.5 × 18cm^2 on the back plus 5 trays of 31.5 × 23.5cm^2 on the front). The ignition trays were evenly positioned under the canopy base and mounted over a structure that was directly resting on the floor. The vertical distance between the ground of the load cell module and the trays was of 0.42 m.

(a) (b)

Figure 12 – Ignitions configuration: (a) 4 trays on 1-tree setup and (b) 9 trays on 3-trees setup.

3.4.1. Experiments naming

Each set of data received a name univocally linked to its fire test. This name was composed with the name of the species tested, the number of the test and the number of trees used in the test.

For example, the test pictured on Figure 11b refers to the first test with 3 trees of *Cupressus arizonica,* hence it was named "*C. arizonica T01_03*".

3.4.2. Data acquisition

The fuels weight was measured in a balance Mettler PM600 (0.01g precision) for the lighter samples (<600g) (Figure 13a) and in a scale AND HW-100KGL (10g precision) for the heavier samples (Figure 13b). Samples were dried during 24 hours in two ovens (MEMMERL 600-D06064 and TCT DHG-9203A; Figure 13, c-d) at temperatures ranging between 90°C and 100°C. The full trees were weighted in a scale (AND HW-100KGL,Figure 13b) before and after the burning and the mass loss was registered continuously during the experiments with the load cell module.

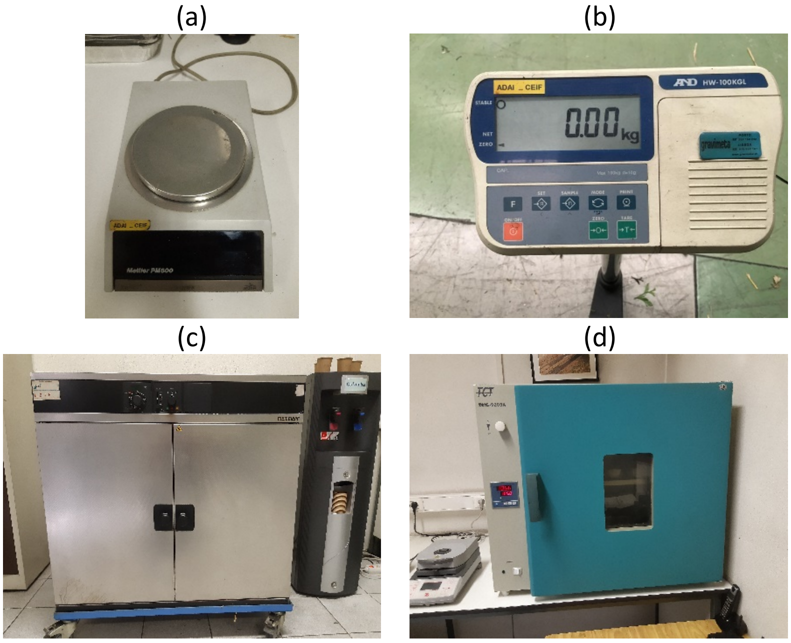


Figure 13 – Scales and ovens used: a) Mettler PM600 balance (precision: 0.01 g); b) AND HW-100KGL scale (precision: 10 g); c) MEMMERL 600-D06064 oven; d) TCT DHG-9203A oven.

The experiments were monitored and recorded with the different instruments and acquisition systems presented in point 3.2.2 – *Structure instrumentation and specifications* – with the following references/models: 3 load cell modules (AEP C3S), two IR cameras (FLIR SC660 & OPTRIS PI 640), two visible cameras (Sony HXR-NX30E & Sony FDR-AX53), three thermocouples (type K; model BT.MiK.1.2.1,5.10000.MFATW0), a pitot tube (type S; Gems 5266-50L transducer) and one radiometer (Vatell TG9000-9).

4. Experimental main results and discussion

As previously mentioned, in this deliverable, only the main results will be presented followed by a brief description. A more detailed scientific description will be carried out in a scientific paper that is intended to be presented to an international scientific journal.

In this document, we present in separate the analysis of the trees' characterization and the burning experiments

4.1. Characterization of the species analysed

The availability of a tree to burn is directly associated to its fuel moisture content and to its composing materials, such as foliage, branches or stems, which can have specific chemical and physical properties. In order to have a preliminary understanding of the combustibility expected for each species analysed, a characterization of each of the four species was carried out. Moreover, an analysis of the variation of the physical and chemical characteristics driven by the different time of dehydration was performed. This division was simplified in 1st series of samples (5 days of dehydration) and 2nd series of samples (28-32 and 100-101 days of dehydration). The parameters considered were the fuel moisture content, the composing material (foliage, green branches, roundwood and dead materials) and the diameter of the round material. From Table 4 to Table 7 of Annex 1 the generality of the results is presented. Figure 14 allows a succinct analysis of the different material compositions for each specie for each series of tests. Figure 15 represents the values of fuel moisture content determined.

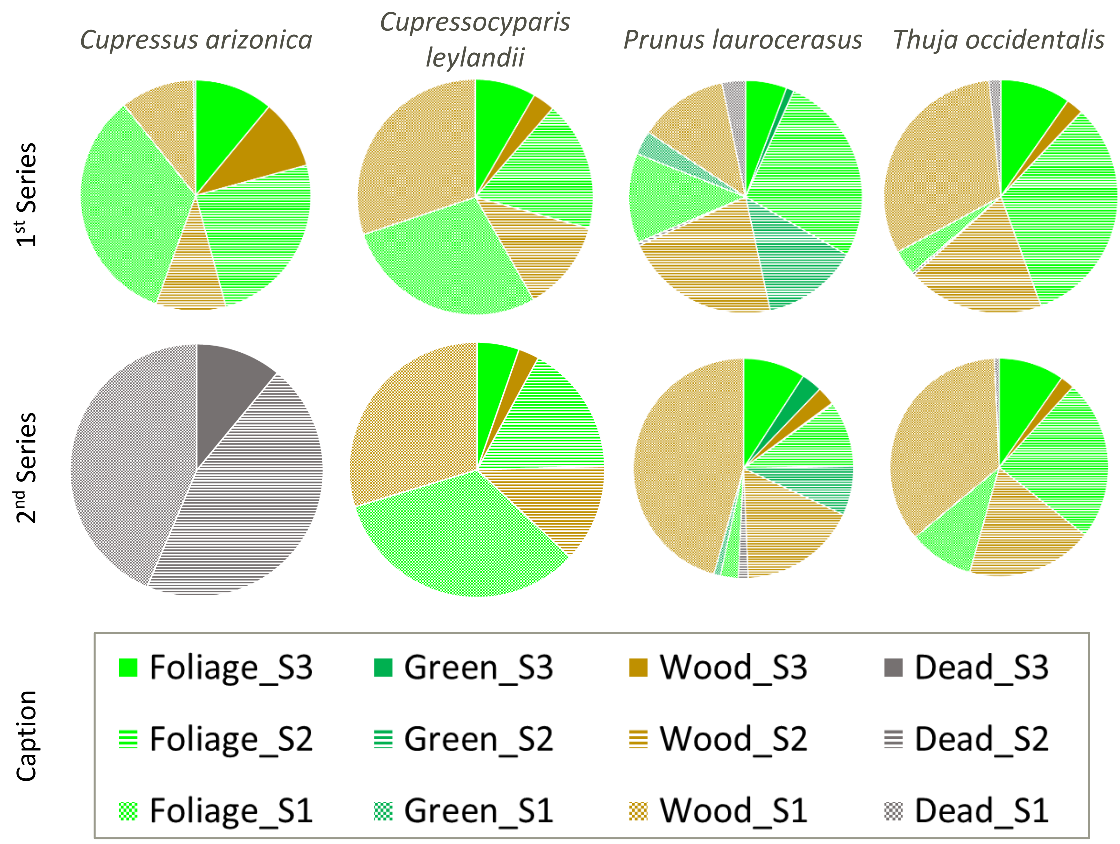


Figure 14 – Distribution of the fuel classes (foliage, green branches, roundwood and dead materials) by the sections of the trees (S1: Section 1- bottom; S2: Section 2- middle; S3: Section 3- top) for the different species analysed.

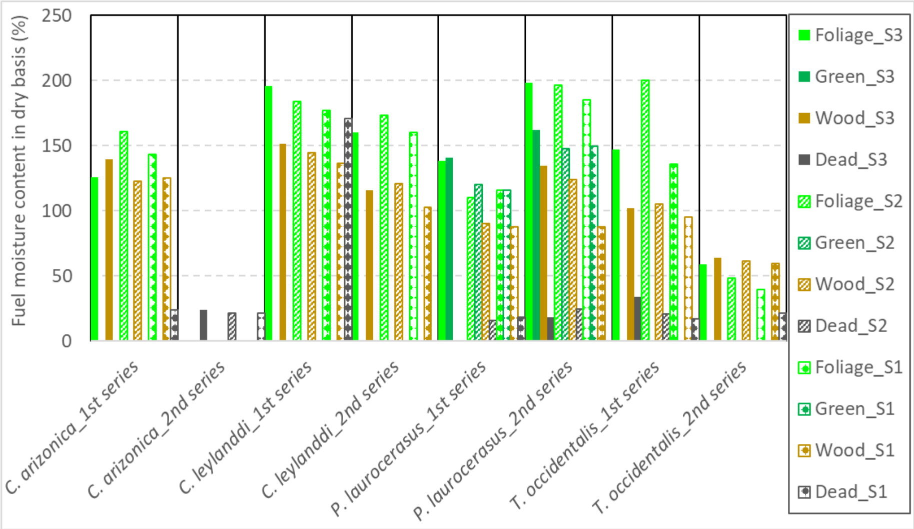


Figure 15 – Fuel moisture content determined for each specie, for the different fuel classes (foliage, round green, round wood and dead material) in each of the series corresponding to the different levels of dehydration: 1st series- 5 days; 2nd series- 28-32 days and 100-101 days.

In Figure 14 is evident that *Cupressus arizonica* is highly affected by the dehydration presenting only dead material after 28-32 days of not being watered. It is also observed that the other species approximately maintain the same composition, however, as can be seen in Figure 15, the fuel moisture content for each fuel class is generally lower.

It is possible to verify that *Cupressus arizonica* is the species that generally has less moisture content which is aggravated by the dehydration. In the opposite side comes the *Prunus laurocerasus* with the moisture content having higher values after the dehydration. The leaves of *Prunus laurocerasus* in a high level of dehydration detach from the plant while in the other species analysed the dead material continues attached to the plant enhancing its combustibility. We believe that for an extreme level of dehydration the *Prunus laurocerasus* loses all the leaves and so its combustibility is much lower than for the other species that keep the dead leaves and other thin material.

Cupressocyparis leylandii is the species with more relative fuel load in Section 1 (bottom) which may drive to an easier and faster ignition by surface flames of low height. In the opposite side, for the 1st Series, *Prunus laurocerasus* comes once again with the relative fuel load mostly concentrated in the middle section (Section 2). After dehydration (2nd Series), many leaves were detached from the *Prunus laurocerasus* plant as previously described, the fuel load in the Section 1 becomes more represented.

4.2. Burning experiments

The following description is structured by subchapters that correspond to the parameters analysed. The data and respective discussion for the up-flow velocity of the thermal plume produced is not presented since technical problems invalidate the data found. Each set of results is divided in the experiments of the 1-tree setup and 3-trees setup, considering the time of dehydration to each of the trees were subjected.

4.2.1. Fuel mass loss

The mass loss is clearly related to the intensity of the combustion and so gives indications of how fast the burning of the tree(s) was. In Figure 16 the variation of the mass is represented. As the mass of the trees varies, the relative mass Figure 16b allows a fair comparison for different experiments.

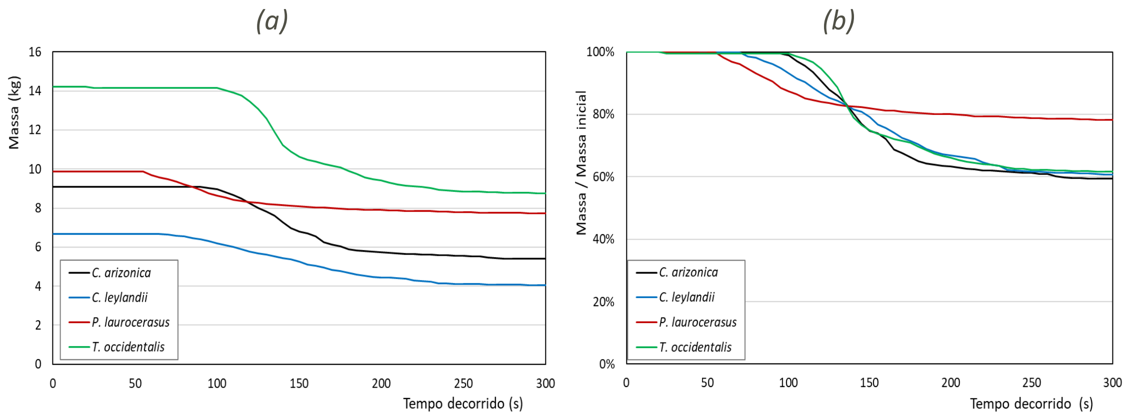


Figure 16 – Example of the variation of the absolute mass (a) and the relative mass (b) for the experiments of the 3-trees setup of the 1st series (C. arizonica T02_03, C. leylandii T01_01, P. laurocerasus T01_01, T occidentalis T01_01).

The constant values of mass in the initial phase are due to the fact that the mass acquisition system was not initiated exactly at the same time as the ignition. On the other side, the final phase of the mass loss drives to values with a variation tending to zero, being very difficult to find exactly when the experiment can be considered as ended. Therefore, we considered the initial phase of the burning to be the moment at which the mass started decreasing consistently and the end of the data acquisition when the variation was inferior to 5g for seven consecutive records. In Figure 17 we can see that the period considered for analysis can be represented by an exponential law (Equation 1), as followed by Viegas et al. (2013).

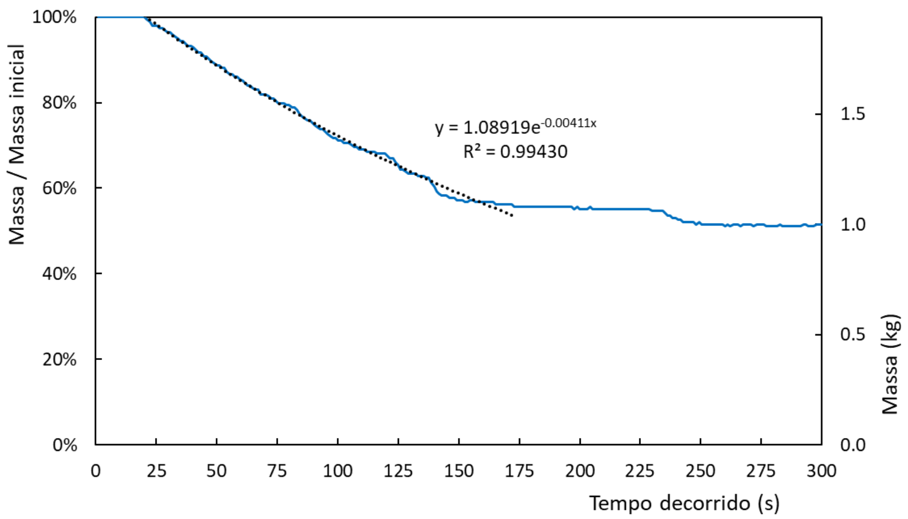


Figure 17 – Example (Test C. leylandii T01_01) of the mass loss represented by the exponential law (Equation 1).

$$Relative\ mass = \frac{mass\ at\ time\ t}{initial\ mass} = \sim 1 \times e^{-k \times t} \quad \text{[Equation 1]}$$

The initial value of the relative mass is theoretically equal to 1 (100%) by definition. Therefore, the value *k* (mass loss coefficient) of Equation 1 represents the mass variation along the burning. A higher value of *k* represents a faster variation of the fuel mass, which is associated to a more intense burning. The values of *k* found for all the experiments are presented in Table 3. The average values are represented in Figure 18.

Table 3 – List of the mass loss coefficient values (k) for the experiments organized by time of dehydration and by the experimental setup.

Specie	Time of dehydration	1-tree setup			3-trees setup		
		Test	k (s^{-1})	r^2	Test	k (s^{-1})	r^2
C. arizonica	5 days	T01_01	--	--	T01_03	---	---
		T02_01	0,00286	0,68	T02_03	0,00284	0,86
	28-32 days	T03_01	0,01755	0,69	T03_03	0,01279	0,65
		T04_01	0,00809	0,76	T04_03	0,00684	0,62
		T05_01	0,01307	0,73	T05_03	0,01076	0,68
	100/101 days	---	---	---	---	---	---
C. leylandii	5 days	T01_01	0,00411	0,99	T01_03	0,00305	0,99
	28-32 days	T02_01	0,00747	0,95	T02_03	0,00498	0,98
		T04_01	0,00661	0,94	T04_03	0,00831	0,81
	100/101 days	T03_01	0,00482	0,93	T03_03	---	---
P. laurucerasus	5 days	T01_01	0,00137	0,96	T01_03	0,00157	0,89
	28-32 days	T02_01	0,00241	0,92	T02_03	0,00110	0,94
		T03_01	0,00063	0,94	T03_03	0,00115	0,90
	100/101 days	T04_01	0,00085	0,98	T04_03	0,00105	0,90
T. occidentalis	5 days	T01_01	0,00210	0,84	T01_03	0,00259	0,86
	28-32 days	T02_01	0,00386	0,92	T02_03	0,00307	0,94
		T03_01	0,00829	0,89	T03_03	0,00963	0,75
	100/101 days	T04_01	0,00050	0,98	T04_03	0,01001	0,78

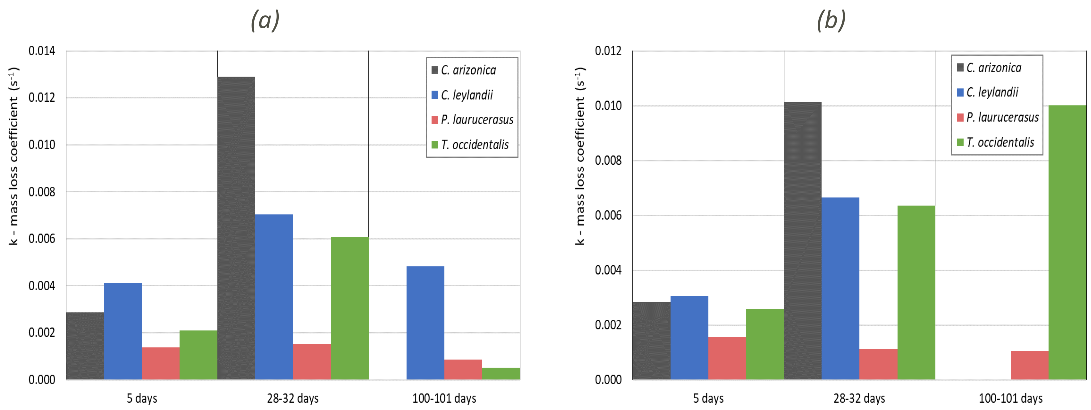


Figure 18 – Average values of the mass loss coefficient (k) obtained for the different species for different periods of dehydration: a) 1-tree setup, b) 3-trees setup.

As can be observed, *Cupressus arizonica* was the species with larger mass loss coefficient value, with a drastic increase after about one month of not being watered. The *Prunus laurocerasus* was the species showing a lower value of *k*, with no evident variation with the time of dehydration. These results are very consistent with the fuel moisture content variation previously described.

4.2.2. Temperature

As mentioned before, the temperature was measured by thermocouples located at three different heights. In Figure 19 we can find the variation of the temperature obtained for the experiments with 28-32 days of dehydration. Some thermocouples did not register correctly the values of temperature (e.g. *C. arizonica T03_01*, 60cm high) so these values must be analysed with much precaution. In a more scientific publication they should not be considered but, in this document, they are presented with the aim of supporting the description of the work performed.

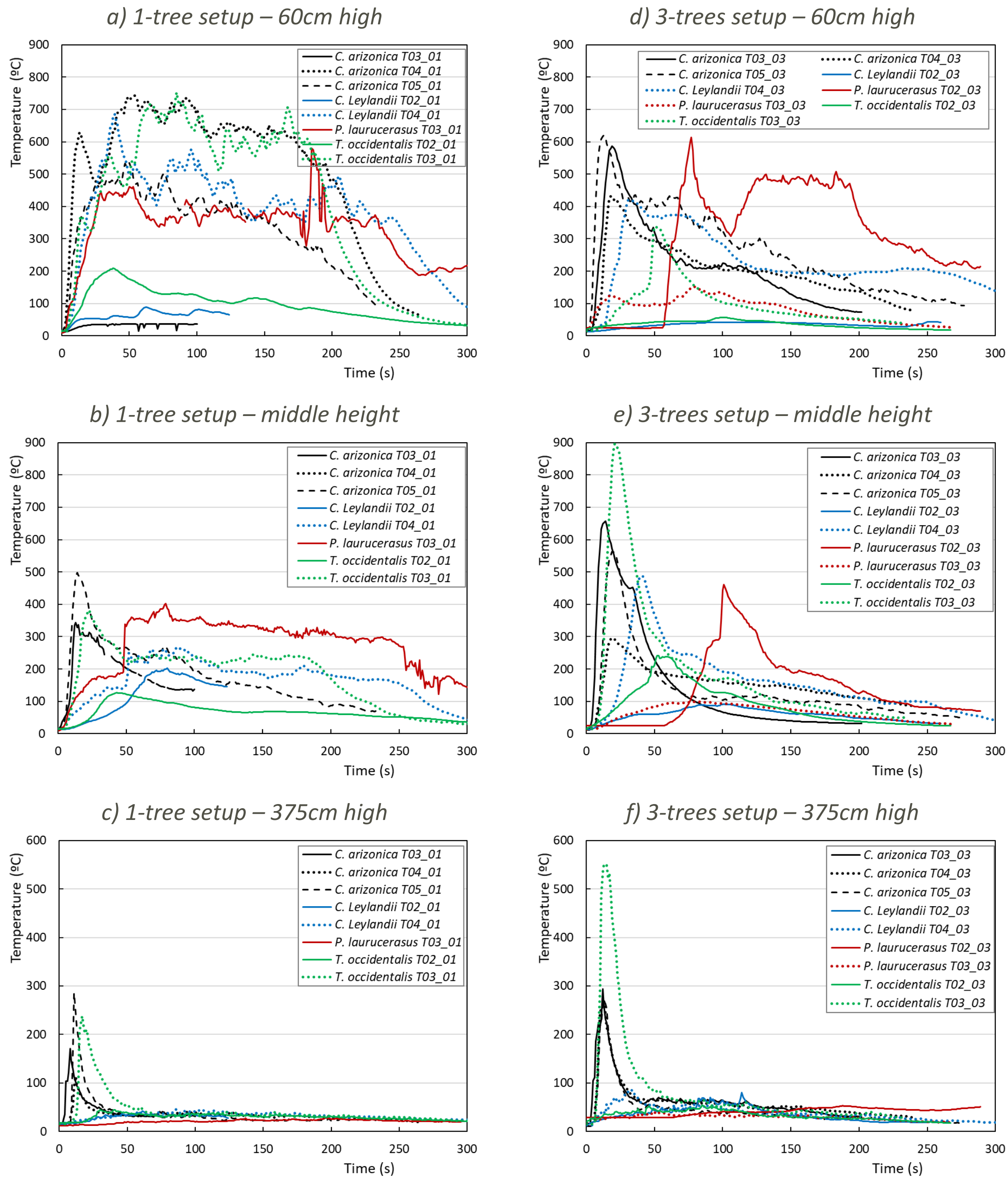


Figure 19 – Variation of the values of the temperature for the different height positions of the thermocouples – 60cm (a, e), middle tree height (b, e) and 375cm (c, f) above the base of the combustion table – for the 1-tree setup and for the 3-trees setup; examples for the series of 28-32 days of dehydration.

Besides the expected lower values of the temperature for the highest thermocouples, since they are more distant from the burning trees, it is possible to verify the larger temperature values of *Cupressus arizonica* and *Thuja occidentalis* for the 375cm high thermocouples. This shows the potential higher heat emissivity of these two species that will be presented in the next subchapter. Following the previous findings, *Prunus laurocerasus* is the species driving to lower values of temperature at the highest thermocouple as a result of a less intense burning.

4.2.3. Heat flux

Two parameters of the heat flux were determined: the radiative heat flux and the total heat flux. Considering negligible the conductive heat flux, we can assume the convective heat flux as the difference between the total and the radiative heat flux. As can be seen in Figure 20, the radiative heat flux is, on average, bout half of the total heat flux.

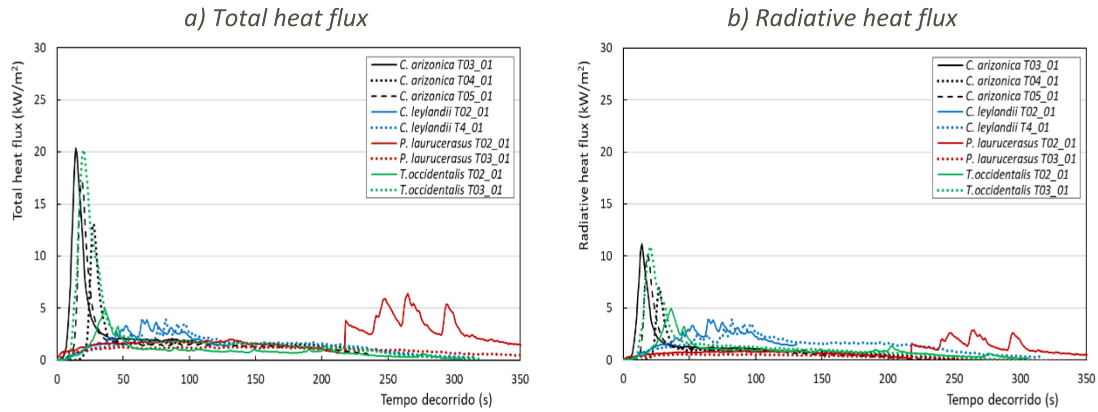
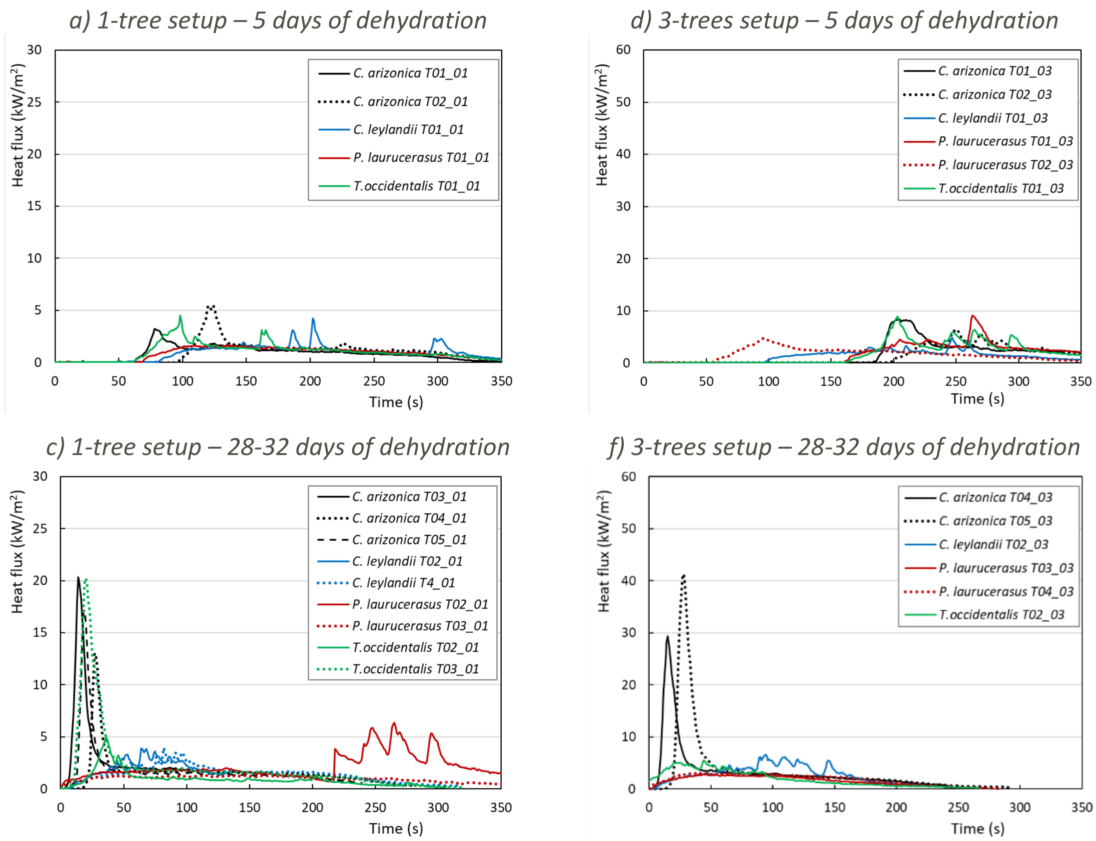


Figure 20 – Example for comparison between the total and the radiative heat flux for the 1-tree setup and a time of dehydration of 28-32 days.

By simplification, hereby we will dedicate more attention to the total heat flux that is reported in Figure 21.



c) 1-tree setup – 100-101 days of dehydration *f) 3-trees setup – 100-101 days of dehydration*

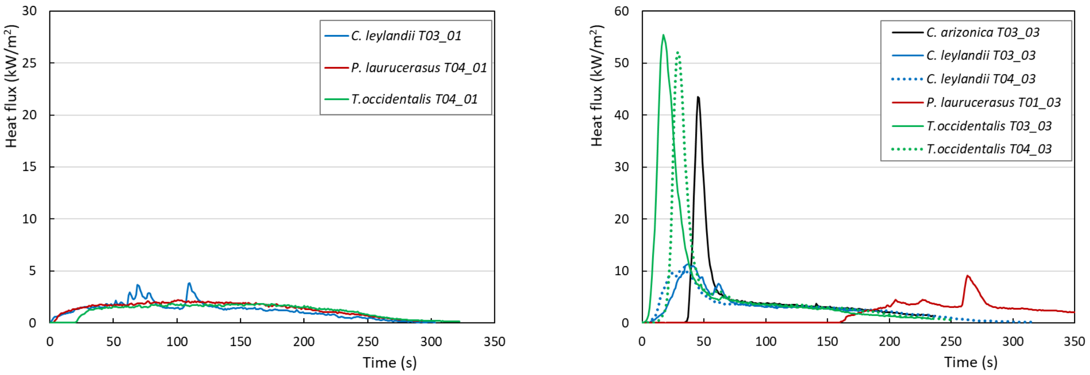


Figure 21 – Variation of the values of the total heat flux for the two tree setups and for the different days of dehydration.

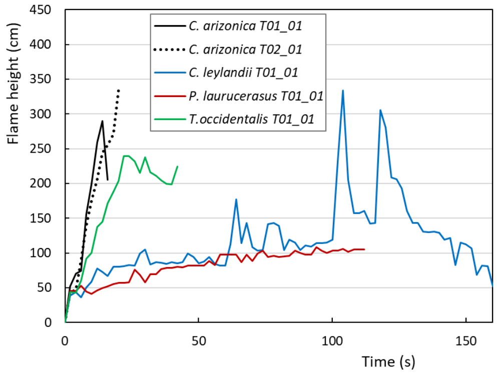
Following the same tendency of the previous parameters, *Prunus laurocerasus* was the species with the lowest heat flux, while *Cupressus arizonica* and *Thuja occidentalis* drove to larger values of this parameter. It can also be observed that the experiments with *Prunus laurocerasus,* and the generality of the experiments for 5 days of dehydration, showed a later pick of heat flux when compared with the other experiments. This is due to the slower and poorer combustibility that delays the arrival of heat flux to the radiometer.

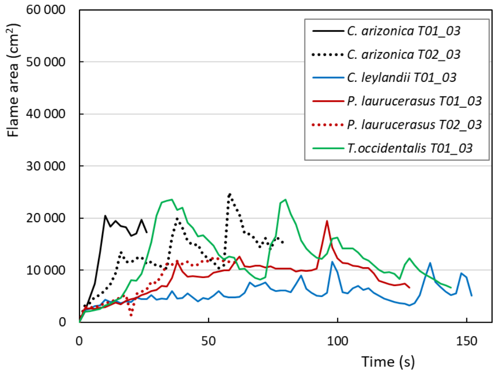
4.2.4. Dimensions of the flames

The flame dimensions are also an important parameter obtained in this set of experiments as they allow the determination of the fire intensity and the propensity to ignite neighbouring exposed elements. Several dimensions were determined such as the flame depth, the flame width, the flame height and the flame projected area. The first two dimensions were quite similar among the experiments as they are deeply related to the size of the tree or set of trees burned. As an example of the values obtained, in Figure 22 the flame height and the flame projected area are represented.

Once again, the largest dimension values were obtained by *Cupressus arizonica* and *Thuja occidentalis* and the lowest values were reached by *Prunus laurocerasus*. It is also possible to verify that in some occasions the values of the flame height are punctually high, what is justified by the individual ignition of some highest branches of some trees, when the rest of the tree(s) were still not ignited.

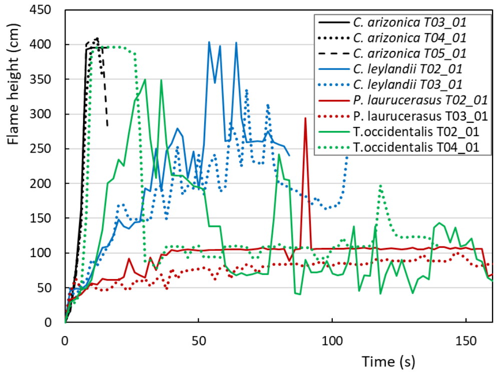
a) 1-tree setup – 5 days of dehydration *d) 3-trees setup – 5 days of dehydration*

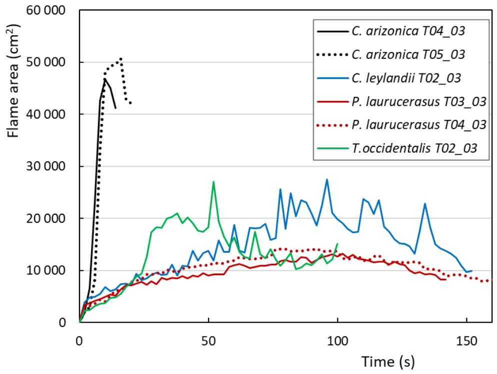




b) 1-tree setup – 28-32 days of dehydration

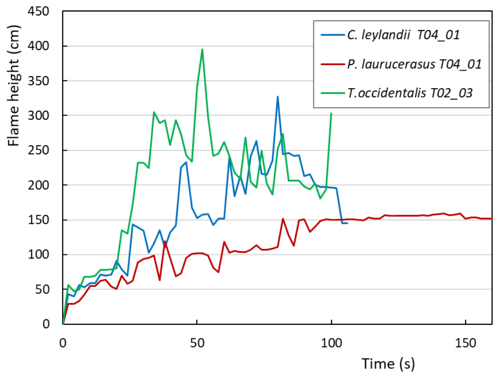
e) 3-trees setup – 28-32 days of dehydration





c) 1-tree setup – 100-101 days of dehydration

f) 3-trees setup – 100-101 days of dehydration



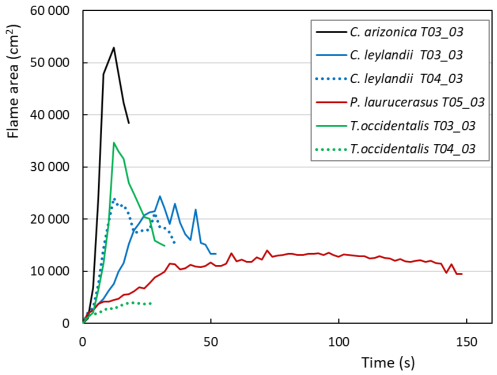


Figure 22- Variation of the values of flame height (a, b, c) and flame area (d, e, f) for the different species analysed, as a function of the days of dehydration – examples for 1-tree setup (a, b, c) and for 3-trees setup (d, e, f).

5. Conclusions

A total of 36 experiments were carried out aiming at the improvement of knowledge associated to the combustibility of four species, typically used in garden hedges. The species analysed were: a) *Cupressus arizonica*, b) *Cupressocyparis leylandii*, c) *Prunus laurocerasus*, and d) Thu*ja occidentalis*. Besides the mass characterization and the fuel moisture content of the components (foliage, green, wood and dead material) for three vertical layers of the species (top layer, middle high layer and bottom layer), burning tests were performed. Moreover, the vulnerability to dehydration of each specie was analysed with three sets of data – 1) trees with 5 days of no watering, 2) trees with 28 to 32 days of no watering and 3) trees with 100 or 101 days of no watering.

The results show *Cupressus arizonica* as the more combustible species and consequently the one that mostly increases the fire risk. In the opposite direction, *Prunus laurocerasus* was the species with lowest combustibility and then with most favourable behaviour in terms of fire risk reduction.

The increase of risk driven by the lack of watering was also the highest for *Cupressus arizonica* and the lowest for *Prunus laurocerasus*, with the other two species with intermediate values, but closer to *Cupressus arizonica* than to *Prunus laurocerasus*. This last species has a particular reaction to dehydration, detaching the leaves before they get dead and dry, while the other species maintain this dead material attached increasing the combustibility and the potential of ignition.

The description hereby presented does not intend as a deep scientific analysis as this will be done in a scientific publication that will be submitted in the near future. Besides the description of the work performed, this deliverable presents data that is of huge relevance for the WUIVIEW database and for the definition and fire behaviour simulation of WUI scenarios that make part of the work to be performed in the WUIVIEW Project.

6. References

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7. Annex 1

Table 4 – Values obtained from the characterization of Cupressocyparis leylandii.

Section	Component	Diameter	1st series Mass (g)	1st series Mass (%)	1st series FMC (%)	2nd series Mass (g)	2nd series Mass (%)	2nd series FMC (%)
3rd section (Top)	Foliage		49.91	8.4	196	28.70	5.3	160
	Green	∅<3mm	0.00	0.0	0	0.00	0.0	0
		3≤∅<6mm	0.00	0.0	0	0.00	0.0	0
		6≤∅<10mm	0.00	0.0	0	0.00	0.0	0
		∅≥10mm	0.00	0.0	0	0.00	0.0	0
	Roundwood	∅<3mm	2.29	0.4	151	2.31	0.4	107
		3≤∅<6mm	7.61	1.3	147	4.22	0.8	119
		6≤∅<10mm	8.33	1.4	156	7.61	1.4	121
		∅≥10mm	0.00	0.0	0	0.00	0.0	0
	Dead	∅<3mm	0.00	0.0	0	0.00	0.0	0
		3≤∅<6mm	0.00	0.0	0	0.00	0.0	0
		6≤∅<10mm	0.00	0.0	0	0.00	0.0	0
		∅≥10mm	0.00	0.0	0	0.00	0.0	0
2nd section (Middle)	Foliage		106.78	17.9	184	89.20	16.6	173
	Green	∅<3mm	0.00	0.0	0	0.00	0.0	0
		3≤∅<6mm	0.00	0.0	0	0.00	0.0	0
		6≤∅<10mm	0.00	0.0	0	0.00	0.0	0
		∅≥10mm	0.00	0.0	0	0.00	0.0	0
	Roundwood	∅<3mm	6.64	1.1	106	10.57	2.0	94
		3≤∅<6mm	12.38	2.1	130	9.53	1.8	105
		6≤∅<10mm	3.42	0.6	164	6.40	1.2	134
		∅≥10mm	52.31	8.8	179	40.25	7.5	150
	Dead	∅<3mm	0.00	0.0	0	0.00	0.0	0
		3≤∅<6mm	0.00	0.0	0	0.00	0.0	0
		6≤∅<10mm	0.00	0.0	0	0.00	0.0	0
		∅≥10mm	0.00	0.0	0	0.00	0.0	0
1st section (Bottom)	Foliage		167.68	28.1	177	178.83	33.3	160
	Green	∅<3mm	0.00	0.0	0	0.00	0.0	0
		3≤∅<6mm	0.00	0.0	0	0.00	0.0	0
		6≤∅<10mm	0.00	0.0	0	0.00	0.0	0
		∅≥10mm	0.00	0.0	0	0.00	0.0	0
	Roundwood	∅<3mm	13.99	2.3	114	13.13	2.4	78
		3≤∅<6mm	20.05	3.4	119	23.10	4.3	82
		6≤∅<10mm	0.96	0.2	145	1.11	0.2	110
		∅≥10mm	145.13	24.3	168	122.12	22.7	141
	Dead	∅<3mm	0.00	0.0	0	0.00	0.0	0
		3≤∅<6mm	0.00	0.0	0	0.00	0.0	0
		6≤∅<10mm	0.00	0.0	0	0.00	0.0	0
		∅≥10mm	0.00	0.0	171	0.00	0.0	0

Table 5 – Values obtained from the characterization of Cupressus arizonica.

Section	Component	Diameter	1st series Mass (g)	1st series Mass (%)	1st series FMC (%)	2nd series Mass (g)	2nd series Mass (%)	2nd series FMC (%)
3rd section (Top)	Foliage		67.21	11.0	126	0.00	0.0	---
	Green	∅<3mm	0.00	0.0	---	0.00	0.0	---
		3≤∅<6mm	0.00	0.0	---	0.00	0.0	---
		6≤∅<10mm	0.00	0.0	---	0.00	0.0	---
		∅≥10mm	0.00	0.0	---	0.00	0.0	---
	Roundwood	∅<3mm	19.6	3.2	130	0.00	0.0	---
		3≤∅<6mm	25.3	4.1	134	0.00	0.0	---
		6≤∅<10mm	14.7	2.4	154	0.00	0.0	---
		∅≥10mm	0.00	0.0	---	0.00	0.0	---
	Dead	∅<3mm	0.00	0.0	---	191.46	10.3	21
		3≤∅<6mm	0.00	0.0	---	11.82	0.6	23
		6≤∅<10mm	0.00	0.0	---	0.00	0.0	---
		∅≥10mm	0.00	0.0	---	2.21	0.1	28
2nd section (Middle)	Foliage		152.73	25.0	161	0.00	0.0	---
	Green	∅<3mm	0.00	0.0	---	0.00	0.0	---
		3≤∅<6mm	0.00	0.0	---	0.00	0.0	---
		6≤∅<10mm	0.00	0.0	---	0.00	0.0	---
		∅≥10mm	0.00	0.0	---	0.00	0.0	---
	Roundwood	∅<3mm	9.65	1.6	117	0.00	0.0	---
		3≤∅<6mm	46.45	7.6	124	0.00	0.0	---
		6≤∅<10mm	3.91	0.6	127	0.00	0.0	---
		∅≥10mm	0.00	0.0	---	0.00	0.0	---
	Dead	∅<3mm	0.00	0.0	---	582.92	31.2	20
		3≤∅<6mm	0.00	0.0	---	62.15	3.3	21
		6≤∅<10mm	0.00	0.0	---	78.33	4.2	22
		∅≥10mm	0.00	0.0	---	124.36	6.7	23
1st section (Bottom)	Foliage		206.31	33.8	143	0.00	0.0	---
	Green	∅<3mm	0.00	0.0	---	0.00	0.0	---
		3≤∅<6mm	0.00	0.0	---	0.00	0.0	---
		6≤∅<10mm	0.00	0.0	---	0.00	0.0	---
		∅≥10mm	0.00	0.0	---	0.00	0.0	---
	Roundwood	∅<3mm	13.2	2.2	105	0.00	0.0	---
		3≤∅<6mm	48.89	8.0	115	0.00	0.0	---
		6≤∅<10mm	1.02	0.2	155	0.00	0.0	---
		∅≥10mm	0.00	0.0		0.00	0.0	---
	Dead	∅<3mm	1.94	0.3	24	369.49	19.8	19
		3≤∅<6mm	0.00	0.0	---	41.80	2.2	22
		6≤∅<10mm	0.00	0.0	---	30.27	1.6	24
		∅≥10mm	0.00	0.0	---	372.30	19.9	21

Table 6 – Values obtained from the characterization of Prunus laurocerasus.

Section	Component	Diameter	1st series Mass (g)	1st series Mass (%)	1st series FMC (%)	2nd series Mass (g)	2nd series Mass (%)	2nd series FMC (%)
3rd section (Top)	Foliage		63.27	5.7	138	92.61	9.2	199
	Green	∅<3mm	0.00	0.0	---	7.52	0.7	182
		3≤∅<6mm	12.03	1.1	141	9.25	0.9	151
		6≤∅<10mm	0.00	0.0	---	13.93	1.4	153
		∅≥10mm	0.00	0.0	---	0.00	0.0	---
	Roundwood	∅<3mm	0.00	0.0	---	0.00	0.0	---
		3≤∅<6mm	0.00	0.0	---	0.00	0.0	---
		6≤∅<10mm	0.00	0.0	---	15.80	1.6	136
		∅≥10mm	0.00	0.0	---	11.60	1.1	133
	Dead	∅<3mm	0.00	0.0	---	0.70	0.1	7
		3≤∅<6mm	0.00	0.0	---	1.14	0.1	30
		6≤∅<10mm	0.00	0.0	---	0.00	0.0	---
		∅≥10mm	0.00	0.0	---	0.00	0.0	---
2nd section (Middle)	Foliage		293.12	26.5	110	97.17	9.6	196
	Green	∅<3mm	27.37	2.5	122	17.02	1.7	161
		3≤∅<6mm	84.81	7.7	119	24.11	2.4	139
		6≤∅<10mm	35.15	3.2	119	32.22	3.2	143
		∅≥10mm	0.00	0.0	---	0.00	0.0	---
	Roundwood	∅<3mm	0.00	0.0	---	0.00	0.0	---
		3≤∅<6mm	6.66	0.6	104	29.31	2.9	131
		6≤∅<10mm	43.10	3.9	90	0.00	0.0	---
		∅≥10mm	188.65	17.0	76	146.61	14.5	116
	Dead	∅<3mm	5.24	0.5	16	4.70	0.5	26
		3≤∅<6mm	0.00	0.0	---	10.03	1.0	22
		6≤∅<10mm	0.00	0.0	---	0.00	0.0	---
		∅≥10mm	0.00	0.0	---	0.00	0.0	---
1st section (Bottom)	Foliage		137.52	12.4	116	26.39	2.6	185
	Green	∅<3mm	13.53	1.2	125	4.63	0.5	151
		3≤∅<6mm	19.15	1.7	115	5.20	0.5	149
		6≤∅<10mm	4.01	0.4	107	0.00	0.0	---
		∅≥10mm	0.00	0.0	---	0.00	0.0	---
	Roundwood	∅<3mm	0.00	0.0	---	2.33	0.2	36
		3≤∅<6mm	28.13	2.5	95	10.67	1.1	90
		6≤∅<10mm	82.97	7.5	90	17.11	1.7	114
		∅≥10mm	26	2.3	78	431.74	42.7	111
	Dead	∅<3mm	36	3.3	18	0.00	0.0	---
		3≤∅<6mm	0.00	0.0	---	0.00	0.0	---
		6≤∅<10mm	0.00	0.0	---	0.00	0.0	---
		∅≥10mm	0.00	0.0	---	0.00	0.0	---

Table 7 – Values obtained from the characterization of Thuja occidentalis.

			1st series			2nd series		
Section	Component	Diameter	Mass (g)	Mass (%)	FMC (%)	Mass (g)	Mass (%)	FMC (%)
3rd section (Top)	Foliage		287.55	9.7	147	197.26	9.7	59
	Green	∅<3mm	0.00	0.0	---	0.00	0.0	---
		3≤∅<6mm	0.00	0.0	---	0.00	0.0	---
		6≤∅<10mm	0.00	0.0	---	0.00	0.0	---
		∅≥10mm	0.00	0.0	---	0.00	0.0	---
	Roundwood	∅<3mm	11.29	0.4	90	11.47	0.6	57
		3≤∅<6mm	33.32	1.1	102	20.41	1.0	64
		6≤∅<10mm	13.01	0.4	103	10.43	0.5	70
		∅≥10mm	12.48	0.4	113	0.00	0.0	---
	Dead	∅<3mm	1.31	0.0	34	0.00	0.0	---
		3≤∅<6mm	0.00	0.0	---	0.00	0.0	---
		6≤∅<10mm	0.00	0.0	---	0.00	0.0	---
		∅≥10mm	0.00	0.0	---	0.00	0.0	---
2nd section (Middle)	Foliage		955.83	32.3	200	484.26	23.9	48
	Green	∅<3mm	0.00	0.0	---	0.00	0.0	---
		3≤∅<6mm	0.00	0.0	---	0.00	0.0	---
		6≤∅<10mm	0.00	0.0	---	0.00	0.0	---
		∅≥10mm	0.00	0.0	---	0.00	0.0	---
	Roundwood	∅<3mm	47.8	1.6	91	45.77	2.3	51
		3≤∅<6mm	119.46	4.0	102	58.53	2.9	63
		6≤∅<10mm	134.12	4.5	115	117.88	5.8	66
		∅≥10mm	258.53	8.7	113	158.07	7.8	67
	Dead	∅<3mm	9.99	0.3	21	0.00	0.0	---
		3≤∅<6mm	0.00	0.0	---	0.00	0.0	---
		6≤∅<10mm	0.00	0.0	---	0.00	0.0	---
		∅≥10mm	0.00	0.0	---	0.00	0.0	---
1st section (Bottom)	Foliage		103.67	3.5	136	194.96	9.6	40
	Green	∅<3mm	0.00	0.0	---	0.00	0.0	---
		3≤∅<6mm	0.00	0.0	---	0.00	0.0	---
		6≤∅<10mm	0.00	0.0	---	0.00	0.0	---
		∅≥10mm	0.00	0.0	---	0.00	0.0	---
	Roundwood	∅<3mm	12.12	0.4	77	9.22	0.5	46
		3≤∅<6mm	22.56	0.8	93	27.27	1.3	52
		6≤∅<10mm	100.97	3.4	97	59.05	2.9	70
		∅≥10mm	788.73	26.6	113	621.47	30.6	69
	Dead	∅<3mm	48.15	1.6	17	14.33	0.7	21
		3≤∅<6mm	0.00	0.0	---	0.00	0.0	---
		6≤∅<10mm	0.00	0.0	---	0.00	0.0	---
		∅≥10mm	0.00	0.0	---	0.00	0.0	---