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Research article

Possible land management uses of common cypress to reduce wildfire initiation risk: a laboratory study

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A B S T R A C T

Accurate determination of flammability is required in order to improve knowledge about vegetation fire risk. Study of the flammability of different plant species is essential for the Mediterranean area, where most ecosystems are adapted to natural fire but vulnerable to recurrent human-induced fires, which are the main cause of forest degradation. However, the methods used to evaluate vegetation flammability have not yet been standardized. *Cupressus sempervirens* is a native or naturalized forest tree species in the Mediterranean area that is able to tolerate prolonged drought and high temperatures. The aim of this study was to characterize the flammability of *C. sempervirens* var. *horizontalis* at particle level by using different bench-scale calorimetry techniques (mass loss calorimeter, epiradiator and oxygen bomb) to determine the main flammability descriptors (ignitability, sustainability, combustibility and consumability) in live crown and litter samples. Our findings indicate that this variety of cypress is relatively resistant to ignition because of the high ash content, the high critical heat flux, the high time to ignition displayed by both crown and litter samples and the ability of the leaves to maintain a high water content during the summer. We also discuss the possibility of exploiting some morphological, functional and ecological traits of the species to construct a barrier system (with selected varieties of cypress) as a promising complementary land management tool to reduce the fire spread and intensity in a Mediterranean context.

1. Introduction

Recurrent human-induced fires represent one of the most frequent causes of forest degradation in the Mediterranean region. More than 269,000 fires were reported in the region in 2006–2010, with about 54,000 fires occurring per year and more than 2 million ha of forest land burnt (on average 400,000 ha per year) (FAO, 2013). Fire risk is increasing in the Mediterranean basin as a result of climate change and of changes in land use (e.g. abandonment of rural areas). In particular, increased temperature, lower rainfall (IPCC, 2007) and more extreme weather events (e.g. droughts and heatwaves) are expected to exacerbate the threat posed by fire (FAO, 2007).

Current fire management, which is mainly based on fire suppression rather than on preventive land management, may further accelerate the transition to a more fire-prone future and magnify the problem (Fernandes, 2013). In a region with altered fire regime, strategies aimed at identifying the areas at greatest risk of fire are recommended. The basic first step in fire hazard assessment is the characterization of fuel in terms of its flammability, an attribute that depends on the interactions between various dynamic parameters (Dimitrakopoulos, 2001; Dimitrakopoulos and Papaioannou, 2001).

The use of green barriers as a silviculture measure aimed at better control of fires is a possible complementary measure to fire suppression. The CypFire project of the EU-funded Programme Med (which investigates the use of multiple-rowed cypress barriers against fires as a feasible, ecological and economical solution for the

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protection of Mediterranean Regions) has considered the use of green barriers established with selected varieties of cypress to counteract natural risks, particularly wildfires, in vulnerable sites, e.g. at the wildland–urban interface (WUI) (Moya and Moya, 2013a). Interest in the use of cypress barriers as a tool for limiting fire arose as a result of field observations indicating that common cypress (*Cupressus sempervirens* L.) trees were sometimes less affected than other tree species by wildfires, as observed in Turkey (Neyisci and Intini, 2006) and Spain (Moya and Moya, 2013b). Common cypress is native to the arid and semi-arid areas of the eastern part of the Mediterranean basin and Middle East. This species grows in pure stands or in association with other xerophytic species such as *Pinus halepensis*, *Pinus brutia*, *Quercus ilex*, *Quercus calliprinos*, *Juniperus excelsa* and *Juniperus phoenicea* (Farjon, 2005; Quézel and Médail, 2003). Common cypress is able to grow on a wide variety of bedrock formations and soil types (including poor, dry, rocky, calcareous, serpentinous and clay soils) from sea level up to 1700 m a.s.l. Since ancient times, the species has been widely grown around the Mediterranean basin as a multipurpose tree, as an ornamental, windbreaks, hedges, for soil protection and for its valuable timber, and has become a typical landscape feature in many regions (Della Rocca et al., 2007).

Two morphological varieties of common cypress are known: the wild type *C. sempervirens* var. *horizontalis* (Mill.) Cord., which is widely represented in the native populations and is characterized by a broad conical crown with the main branches forming a wide angle with the trunk, and *C. sempervirens* var. *pyramidalis* Nymann (= var. *stricta* Ait.), which has a fastigiated, columnar and dense crown with main branches growing upwards close to the trunk. As a consequence of the different crown architecture, the *horizontalis* form has a sparse canopy and dead foliage does not usually remain trapped within the crown. The fastigiated form has a very dense crown, which favours the accumulation of dead vegetal material inside (Moya and Moya, 2013c). Hence, the effect of tree habit may have a marked influence on the flammability.

In previous studies, crown samples of *C. sempervirens* were classified as of low or moderate flammability (Valette, 1990; Neyisci and Intini, 2006), not very flammable (Ganteaume et al., 2013a) or highly flammable (Dimitrakopoulos and Papioannou, 2001; Liodakis et al., 2002). Some of these works, which focused on ornamental plants grown as hedges, classified *C. sempervirens* as highly flammable, mainly because the denser vegetation increases the surface area-to-volume ratio of the structure, which also favours the accumulation of dead fuel in the crown (Moya and Moya, 2013c; Ganteaume et al., 2013a). The results of such works are inconsistent and difficult to compare, and more studies are therefore needed for better evaluation of the flammability of cypress.

The flammability of vegetation can be measured at different scales, ranging from landscape to leaf, and the methods of measuring this parameter have not yet been standardized. This may reflect a view of flammability as a qualitative rather than a quantifiable property, which makes comparison of results problematic (Xanthopoulos et al., 2003; Corona et al., 2014). The most common definition of flammability has been described by White and Zipperer (2010), who identify four components: ignitability, combustibility, sustainability and consumability. The ignitability depends on the ignition characteristics of the fuel and it is determined by recording the time to ignition or fire frequency of the tested sample, showing the easiness to burn. The sustainability evaluates the heat evolved in the combustion. The combustibility is an indicator of the rapidity of the fuel combustion. Finally, the consumability under specified test conditions evaluates the residual mass fraction from combustion process or, in other words, the efficacy of combustion to consume the fuel biomass.

The flammability of plants is usually assessed by means of laboratory assays in which several methods and devices are used (Etlinger and Beall, 2004; Weise et al., 2005; Madrigal et al., 2012; Ganteaume et al., 2013a, 2013b). The epiradiator, or radiant heater, has been used to evaluate flammability parameters in many studies (Valette, 1990; Hernando, 2000; Dimitrakopoulos and Papioannou, 2001; Alessio et al., 2008; Ganteaume et al., 2013a). However, epiradiator tests do not allow evaluation of the heat release rate (HRR), which is essential for understanding sustainability and combustibility. Furthermore, until now, most of the proposed HRR bench-scale tests for evaluating forest fuel flammability have been based on the characterization of oven-dried or conditioned samples (Dibble et al., 2007). Some recent studies have attempted to carry out tests with fresh samples of live forest fuel (Madrigal et al., 2013; Possell and Bell, 2013). In this respect, Madrigal et al. (2013) proposed a new method that takes into account fuel moisture content (FMC) in flammability studies.

Information about the characteristics of crown architecture and FMC of live fuels is crucial for developing and understanding fire initiation and propagation (Cruz and Alexander, 2010). However, there is a lack of knowledge about the interaction between heat flux and FMC at different crown heights (Cruz et al., 2011). Assessment of this process (Madrigal et al., 2013) may help to characterize flammability at tree level, including its involvement in crown fires.

The aim of the present study was therefore to characterize the flammability of *C. sempervirens* var. *horizontalis* by using different bench-scale techniques to determine the main descriptors of flammability, taking into account the fuel moisture content. For this purpose, trials were carried out with samples of necromass (surface dead fine fuel or litter) and biomass (live fine twigs with leaves) taken from different crown heights.

2. Materials and methods

2.1. Study area

The cypress samples were collected in a plantation located in a forest area known as Barranco de Herbasana, in the municipality of Jérica (Valencia, Spain), at an elevation of 923 m a.s.l. (Fig. 1).

In June 2012, the cypress plantation was slightly affected (only 1.27% of the trees were burned, 37.09% were more or less dehydrated and 61.64% were unaffected) by a large fire that destroyed all of the surrounding vegetation represented by a *Q. ilex* community with the presence of scattered *Quercus faginea*, *Juniperus oxycedrus* and planted *P. halepensis* (Moya and Moya, 2013b). The cypress plot was established in 1988 with several clones of *C. sempervirens* from France, Greece and Italy and with seedlings from Spain. The trees were planted at 3 × 3 m spacing and the area of the plot was 0.9 ha (228 × 39 m) (Tuset, 2013). The climate in the area is semi-arid and mesothermal (Thornthwaite, 1948) with 48% of the evapotranspiration occurring in summer and a dry season occurring between June and early September (Fig. 1). The plot is located in a slight depression (between 9 and 18% slope around the plot) formed by material eroded from the surrounding Jurassic limestone, in which bicarbonate-laden waters accumulate on soils, thus forming calcic horizons.

Cypress trees in the plantation were characterized by a wide crown and long branches, inserted into the trunk at an angle of between 50° and 60°; the height of the cypress trees ranged between 5.05 and 7.15 m, the diameter of trunk at the base was 18–24 cm and the crown width varied from 1.94 to 3.74 m.

2.2. Fuel sampling

In April 2013, three samples of twigs Ø < 0.6 cm with foliage (live fine fuel, according to Deeming et al. (1972) were collected,