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► **To cite this version:**

T. Curt, A. Schaffhauser, L. Borgniet, R. Esteve, Anne Ganteaume, et al.. Litter flammability of French Mediterranean vegetation types : a cross-substratum analysis. VI International Conference on Forest Fire Research, Nov 2010, Coimbra, Portugal. 10 p. hal-00583411

HAL Id: hal-00583411

<https://hal.science/hal-00583411>

Submitted on 5 Apr 2011

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Litter flammability of French Mediterranean vegetation types: a cross-substratum analysis

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Abstract

Assessing the flammability of litters in fire-prone ecosystems of major importance to quantify the wildland fire hazard. We compared undisturbed litter samples typical of French ecosystems on the two main types of substratum, i.e. acidic versus limestone, to investigate to which extent their characteristics and flammability may differ. We measured in the laboratory several flammability parameters on oven-dried samples that mimic the high fire hazard level in summer. On average, litters on limestone were much denser and had higher biomass than those on acidic soils. They also ignited more slowly, but they burned much more completely. The different components of flammability (i.e. ignitability, combustibility, sustainability, and consumability) have been correlated to the characteristics of the litters such as biomass and bulk density. We discuss to which extent the management of these ecosystems could limit the fire ignition hazard

Keywords: [Litter, flammability, Mediterranean ecosystems, fire ignition hazard]

1. Introduction

Southeastern areas of France (so-called Provence) constitute a fire hotspot (JRC-EFFIS, 2006) and include a wide range of Mediterranean-type fire-prone ecosystems. In Provence, a major contrast has long been stated between the wildland ecosystems due to their substratum (Quézel and Médail, 2003): (i) ecosystems on limestone substratum are dominated by *Pinus halepensis*, *Quercus ilex* and *Q. pubescens*, and *Q. coccifera* shrublands; while (ii) ecosystems on acidic substratum are dominated by *Q. suber*, and *Erica-Cistus* shrublands. In spite of quite similar fire regimes along the past decades, this major ecological contrast has led to different postfire dynamics of the vegetation types (Trabaud, 1998). However, to which extent the contrast between vegetation on limestone soils *versus* acidic soils could entail a difference of litter flammability and fire ignition hazard remains unknown. Actually, the composition of wildland fuels and forest ecosystems is expected to influence the amount and the composition of litter fuels then, in turn, the flammability of litter fuels (Dimitrakopoulos, 2002; Fernandes and Rigolot, 2007). Dead fuel beds lying on the ground (i.e., litters *sensu lato*) are made of various necromass particles including woody and shrubby debris (needles, leaves, twigs, bark), and dead herbs (Anderson, 1970). The accumulation of necromass on the ground depends on the balance existing between the supply by the above vegetation (i.e. the litter fall) and the rate of decomposition that relates mainly to the biological activity of soils (Rapp, 1999; Arianatsou and Radea, 2000). These processes are expected to differ strongly between limestone ecosystems and acidic ecosystems (Quézel and Médail, 2003). Litter is especially important for wildland fire as it is both the receiving fuel that may ignite, and the ground fuel bed that participates to the initial fire propagation (Behm et al., 2004; Plucinski and Anderson, 2008).

As a consequence, assessing the flammability of litter fuels is of major importance to evaluate the fire ignition hazard, and more generally to assess the fire risk (Dimitrakopoulos, 2001). Since Anderson (1970) then Martin et al. (1994) most studies describe flammability as the combination of four components: ignitability, sustainability, combustibility, and consumability. The ignitability component refers to the time until ignition once exposed to a heat source. Sustainability is the ability to sustain fire once ignited, while combustibility is defined as the rate of burn after ignition, and consumability is the proportion of mass or volume consumed by fire (Martin et al., 1994).

In this study we hypothesized that the characteristics of vegetation such as composition or biomass would impact the characteristics of litter, then in turn its flammability. As a consequence we expect that the flammability of litters on acidic substratum would differ from that on limestone substratum.

2. Materials and Methods

The two study areas were located in southeastern France. The area on limestone substratum (43.1° N, 5.2° E) comprised ecosystems dominated by *Pinus halepensis* and oaks (*Quercus ilex*, *Q. pubescens*), and *Q. coccifera* shrublands (Ganteaume et al., 2009). As the substratum is mainly composed of limestone, most soils are carbonated and have a low moisture content, and a short period of biological activity (Peltier et al., 2001). The

area on acidic substratum (the Maures massif, 43.3° N, 6.3° E) was dominated by the highly fire-resilient *Quercus suber*, and by *Erica-Cistus* shrublands (Curt et al., 2009). The Maures massif is made of granitic and metamorphic basement and covered with acidic Cambisols. These soils have generally a high biological activity and vary from an acidic to a mesotrophic gradient. In both areas, the climate is typically Mediterranean and classed as subhumid xerothermic (Quézel and Médail, 2003).

To test the hypothesis that litter flammability would differ between limestone and acidic soils, we collected undisturbed (= non-reconstructed) litter samples (diameter 38 cm) in the three main vegetation types typical of each type of substratum, i.e. acidic versus limestone. The litter collection was operated using a 40x40 cm iron plate dug into the soil at ca. 5-cm depth in order to collect the whole undisturbed litter. The litter collection was replicated 5 to 10 times in each of the vegetation types to ensure the repeatability of the results. The samples were dried during 48 hours at 60°C in a gently ventilated oven in order to get a similar and low fuel moisture content (ca. 5%) that mimics severe summer conditions. Each sample was then burned in the laboratory at the INRA Avignon facility. All the burnings were operated with a constant wind speed of ca. $9.8 \pm 0.1 \text{ km.h}^{-1}$ using a fan. Ignition was provided by a standardized wood cube (2 x 2 x 1 cm) made of *Pinus sylvestris* and oven-dried to get a standard fuel moisture content of ca. 12%. The cube was ignited using an epi-radiator providing a standard 415°C temperature (NF P92-501), then we waited for the total extinction of flames. After the extinction of flames, the glowing cube was then put in the center of the sample. Before burning, the biomass (g of dry weight), the depth (cm) and the bulk density (kg.m^{-3}) were measured for each litter sample.

The burning apparatus was put on a scale (accuracy 0.1 g) to follow up the mass loss rate during the burning process. Temperature was measured using *k*-type thermocouples (accuracy 0.2°C at 1000°C) placed at 10, 20 and 40 cm above the litter sample. The mean temperature was computed as the mean value of all the thermocouples along the combustion process. We also estimated the flame height using a digital camera: the maximal flame height was estimated every 2 seconds using rulers positioned beside the burning apparatus. We assessed the time to ignition (s), the burning duration (s), the mean temperature (°C), the maximal flame height (cm), the number of sides reached by flames (n), the rate of spread of flames (cm.s^{-1}), and the mass loss at the end of burning (%). We also measured the air temperature and humidity during the experiments to test if they could affect the flammability. The statistical tests indicated no significant effect and variation among the experiments ($P > 0.005$).

The comparison of the flammability variables between the two types of substrata (acidic versus limestone) was operated using analysis of variance (ANOVA) and a least significant difference (LSD) procedure with a 95% confidence interval. Data were log-transformed to meet the normality assumptions. These analyses were performed using the Statgraphics® Centurion v. 15 software. We coupled a principal component analysis (PCA) with a canonical component analysis (CCA) to investigate the relationships between the characteristics of vegetation (stand density, composition, a.s.o.), the characteristics of litters (depth, biomass, and bulk density) and the flammability variables.

3. Results

An overall comparison of litters on limestone versus acidic soils indicated that the biomass, the bulk density, the time to ignition, the flaming duration, the area burned and the mass loss differed significantly (Table 1). Litters on limestone were much denser and had higher biomass than those on acidic soils. They also ignited more slowly, but they burned much more completely.

Variable	Acidic substratum	Limestone substratum	Tests ^a
Litter depth (cm)	2.78 ± 0.86	2.73 ± 1.57	0.746 ^{NS}
Litter bulk density (kg.m ⁻³)	36.5 ± 9.0	140.8 ± 52	< 0.0001 ^{****}
Litter biomass (g, dw)	98.7 ± 50.0	364.9 ± 84.0	< 0.0001 ^{****}
Time to ignition (s)	30.0 ± 15.0	63.5 ± 54.3	0.0057 ^{**}
Flaming duration (s)	135 ± 36	170 ± 76	0.0025 ^{**}
Rate of spread (cm.s ⁻¹)	0.74 ± 0.38	0.61 ± 0.37	0.1045 ^{NS}
Number of sides (n)	2.3 ± 0.7	2.6 ± 1.1	0.2180 ^{NS}
Mean temperature (°C)	74.7 ± 51.5	60.4 ± 12.8	0.1722 ^{NS}
Mean flame height (cm)	11.2 ± 5.0	9.6 ± 3.2	0.1161 ^{NS}
Maximal flame height (cm)	24.4 ± 8.7	24.3 ± 7.7	0.9445 ^{NS}
Area burned (%)	59.4 ± 20.2	80.1 ± 15.8	< 0.0001 ^{****}
Mass loss (%)	63.7 ± 13.2	90.2 ± 17.7	< 0.0001 ^{****}

Table 1. ANOVA for the litter characteristics and the flammability variables according to the type of substratum (acidic *versus* limestone). Values are mean ± standard error. ^a We performed LSD procedure (95%) with a t-test, or the non-parametric Kruskal-Wallis test

The coupling of two multivariate analyses (PCA and CCA) allowed making correlations between the characteristics of the different types of litter and the variables describing their flammability (Figure 1). The most mature and dense forests and woodlands (i.e. pine-oak mixings on limestone, and mixed oak woodlands on acidic soils) correspond to thick litters with a long time of combustion, and a large proportion of litter burned during the experiments. *Pinus halepensis* forests on limestone corresponded to litters having high flames and temperatures, and a high proportion of litter burned. High and dense shrublands on acidic soils dominated by *Erica arborea* corresponded to the maximal litter amount but not to the maximal combustibility. On limestone, the shrublands dominated by *Quercus coccifera* had a high bulk density and a long time to ignition. The shrublands recurrently burned on acidic soils and dominated by *Cistus* species corresponded to high rates of fire spread.

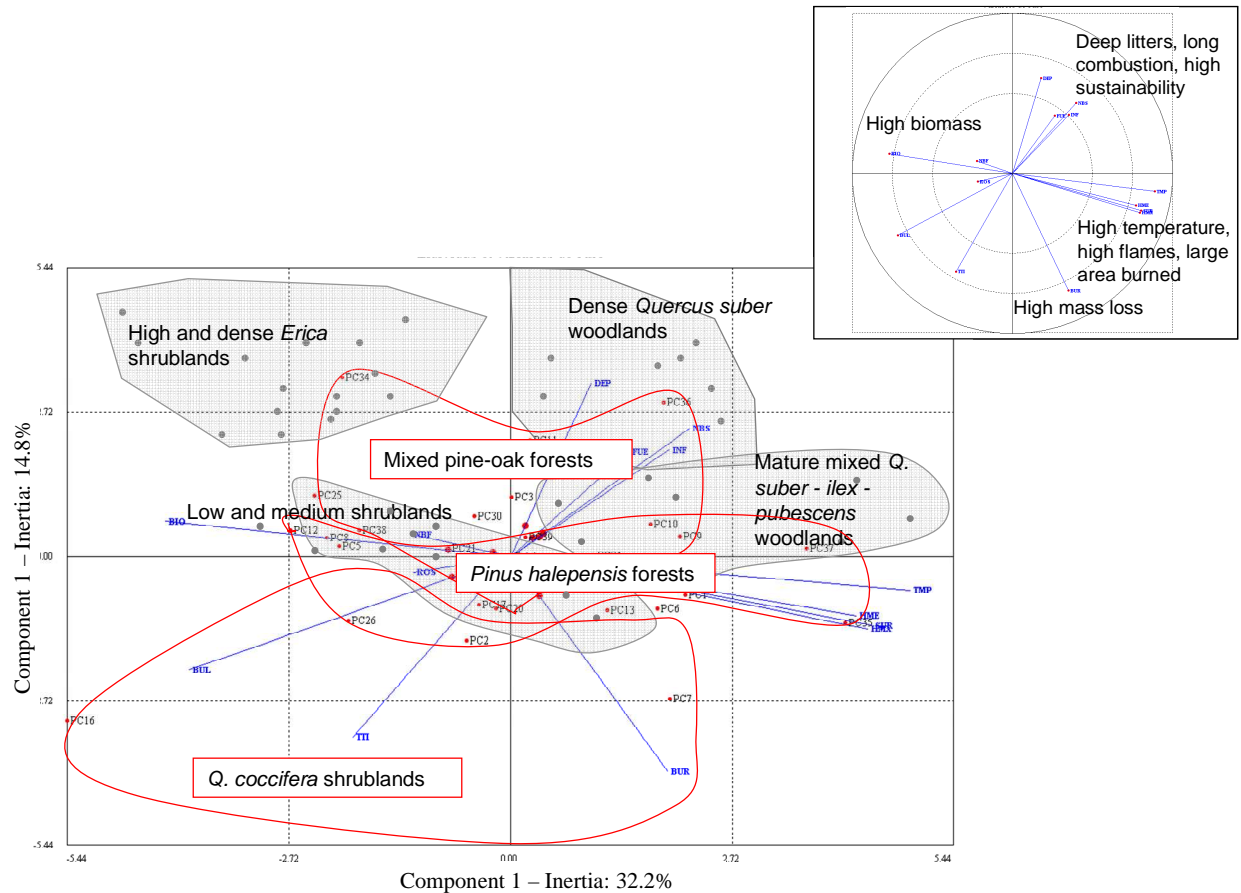


Figure 1. Canonical correspondence analysis for the litter characteristics and flammability components on limestone and acidic soils of southeastern France. The enclosed graph (upper right) details the principal component analysis on litter characteristics. Red lines: litters and vegetation on limestone soils. In grey: litters and vegetation on acidic soils. Data were log-transformed to meet the normality assumptions

4. Discussion

Our results indicate that the litters on limestone substratum differ from those on acidic soils, and that this entails differences of flammability. In short, litters on limestone are more abundant and denser than those on acidic substratum. As a consequence, they ignite less easily but sustain flames more efficiently. Our results on litter's characteristics are coherent with the existing studies on litter decomposition, which suggest that litter accumulates strongly and/or decomposes slowly on limestone soils regardless of the vegetation type. Litter especially accumulates under closed *Pinus halepensis* stands and dense *Quercus coccifera* shrublands (Trabaud, 1985; Trabaud, 1994; Rapp, 1999; Arianatsou and Radea, 2000). First, this could be due to a high litter supply: the dense and mature pine stands and the dense shrublands dominated by the long-lasting resprouter *Q.*

coccifera provide a high annual amount of dead particles that accumulate on the soil. Second, literature suggests that soils on limestone have low fertility, biological activity, and moisture content in summer, thus limiting the decomposition of litter fuels (Oyonarte et al., 2008). In contrast, the rate of litter decomposition is likely to be higher on acidic soils (Castells and Penuelas, 2003; Aranda and Oyonarte, 2006), this being clearly visible in our data that indicate low values of biomass and bulk density. Literature has stated that *Quercus suber* stands on acidic soils have a rapid litter mineralization that limit the accumulation of litter fuel (Robert et al., 1996; Caritat et al., 2006). In addition, most *Quercus suber* stands and *Erica-Cistus* shrublands in the Maures massif have experienced a high number of severe fires in the past decades (Curt et al. 2009), thus logically decreasing the biomass of litter (Schaffhauser et al., 2008).

As the combination of different substrata and vegetation types control for a part the characteristics of the litters (composition, biomass, bulk density), this logically influences their flammability. Oak woodlands mixed with pine and mature oak forests generally correspond to low fire recurrence and have favored the accumulation of deep litters that have a high sustainability, whatever the type of substratum. The large leaves of the deciduous downy oak (*Quercus pubescens*) especially lead to the accumulation of thick litters that are favorable to the propagation and the sustainability of flames. For these mixed oak forests, we suggest that a contrast exists between the potential for sustainable ground fires driven by an abundant litter, and the low combustibility of the whole forests due to the scarcity of understory fuels (Dimitrakopoulos, 2002; Fernandes, 2009). Pine forests on limestone accumulate large amounts litter made of highly-flammable needles, which generate high temperatures and flames and generally propagate throughout the whole litter sample. This is coherent with the idea that *Pinus halepensis* stands are especially at high fire risk (Liodakis et al., 2005). The different types of shrublands exhibit clear differences of litter flammability depending upon their composition and their fire history. High and dense *Erica* shrublands on acidic soils are generally unburned since 15-30 years (Curt et al., 2009) and have accumulated high amounts of senescent fine particles including twigs and very fine *Erica* leaves, well-aerated, which can generate high fire intensity. In contrast, *Quercus coccifera* shrublands on limestone generate litters of high bulk density composed of thick and tough leaves, which entail long time to ignition and thus low ignitability. The low and medium shrublands *Cistus* shrublands that are recurrently burned have thin and loose litters that cannot sustain flames, and thus have a low combustibility. However, they can produce high rate of flame spread due to the high supply of oxygen in the loose litter.

5. Conclusions

Clear differences exist in vegetation and litter fuels between the two types of substrata present in Provence. This controls for a part the flammability of litters through their biomass and composition. However, another major contrast of litter characteristics and flammability results from the recent fire history of vegetation: it opposes shrublands recurrently burned to mixed woodlands and mature forests.

Acknowledgments

We greatly acknowledge the technical and scientific staff of the INRA burning facility (J.C. Valette, J. Maréchal, D. Portier). This study was funded by the European Community in the framework of the Fire Paradox Integrated EU Research Program (FP6 - 018505).

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