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Comparison of flammability of undisturbed and disturbed litters sampled on limestone-derived soils in Provence (SE France).

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Abstract

Knowledge about wildland fuel is essential to fire prevention and to both biodiversity conservation and reduction of the negative impacts of fire. Little is known of flammability of dead fuels, especially for non-reconstructed samples that are hypothesized to represent the field conditions.

To assess the impact of the sampling method on the flammability, samples of litter were collected undisturbed (i.e. keeping intact the structure of litter layers, compactness and bulk-density) and disturbed (sample reconstructed using mainly the upper litter layer with a depth equal to the mean litter depth recorded on the plot) in limestone-derived soils in Provence.

The sampling plan also comprised three types of vegetation among the most representative ecosystems of the study area: pure *Pinus halepensis* stands, mixed pine-oak stands and shrublands. At last, the sampling included four types of fire regime defined by the number of fires having occurred on each site since 1960 and the time interval since the last fire.

Flammability experiments were carried out in laboratory using a glowing firebrand and a 10 kmh⁻¹ wind. The main variables recorded were: time-to-ignition, flaming duration, flame rate of spread, flame propagation, mean flame temperature, mean flame height and rate of consumption in order to assess the ignitability, sustainability, combustibility and consumability of each litter sample.

Results showed that there was no significant effect of the fire regime (time interval since the last fire and number of fires) on the flammability parameters. The type of vegetation had a significant effect on all the parameters except on flaming duration, flame temperature and flame height. Litter sampled in mixed stands and in pure pine stands were more flammable than litter sampled in shrublands and mixed stand litter was more ignitable than pine litter. The type of sampling had a significant effect on all the parameters except on time-to-ignition and flaming duration; undisturbed litter being more flammable than disturbed litter, with higher combustibility and consumability.

The intact litter structure seemed to be a very important factor in the flammability, especially in the combustibility and consumability of litter samples and these parameters might be underestimated using reconstructed litter samples. The type of vegetation was a significant factor especially on the ignitability of the litter samples, the sampled collected under mixed stands being more ventilated than the compacted pine needle litter.

Keywords: flammability, Mediterranean fuels, litter sampling

1. Introduction

In the Mediterranean Basin, fires are of major concern for forest and shrubland ecosystems. Wildland fire occurrence and area burned have significantly increased since the 1960s, as a consequence of climatic change and alterations in land use (Piñol *et al.* 1998). Knowledge about wildland fuel is essential to fire prevention and to both biodiversity conservation and reduction of the negative impacts of fire. However, little is known of flammability of dead fuels, especially for non-reconstructed samples that are hypothesized to represent the field conditions in contrast of reconstructed litters usually studied. Even if some authors worked in field conditions, like Fernandes *et al.* (2008), only very few studies were carried out on non-reconstructed samples. For instance, Kurz *et al.* (2000) used undisturbed soil blocks, including all the organic profile and the upper part of the mineral soil, to assess the decomposition rate of *Pinus pinaster* needles. Gomez-Gonzales & Cavieres (2009) assessed the effect of litter burning on seedling emergence. However, none of these authors studied the flammability parameters of the litter. Most studies on litter flammability were carried out on reconstructed litter samples, usually calibrated samples of leaves of a given species. Indeed, the leaf litter was considered as the wider component of the total litter on forest floor (Petriccione *et al.* 2006). Others works, carried out on wider disturbed samples of litter used burning tables, took into account more flammability parameters than in the previous works. They tested the impact of different factors such as the FMC or the bulk density (Plucinski & Anderson 2008), but also the vegetation type (Fonda *et al.* 1998 2001; Fonda & Varner 2004; Kane *et al.* 2008; Ganteaume *et al.* 2009a) or the terpene content (Ormeño *et al.* 2009) on the flammability of a given species. At another level, Taylor & Fonda (1990) assessed burning characteristics of fuel using Mutch's methodology (1970) on reasonably intact litter samples mixing some woody fuels with the largely non woody fuels.

A previous work was carried out on the flammability of undisturbed litter enhancing the need to be closer to the field conditions (Ganteaume, comm. pers.) than usually done with disturbed litter (Ganteaume *et al.* 2009a). Using non-reconstructed litter samples, the litter structure is kept intact during the sampling while using disturbed litter samples, the structure is reconstructed using mainly the upper layer of the litter and a calibrated litterbed depth.

The aim of this work was to check if the sampling method affected the flammability of the litter.

2. Material and methods

Sampling methodology

To assess the impact of dead fuel characteristics on the flammability, samples of litter were collected undisturbed (taking into account all the litter layers and keeping intact the structure of litter layers, compactness and bulk-density) and disturbed (sample reconstructed using mainly the upper litter layer) in 28 study sites spread over the limestone Provence.

The sampling of undisturbed litter was performed using an iron plate (40x40cm) to cut the litter layer without any disturbance of the litter structure (Fig.1). Once cut, the litter sample

was carefully slipped from the iron plate into a cardboard box to protect it during the carriage to the laboratory.

The sampling of the disturbed litter was carried out along a 20m transect placed in the middle of each 20x20m study plot. Every 2m, a sub-sample of the upper litter was collected using a calibrated iron circle of 0.2m diameter (Fig.2). For each plot, the ten sub-samples allowed the reconstruction in laboratory of one litter sample of 0.36m diameter, with a depth equal to the mean litter depth recorded in the plot



Figure 1 : Sampling of undisturbed litter



Figure 2 : Sampling of disturbed litter

The sampling was carried out according to the sampling plan used in Ganteaume *et al.* (2009b), on different vegetation types and fire regimes in limestone Provence (southeastern France).

As water is known to be one of the most important factors influencing fire behaviour, the litter samples were oven-dried for 48 h at 60°C in laboratory.

The Bulk-Density (BD in kgm^{-3}) was calculated for each sample dividing the sample weight by the sample litter volume (litter surface area*litter depth).

Burning experiments

Litter burning experiments were conducted under controlled laboratory conditions at the INRA Vignères facility (Avignon, France). The experiments tried to reproduce the effect of a surface fire on heterogeneous litter.

Flammability of the litterbeds has been analyzed, according to the definitions given by Anderson (1970) and Martin *et al.* (1993), as the result of the following four phenomena: ignitability (the amount of time until ignition once a material is exposed to a known ignition source), sustainability (how the fuel continues to burn), combustibility (how rapidly or intensely a material burns), and consumability (quantity of material that is consumed). Therefore, the main variables recorded were: ignition frequency (%), time-to-ignition (s), flaming duration (s), spread or flame propagation (number of sample sides

reached by the flames), rate of spread (kmh^{-1}), mean flame temperature ($^{\circ}\text{C}$), maximum flame height (cm) and percent consumption (burned biomass) (%).

The experimental burns were conducted on fire benches made of cellular concrete, on which the different litter samples were laid, forming round layers of a surface area of 0.10m^2 . This size allowed enough fire development indicating sustainable ignition. The distance of 0.19m, from the ignition point to a side of the sample, allowed enough fire development to demonstrate sustainability of fire spread. The fire benches were placed on a scale (sensitivity 1g) to assess the weight loss during the burn. Two rulers, in cm, which enabled visual assessment of the flame height during the tests, were placed on each side of the bench. A set of seven thermocouples (thermocouple type k with a 30μ diameter), previously calibrated were positioned at each side and in the middle of the sample at three different heights (10cm, 20cm and 40cm high). They were connected to a computer to record the variation of temperature during the burn (Fig.3). In order to ensure that the ignitions of the litter samples occurred under identical conditions, standard ignition sources were used. These were cubes ($2 \times 2 \times 1$ cm) of *Pinus sylvestris* wood (FMC = 12%), ignited using an electric radiator (Standard NF P 92-509-1985). Once the ignition occurred, the glowing “firebrand” was placed in the centre of the sample and the chronometer was connected. The temperature variations were then recorded as well as the parameters characterizing the flammability of the litter samples as described in Ganteaume *et al.* (2009a). A 10 kmh^{-1} wind was generated using a domestic fan that had grills and mesh filters to obtain even flow across the burning area. During the experiments, the mean relative temperature was 24°C and the mean relative humidity was 56.29%.

The dry litter weight was calculated for each sample adding up the weight loss recorded during the experiment and the unburned litter weight.

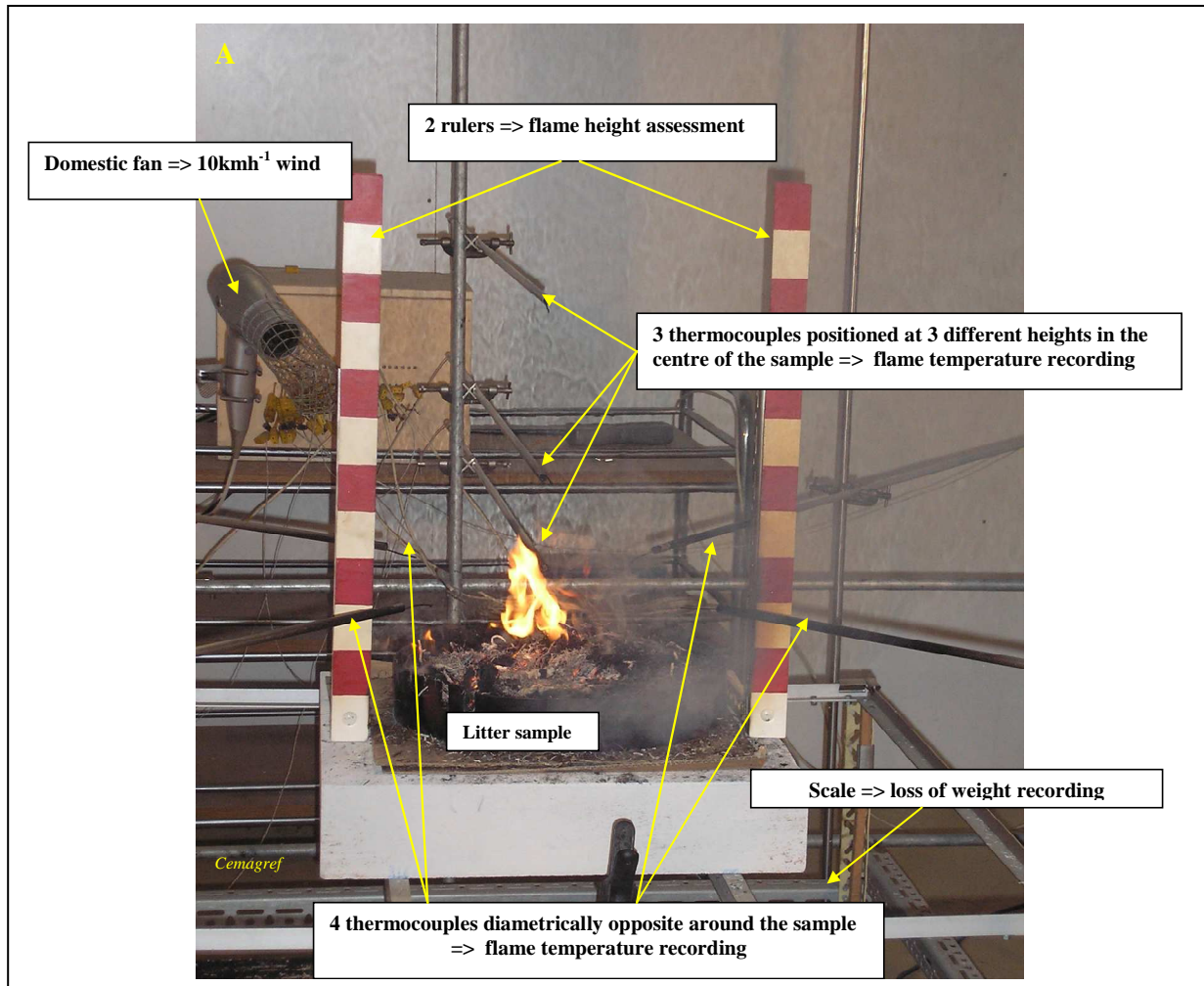


Figure 3: the burning device

Statistical analyses

The effects of the factors “type of vegetation”, “fire regime” and “sampling method” on the flammability parameters were analyzed using multiple ANOVA. On overall significant ANOVA results, a LSD test was used to test significant differences between the different factors. Comparisons of means, using a parametric Mann Whitney-test, were performed in order to test the significance of the sampling methods on the flammability parameters. Some variables were log-transformed due to non-normality of distributions. The α level for all tests was 0.05 and all analyses were performed using Statgraphics Centurion XV software.

3. Results

Litter parameters

The litter sample parameters (weight, depth, and bulk-density) are presented in table 1. The bulk-densities of the disturbed and undisturbed litter samples were not significantly different and there was no significant difference between the bulk-densities according to the vegetation type.

Impact of the different factors on litter flammability

The multiple ANOVA allowed us to highlight that the type of sampling was the most significant factor regarding of litter flammability and that there was no significant effect of the fire regime on overall flammability parameters (Tab. 2).

The type of sampling had a significant effect on time-to-ignition ($F=4.07$; $p=0.049$), flame spread ($F=14.11$; $p=0.0005$), rate of spread ($F=5.90$; $p=0.019$), maximum flame height ($F=5.19$; $p=0.027$), mean flame temperature ($F=22.66$; $p<0.0001$) and percent consumption ($F=36.09$; $p<0.0001$).

The type of vegetation had a significant effect on all the parameters except on flaming duration, rate of spread and flame temperature. Litter sampled in mixed stands ($TTI=40.02s$) was significantly more ignitable ($F=5.82$; $p=0.005$) than litter sampled in pure pine stands ($TTI=89.90s$) and in shrublands ($TTI=75.34s$). The spread ($F=8.99$; $p=0.0005$) and the percent consumption ($F=6.84$; $p=0.0024$) were significantly lower in shrublands ($S=2.08$ sides, $RC=48.98\%$) than in pine stands ($S=3.19$ sides; $RC=71.73\%$) and in mixed stands ($S=3.13$ sides; $RC=69.16\%$). The maximum flame height was significantly higher ($F=5.26$; $p=0.027$) in pine stands ($FH=24.23cm$) than in mixed stands ($FH=18.42cm$) and shrublands ($FH=15.16cm$).

Differences between the types of sampling

Undisturbed litter samples were found to be more flammable than disturbed litter samples with higher combustibility (spread, rate of spread, mean flame temperature, maximum flame height) and consumability (percent consumption). Ignitability and sustainability did not differ between the types of sampling. The data recorded on the undisturbed litter samples were always higher than the data recorded on disturbed litter samples, except for the time-to-ignition (Tab. 3).

Table 1: Weight, surface area, depth and bulk-density of the undisturbed and disturbed litter samples (Mean and standard deviation).

	Litter Weight (kg)	Sample surface area (m ²)	Litter Depth (m)	Bulk Density (kgm ⁻³)
Undisturbed	0.14 (0.061)	0.1	0.029 (0.011)	51.26 (19.28)
Disturbed	0.17 (0.059)	0.1	0.030 (0.014)	60.10 (29.02)

Table 2: Effects of vegetation, sampling and fire regime on the different parameters of litter flammability (MANOVA, TTI: time-to-ignition; FD: Flaming duration; S: Flame spread; RS: Rate of spread; FH: Maximum Flame height, FT: Flame temperature, PC: Percent consumption; *: significant; **: very significant; ***: highly significant; NS: non significant)

	logTTI	FD	S	RS	FH	FT	PC
Vegetation	**	NS	**	NS	**	NS	*
Sampling	*	NS	***	*	*	***	***
Fire regime	NS	NS	NS	NS	NS	NS	NS

Table 3: Comparison of the flammability of undisturbed and disturbed litter samples (Mean (standard deviation); N: number of samples; TTI: time-to-ignition; FD: Flaming duration; S: Flame spread; RS: Rate of spread; FH: Maximum flame height, FT: Flame temperature, PC: Percent consumption; W: Mann Whitney test, NS: non significant)

	N	TTI (s)	FD (s)	S (nb of sides)	RS (kmh ⁻¹)	FH (cm)	FT (°C)	PC (%)
Undisturbed	28	61.14 (51.87)	186.83 (49.10)	3.36 (0.72)	0.040 (0.016)	22.17 (10.38)	61.08 (12.81)	82.13 (20.69)
Disturbed	28	65.86 (55.30)	169.75 (78.13)	2.54 (1.10)	0.028 (0.022)	17.25 (7.07)	45.87 (11.49)	51.23 (21.45)
Statistical test		NS	NS	W=209; p=0.002	W=229; p=0.008	W=265.5; p=0.04	W=140.5; p<0.0001	W=116; p<0.0001

4. Discussion

The results of burning undisturbed and disturbed litter sampled on limestone-derived soils in Provence showed differences in their relative flammability. The lower combustibility and consumability values in disturbed litter samples could be due to the artificial compactness in reconstructed samples performed in order to mimic the mean litterbed depth recorded in the field. The intact litter structure and especially the composition in litter components seemed to be a very important factor in the flammability, especially in the combustibility and consumability of litter samples. These parameters might be underestimated using reconstructed litter samples; indeed, in these samples, all the litter components are not present and their proportions differ. However, some authors (Kane *et al.* 2008 ; Ormeño *et al.* 2009), working on disturbed litter samples, showed that litterbed depth had a significant effect on flame temperature, flame height and sometimes, rate of consumption. In addition, Scarff & Westoby (2006) pointed out the effect of the litter packing ratio on the flammability. Indeed, a better ventilated litterbed entailed a faster supply of oxygen to the fire involving a better litter flammability. Both fuel structure and area-volume ratio are also involved in fire behaviour (Fernandes & Rego 1998; Bilandzija & Lindic 1993). Contrary to finding herein, Ormeño *et al.* (2009) showed that litterbed depth was likely partially responsible for fire being self-extinguished in decreasing the flame propagation. They also pointed out that fuel flammability may vary according to the burning techniques employed (e.g. epiradiators at different temperatures or burning tables). However, the flame height in their study was clearly sensitive to fuel loads and their arrangements explained differences between burning techniques.

Regarding the flammability of the disturbed litter, the results obtained in this work are quite different from the results found in the literature. The burning protocol was different from the protocol used by Ormeño *et al.* (2009) or Kane *et al.* (2008), but it was the same than the one used in Ganteaume *et al.* (2009a). However, the results on flammability parameters are quite different for the disturbed samples that can be compared to the type of samples used by these last authors (longer time-to-ignition, higher rate of spread, lower flame height). These differences could be due to the heterogeneity of the litter used in this study. Indeed, in Ganteaume *et al.*'s samples (2009a), the litter was homogeneous, only composed of calibrated pine needles or oak leaves of one same species. On the contrary, in this work, the litter was heterogeneous, composed of different elements, not calibrated, coming from different species, related to the upper vegetation type. This litter composition could entail the strong differences of burning behaviour of the litter samples previously highlighted.

5. Conclusions

The litter sampling was the most significant factors regarding of the litter flammability. The undisturbed litter samples always had a better combustibility and consumability than the disturbed samples due to the strong influence of the litter packing ratio and of the proportions of litter components. Indeed, the structure of the undisturbed litter samples was kept intact and these samples were not artificially reconstructed. Even if the sampling of disturbed litter is easier and faster, this methodology has to be used carefully according to

what has to be highlighted. Indeed, the reliability of the results will differ if the litter structure or composition is taken into account.

The vegetation type was found to have a significant effect on the ignitability, the flame spread, maximum flame height and consumability but this variable was less significant than the previous one. The fire regime had no effect on the litter flammability.

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