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Flammability of regenerated vegetation after two post-fire soil stabilization treatments in NW Spain

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Introduction

One of the main ecological consequences of forest fires is soil degradation, due to the combined effect of direct soil heating by fire and the loss of litter and vegetation (Vallejo, 1999). In Europe, Northwestern Spain, namely Galicia, is one of the areas with higher fire number and average area burned, resulting in a high fire incidence (San Miguel and Camia, 2009). In addition, this region has high precipitation and steep terrain, what makes it as particularly prone to post-fire erosion. For that reason, bioengineering treatments for post-fire soil stabilization are increasingly being used in Galicia (Vega *et al.*, 2013). Among these treatments, grass seeding has been widely used for post-fire erosion control because it is relatively inexpensive and easy to apply, although its efficacy is questioned (Beyers, 2004), whereas mulching is used to cover ground instantaneously and has proved suitable for reducing soil losses after wildfire (Vega *et al.*, 2014).

Stabilization treatments may also have consequences on the flammability of the vegetation that recover the ground in the years following the fire. Because assessment of vegetation flammability is a way of addressing fire hazard in fuel complexes (Marino *et al.*, 2011), specific information concerning the flammability of the vegetation resulting after the treatments is of interest to complement the information currently available on the effectiveness of said treatments. In this perspective, the aim of the present study is to assess the effects of two soil stabilization treatments (seeding and mulching + seeding) on the flammability of recovered vegetation, relative to that in an untreated control, in a shrubland of Galicia, three and five years after the treatments. Flammability tests have been conducted in laboratory at particle level, and then extended at plot level.

This study is part of two more comprehensive research projects: (a) on the effects over time of post-fire rehabilitation and restoration treatments on vegetation recovery, its flammability and on soil quality, and (b) on integrated vulnerability of forest systems to wildfire.

Materials and Methods

The study was conducted in the municipality of O Irixo (Ourense, NW Spain), in a 350 ha area of shrubland burned in September 2009. Prior to the wildfire, the area was dominated by *Pterospartum tridentatum* (L.) Willk., *Ulex gallii* Planch., *U. europaeus* L., *Erica umbellata* Loefl. (L.) and *Halimium lasianthum* ssp. *alyssoides* (Lam.) Greuter, which form a continuous thick layer of vegetation that completely covers the soil. Immediately after the fire, and before

appreciable rains occurred, 15 experimental plots of 22 m x 5 m were established, with its longer side parallel to the maximum slope angle (Figure 1, left). The plots were delimited with geotextile bands for the periodic measurement of erosion. Then, three post-fire treatments were randomly applied, with five replications of each of them: (a) Manual seeding of herbaceous plants (3 g m^{-2}), (b) Manual seeding of herbaceous plants (3 g m^{-2}) and mulching of wheat straw, applied uniformly by hand (250 g m^{-2}) and (c) Control (burned area, without further treatment). More information about the study area and treatments can be found in Vega *et al*. (2015).

At 3 and 5 years after the fire (July 2012 and 2014, respectively), the main types of regenerated vegetation were identified in the plots, based on which a field inventory was carried out on the basis of the Comparative Yield Method described by Haydock and Shaw (1975). Following ranks were established:

(a) Five ranks 3 years after of the fire: Rank 3.1: Low shrub (mostly *Halimium lasianthum* ssp *alyssoides* and *Pterospartium tridentatum*); Rank 3.2: Low shrub + Herbaceous; Rank 3.3: Medium size *P. tridentatum* resprouts; Rank 3.4: Medium-sized shrub + Herbaceous; Rank 3.5: Medium size *P. tridentatum*, *Ulex gallii* and *U. europaeus* shrub.

(b) Five ranks 5 years after the fire: Rank 5.1: *P. tridentatum* shrub; Rank 5.2: *Ulex* sp. shrub; Rank 5.3: *P. tridentatum*, *Hallimium lasianthum* ssp. *alyssoides* and *Ericaceae* shrub; Range 5.4: *Ulex* sp., *H. lasianthum* ssp. *alyssoides* and *Ericaceae* shrub; Rank 5.5: *Ericaceae* or *H. lasianthum* ssp. *Alyssoides* shrub.

Subsequently, a destructive inventory of three 1 m x 1 m quadrats per rank was carried out each study year. Due to its scarce presence in the field, rank 5.5 was not collected. More information about field inventory is available in Guijarro *et al.* (2017).

In order to assess the flammability of the main recovered shrub species at particle level, ≈ 300 g of leaves and fine twigs (< 1 cm Φ) of these species were collected in the summer of each study year. All samples were transported to the laboratory in hermetically sealed plastic bags and stored in a climatic chamber at 4 °C to avoid loss of water content. Flammability tests were carried out in a Mass Loss Calorimeter (Madrigal *et al.*, 2013) (Figure 1, right). This bench-scale methodology allows estimating the flammability of forest fuels, by evaluating its four components: ignitability, sustainability, combustibility and consumability. The tests were conducted with a radiant heat flux of 50 kW m^{-2}, in order to simulate conditions similar to those of a real fire, with samples of 10 g of dry mass, corresponding to a bulk density of 20 kg m^{-3}. Species flammability results were first extended to rank level by weighting loads and humidity per species. Finally, the effect of the post-fire treatments on the flammability was assessed taking into account the frequency of the ranks in the experimental plots.

For the purpose of this study, two of the four flammability components have been selected: combustibility, an indicator of the rapidity of combustion after ignition, evaluated by means of the Peak Heat Release Rate (PHRR, kW m^{-2}), and consumability, that addresses fire intensity in terms of the amount of fuel consumed in the burning process, evaluated by recording the Residual Mass Fraction (RMF, %).

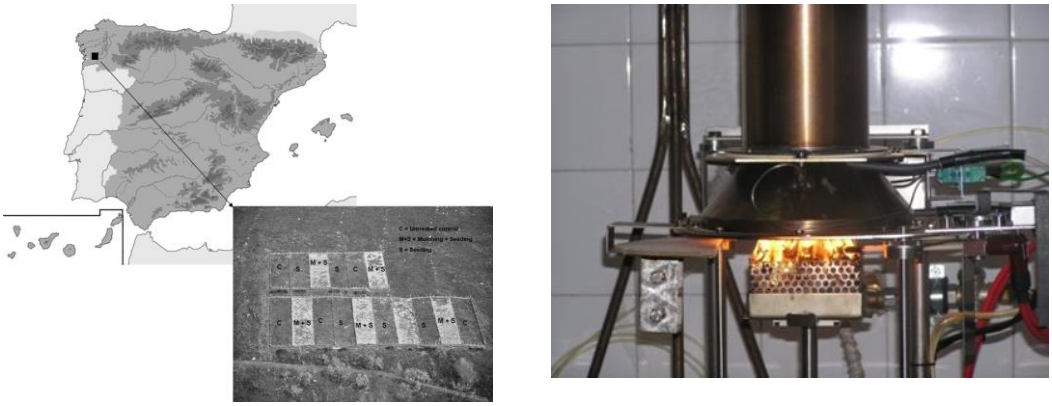

Figure 1. Left: Location of the study area and plot layout (from Vega *et al.*, 2015). Right: Flammability test in the Mass Loss Calorimeter

Results and Discussion

Although the assessment of flammability by means of laboratory tests is limited by the scale of the experimentation (Fernandes and Cruz, 2012), integration of bench scale results according to the variation in relative cover of different fuel types enables an assessment of fire hazard in treated areas (Marino *et al.*, 2012).

The results obtained show that post-fire stabilization treatments of "seeding" and "straw mulching + seeding" affect the flammability of the regenerated vegetation. Three years after the treatments, the combustibility of the treated plots was higher than that of the control plots, whereas the consumability was lower in the treated plots than that of the control plots, being similar these two flammability components in both treatments (Table 1).

Table 1. Frequency of ranks (%), Peak Heat Release Rate (PHRR, kW m^{-2}) and Residual Mass Fraction (RMF, %) in control (C), seeding (S) and straw mulching + seeding (M+S) plots

	% in C plots	% in S plots	% in M+S plots	PHHR	C PHRR	S PHRR	M+S PHRR	RMF	C RMF	S RMF	M+S RMF
Three years after de treatments											
Rank 3.1	37	23	9	19.88	7.26	4.57	1.79	61.38	22.40	14.12	5.52
Rank 3.2	7	35	35	30.83	2.16	10.79	10.79	56.37	3.95	19.73	19.73
Rank 3.3	42	24	22	1.80	0.77	0.43	0.41	99.00	42.08	23.76	22.28
Rank 3.4	9	15	31	20.3	1.83	3.05	6.19	39.61	3.56	5.94	12.08
Rank 3.5	5	3	3	79.83	3.99	2.39	2.39	7.40	0.37	0.22	0.22
Total					**16.00**	**21.23**	**21.57**		**72.36**	**63.77**	**59.83**
Five years after the treatments											
Rank 5.1	55	45	51	174.69	95.21	78.61	89.09	11.12	6.06	5.00	5.67
Rank 5.2	7	8	7	205.49	14.38	16.44	14.38	29.83	2.09	2.39	2.09
Rank 5.3	30	33	34	129.30	39.44	42.67	43.96	14.64	4.47	4.83	4.98
Rank 5.4	8	14	8	186.13	14.89	26.02	14.889	18.65	1.49	2.61	1.49
Total					**163.92**	**163.78**	**162.33**		**14.11**	**14.83**	**14.23**

Concerning combustibility (PHHR), these differences might be explained by the higher frequency of ranks 3.2 and 3.4 in the treated plots (Table 1). In these ranks, the presence of herbaceous as a result of the treatments leads to an increase in the heat release rate and therefore of the PHHR. With regard to consumability (RMF), its decrease in the treated plots may be due to the lower frequency in these plots of the rank 3.3, the rank with higher FMR (99 %). Rank 3.3 goes from 42 % in the control plots to 24 % and 22 % in the seeding and straw mulching + seeding treatments, respectively, which results in a lower value of RMF in the treated plots. However, five years after the treatments, no differences between treated and untreated plots were observed in combustibility or consumability. After that time, the predominant species in the formation of treated plots tend to retrieve their initial recovery, due to their capacity for reproduction by sprouting and by seeds (Calvo *et al.*, 2002), whereas the herbaceous species are practically absent. Therefore, both combustibility and consumability of the recovered shrub are similar among control, seeding and straw mulching + seeding plots. Several authors (Marino *et al.*, 2011; Madrigal *et al.*, 2012) have pointed out that five years after prescribed burning in gorse (*Ulex europaeus*) shrubland, fire hazard increases significantly, due to the rapid physiological and structural changes that take place in gorse resprouts after the fire. Our results confirm this trend.

Conclusions

This work is an approach to the effects over time of two soil stabilization treatments, "seeding" and "straw mulching + seeding" on recovered shrub flammability in North-western Spain. The results have shown that the treatments increase the combustibility three years after the treatments. From the point of view of shrubland management and in a re-burn scenario, in which the probability of occurrence of a subsequent wildfire is high, this fact should be taken into consideration.

However, this effect disappears five years after the treatments. Considering that the treatment of straw mulching + seeding does not affect both combustibility and consumability with respect to seeding, and that straw mulching + seeding was a more effective treatment in reducing erosion (Vega *et al.*, 2015), this seems to be the most advisable post-fire treatment in shrublands in Galicia.

Nevertheless, full-scale experiments are also needed to achieve a deeper knowledge of the flammability in natural conditions at landscape level.

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