Comparing The Effect Of Polyphosphate And Foam Addition To Water On Fire Propagation In Shrubland.

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Summary

Several chemical components are commonly added to water during forest fires to improve its extinction capability. Although these additives have been extensively tested in laboratory, information on their actual effect on fire behaviour at the field scale is scarce, and particularly in fires affecting dense continuous shrublands. One study has been developed to quantify the relative effectiveness of the two most frequently used fire-suppressant additives, ammonium polyphosphate and foam, applied at their respective usual concentrations, compared to water. Fifteen experimental fires were conducted in goarse-dominated shrubland fuel complexes in Galicia (NW Spain), five for each treatment (water, water + polyphosphate and water + foam), applied at a rate of 1 liter/m^2. Fuel characteristics were pre and post fire measured in each adjacent untreated and treated area for each fire. Meteorological variables were monitored and fire behaviour parameters measured for both treated and untreated areas in each experimental fire. The results showed that water, water + foam and water + polyphosphate reduced fire rate of spread to 63%, 53% and 25 % of their corresponding observed value in each untreated area, respectively. Polyphosphate significantly decreased rate of spread compared to the other treatments. Both additives met the usually required standard (60 %) superiority factor for forest fire retardants.

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Introduction

The use of several chemical components added to water during forest fires to improve its extinction capability has increased notably in the last decades. Most commonly used fire suppressant water additives or retardants are polyphosphates (CSIRO, 2000; Giménez and others, 2004) and foam (NWCG, 1992). Since their development in the 30s (Barrett, 1931; Truax, 1939) fire retardants have been widely used in fire extinction, but their actual evaluation under field conditions remains largely unknown.

Numerous laboratory works were conducted for testing fire retardant efficiency by recording the rate of diminution in fire behaviour parameters, such as fire rate of spread and fuel load consumption (Hardy, 1962; Rothermel and Philipot, 1975; George and Blakey, 1972, George and others, 1977; George and Susot, 1971; Blakely, 1985, 1988, 1990;), mainly during the decades of the 70s and the 80s. More limited operational retardant testing (Connell and Holmes, 1963; Davis and others, 1963) has taken place, with little quantitative information on fire behaviour parameters or fire effects.

During the last two decades, a great attention has been paid to the ecological effects of fire retardants on fauna, flora, human beings, and soil and water resources (i.e. Kalabokidis, 2000; Bell, 2003), but no equal effort has been made on the knowledge of their actual interaction with fire behaviour and fire severity, specially at a field scale.

Although these additives have been extensively tested in laboratory, quantitative information on their actual effectiveness at the field is still scarce, despite their widespread use. Increasing prize of fire retardants has lead to further studies to determine which fire retardant is the most effective (Giménez and others, 2004), and how do they perform at real fuel complex situations (CISRO, 2000). There is one need to test how efficiently the different treatments perform under field conditions, at the scale and landscape conditions representative of actual wildfires, and particularly in fires affecting dense continuous shrublands.

Consequently, the goal of the present study was to quantify the relative effectiveness of the two most frequently used fire-suppressant additives, ammonium polyphosphate and foam, applied at their respective usual concentrations, compared to water, under field conditions in dense continuous shrublands fires.

Materials and methods

The study was conducted in a shrubland community near A Estrada, in Galicia, NW Spain, at an area of approximately 29 has, covered by a continuous, dense and relatively homogeneous shrub fuel complex. UTM coordinates of the area of study are given in Table 1.

Table—1. UTM coordinates of the area of study.

	X	Y
UTM ED-1950	541795	4721137

UTM ED50 (29). Coordinates correspond to the centre of Fig. 1.

Vegetation of the area was integrated mainly by a mixture of *Ulex gallii* and *Ulex europaeus,* with an average height of around 1.2 m, and a 100% ground cover, a very representative situation in Galician shrublands. *Pteridium aquilinum*, *Daboecia polifolia*, *Erica umbellata*, *Lithodora diffusa*, and *Halimium alysoides* were also present in minor amounts.

Twenty-two hexagonal plots with a side length of 30 m were installed in the area. Plots were surrounded by 10-m wide fuelbreaks. Fig. 1 shows a layout of the area of study. The shape and sizes of the plots is shown in Fig. 2. The hexagonal shape of the plots allowed to lit an ignition line almost perpendicular to wind direction without loosing practically any surface in the plot to be burned. As shown in Fig. 2, fire was lit in one of the sides of the plot, and treatments were applied right before starting the fire at the last ten meter strip of the plot. Accordingly, two sections can be distinguished in the plots. The first 42 m of length from the fire ignition line (Zone B, see figure 2), allowed the fire to establish a quasi steady-state, in equilibrium with the environmental conditions, reaching values of rate of spread and intensity representatives of usual fire behaviour conditions in this type of fuel complex in summer, just before entering into Zone A, the last section to be reached by the fire with 10 m of length, where the fuel was treated with fire suppressants (polyphosphates or foam) and/or water (see Fig. 2 for a representation of both areas).

Fire behaviour was monitored in both areas, with the aid of three parallel lines of ten metal posts each, spaced at 5.8 meters (Fig. 2), and placed following fire spread direction. Using these metal posts, fire flame length was determined by comparing photographs and video recordings of the fire front flame arrival at each reference post with the known height of the post. Arrival time of the fire front flame at each post was registered for measuring fire rate of spread at each metal reference post.

Pre and post fire destructive inventories were used to determine fuel complex characteristics. Fuel height and cover were measured at each plot in three parallel continuous linear transects, following the reference post lines shown in Fig. 2. At each plot, six 2x2 m square inventory points were systematically placed along one transect perpendicular to fire spread direction, three in the middle of zone A and three in the contiguous 10 m wide strip in the zone B, as shown in Fig. 2.

All the material within the 4 m^2 inventory square was cut and taken to laboratory for classification and measurement. After the fire, measures of the terminal branch residual diameters were conducted at 66 points at each post-fire fuel inventory plot.

Additionally, remaining burned tips of the shrubs were also measured following three linear transects at each zone. Tips were measured every 0,5 m, resulting in a total of 480 burned plant tip diameter measures. Just before burning, the holes of the removed fuel were filled again with similar vegetative material clipped from the surroundings to minimize the effect of fuel removal on fire behaviour. To minimize variability between pre and post fire inventories, a similar point was marked near each inventory square for post fire destructive sampling. A 1x1 m metal square was placed at the centre of each square inventory point.

All the litter from the square was removed and taken to laboratory for measuring its dry weight. In the laboratory, fuels were oven-dried at 105ºC for 24 h.

Fuel from the destructive inventories was classified at the laboratory into size classes (0-6 mm, 6-25, >25 mm) and each fraction dry weight was recorded.

Meteorological variables were monitored during the study. Table 2 shows temperature, relative humidity and wind values measured during the study.

Table—2. Meteorological variables measured during the study.

RH	T (ºC)	U-6 (m/s)
52 (3,9)	19,9 (1,3)	4,5 (0,4)

RH: relative humidity, (%); T: air temperature (ºC); U-6: wind speed (m/s) at 6m.

Treatments applied at zone B were: addition of water (W), addition of water plus foam (RFC-88 at 1 pct., Auxquímica) (F), and addition of water plus polyphosphate (FR Cross at 20 pct.) (P). In seven of the twenty two experimental fires, a shift in wind direction resulted in the occurrence of a flank fire. Data from these seven fires was consequently discarded from the analysis, resulting in a total of fifteen experimental fires, five replicates for each treatment (water, water + polyphosphate and water + foam).

Treatments were applied at Zone B with a pump tanker truck, at rate of 1 liter/m^2. This quantity was chosen as a value enough to partially stop fire advance, not causing its total extinction, as it would happen with the addition of great quantities of water, based on the results of a pilot test, conducted on the previous year, of different fire suppressant concentrations on water at several experimental burns at the area of study. A retardant rate of 1 liter/m^2 has been recommended by Australian and American studies as effective for operational use over a wide range of fire conditions and fuel complexes (CSIRO, 2000).

Figure 1—Layout of the twenty-two plots of the study.

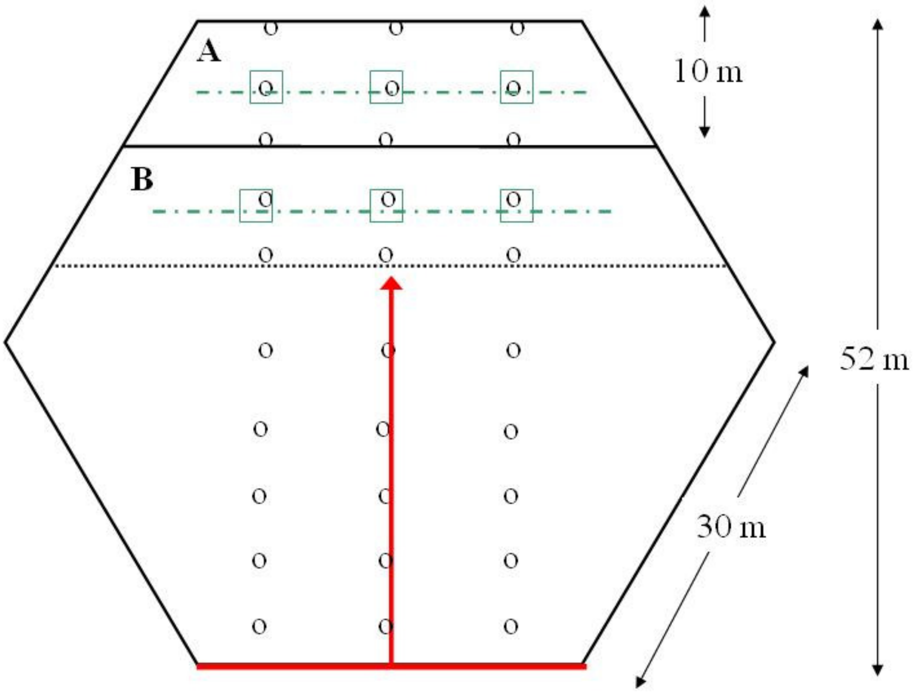

Figure 2—Plot design. Zone A corresponds with the treated area. Zone B designs the untreated area. A dotted line represent the last 10 m of Zone B. **o** indicates the placement of a reference post. Red thick line represents fire ignition line. Red thick arrow indicates fire spread direction. Squares represent the placement of a fuel destructive inventory point, across linear transects.

Results and discussion.

Fuel load reduction and fuel residual terminal branches average diameter.

Table 3 resumes observed pre and post fire fuel loads (kg/m^2), for both treated and untreated areas. No significant differences were found between treatments in fuel load reduction after fire. An indirect measure of fuel combustion completeness, shrub terminal branches residual diameters, was also measured at zone A and at the contiguous last ten meters of the zone B.

Table 3. Fuel loads (Kg/m^2)

	Zone B		**Zone A**	
	W12BB	W12AB	W12BB	W12AB
Water	3,35 (0,23)	0,74 (0,21)	3,36 (0,32)	0,76 (0,15)
Foam	2,85 (0,26)	0,63 (0,13)	3,59 (0,38)	1,03 (0,21)
Polyphosphate	3,04 (0,20)	0,81 (0,21)	2,61 (0,44)	0,75 (0,23)

W12BB: Fuel load of sizes <2.5 cm before burn; W12AB: Fuel load of sizes <2.5 cm after burn.

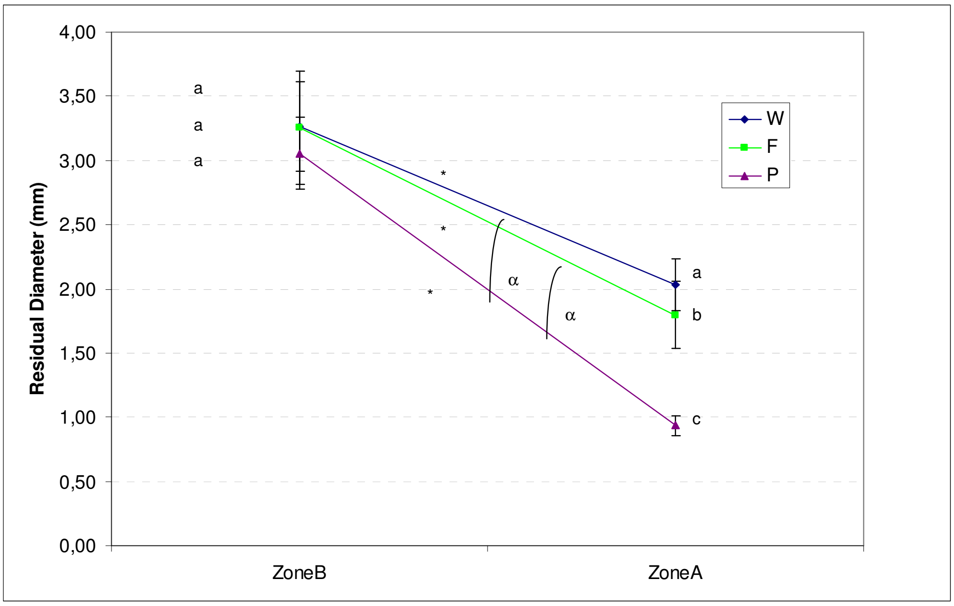

Figure 3—Terminal branch residual diameter at Zone A and B.
Different letters denote significant differences at a same zone between treatments.
* denotes a significant variation between zones for a treatment.
α denotes differences in the variation from zone B to A between treatments.

Figure 3 shows the results of the ANOVA of repeated measurements analysis for this parameter. At zone B (untreated area of the plot), no significant differences existed in the measured terminal diameters of the shrubs after the burn. The three values were significantly different at treated zone A, with the higher residual diameter value for the plots treated with water, followed by foam and polyphosphate, respectively. A smaller terminal diameter in the fuels after the fire indicates a greater effectiveness of the treatment in reducing fire severity, since a more severe fire will generally leave only thick branches after its occurrence. These data suggest that a less severe fuel consumption occurred at the treated plots, and confirm the value of residual terminal branches diameter as an useful indicator of fire severity, which proved to be sensitive to the effectiveness of the treatments in reducing combustion completeness. Polyphosphates were the most efficient treatment in reducing fire severity, with a significant diminution in the terminal diameter after fire from the untreated zone B to the treated area A, as shown in Figure 3.

In Figure 4 it can be seen how for all the polyphosphate treated plots an apparent reduction to a post-fire terminal diameter values of less 1 mm occurred, from higher observed values in the untreated zone B (from 2 to 4 mm). A group regression analysis confirmed these results, finding significant differences between polyphosphates and water, and between polyphosphates and foam.

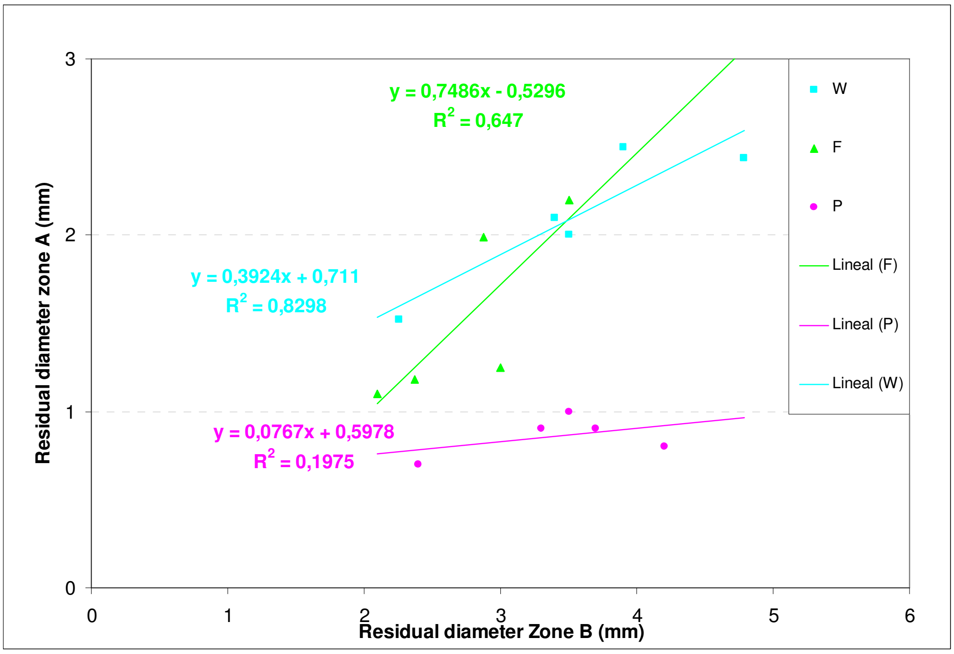

Figure 4—Terminal branch residual diameter at Zone A versus B
Best-fitted linear regression equations are shown in the graph for each treatment.

Fire behaviour.

Rate of spread data for the analysis were considered from the last ten meters of the untreated area, to minimize variations in wind speed for comparison of fire behaviour with the immediately adjacent treated area. Wind speed, measured at 6 m during the experiments, ranged between 4.0 y 5.7 $m.min^{-1}$. No significant differences in measured wind speed values were detected neither between treatments nor between zones A and B.

Figure 5 shows the results of the repeated measures ANOVA for fire rate of spread between the two zones. Fire rate of spread did not show any significant differences in the last ten meters of the untreated zone B between any of the three treatments, whereas in the treated zone A it was significantly lower for the polyphosphate treated plots than for the foam and water treated plots.

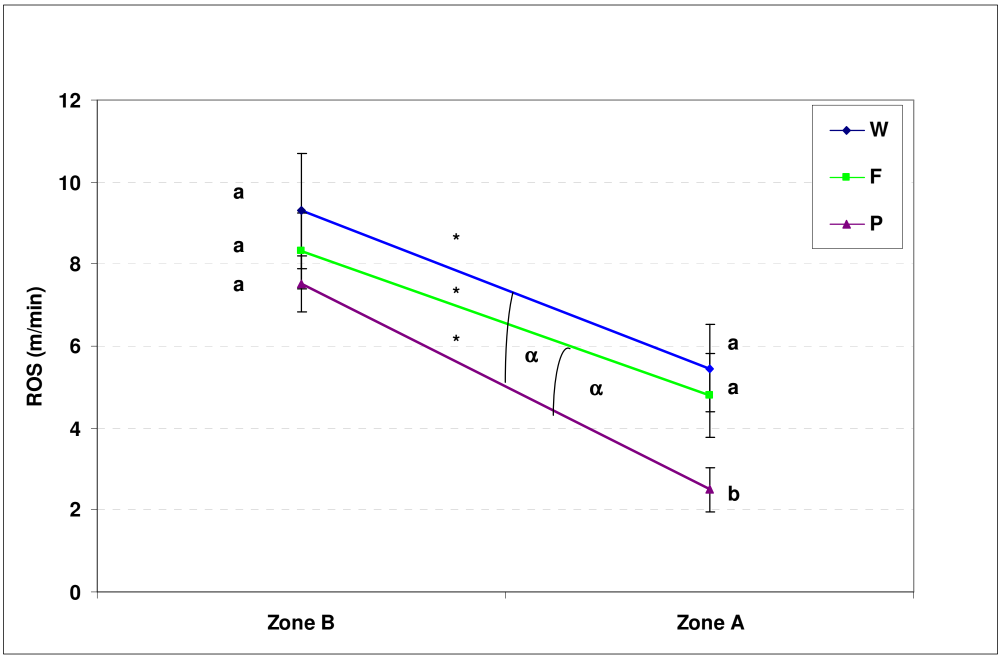

Figure 5—Fire rate of spread at Zone A and B.
Different letters denote significant differences at a same zone between treatments. * denotes a significant variation between zones for a treatment. α denotes differences in the variation from zone B to A between treatments.

A group regression analysis revealed that, for water and foam treated plots, rate of spread in the treated zone A increased with increasing contiguous untreated zone B rate of spread. (Fig. 6). This trend was not observed for the plots treated with polyphosphates, where fire rate of spread on the treated area was independent from the previously achieved rate of spread in zone B. Moreover, the slopes of the regressions for water and foam plots were not significantly different, all of this suggesting an apparent superiority of polyphosphates to the other two treatments.

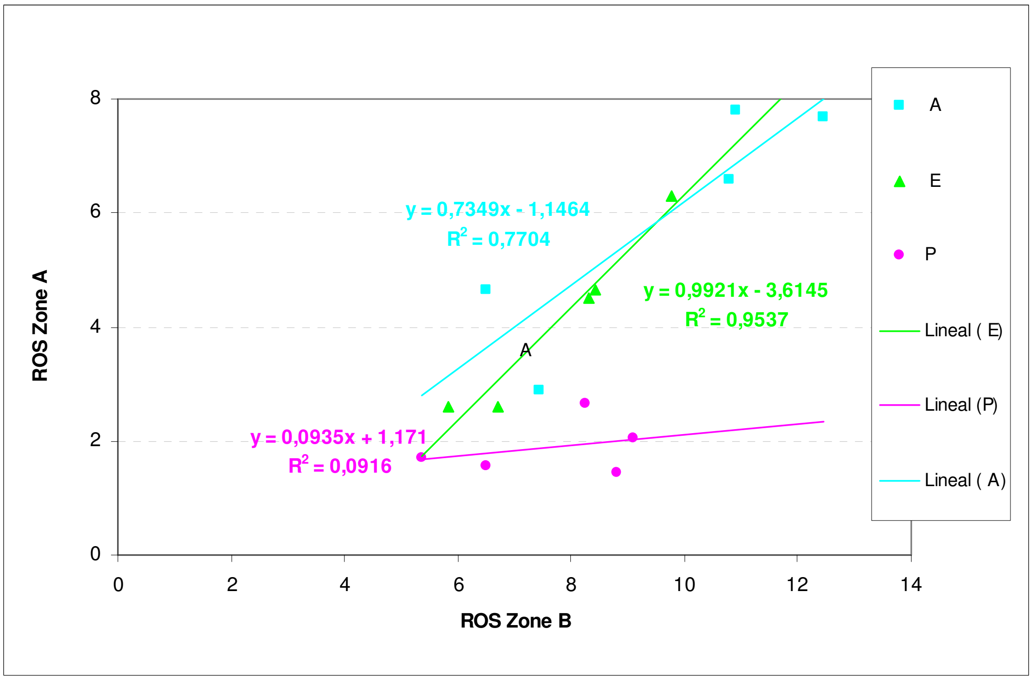

Figure 6— Fire rate of spread in zones B and A.
Best-fitted linear regression equations are shown in the graph for each treatment.

Figure 7 shows the relative reduction in rate of spread at zone A, compared to untreated ROS. Water, water + foam and water + polyphosphate reduced fire rate of spread to 63 percent, 53 percent and 25 percent of their corresponding observed value in each untreated area, respectively, this meaning that both additives met the usually required standard (60 percent) superiority factor for forest fire retardants (USDA, 1986; Blakely, 1988; Giménez and others, 2004).

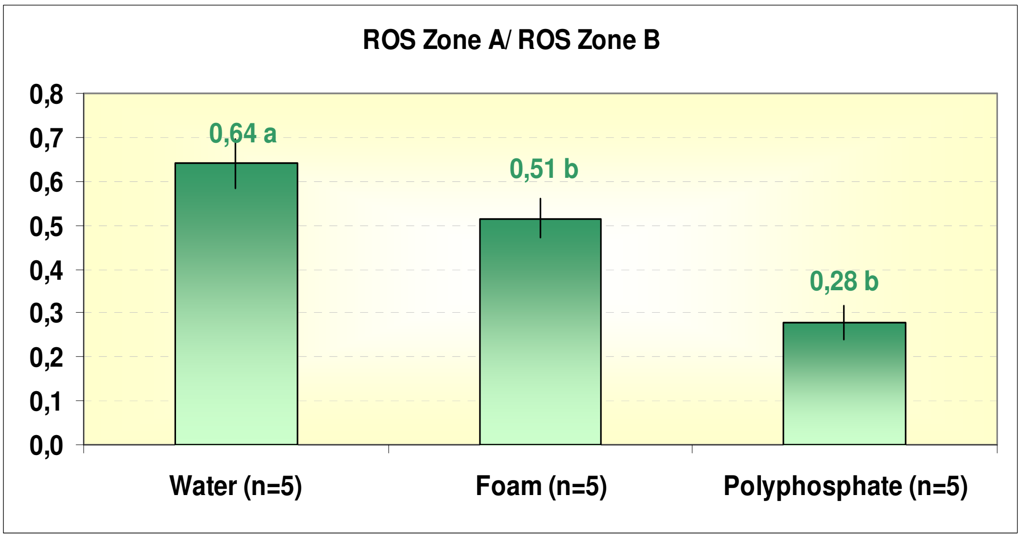

Figure 7—Relationship between fire rate of spread in zone A/ fire rate of spread in zone B.

Conclussions.

The actual effectiveness of the two most usual fire retardant agents has been tested in this study under field conditions in fires on dense, continuous shrublands. Both foam and retardants demonstrated their effectiveness in fifteen experimental fires. Polyphosphate proved to be the most efficient fire suppressant agent, both in terms of reducing fire severity effects and decreasing fire rate of spread. The addition of foam, at the rate used in the study, although less effective than polyphosphate, reduced rate of spread to les than 60 % of its pre-treatment value, confirming the utility of these products in fire extinction operations and in minimizing fire severity effects on the vegetation.

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