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FOREST FIRE RESEARCH

Edited by

DOMINGOS XAVIER VIEGAS

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Gestosa fire spread experiments

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ABSTRACT: A series of field experiments of fire spread in shrub vegetation on slopes that were performed in Portugal in 1998, 1999, 2000, 2001 and 2002 are described. The test site topography and vegetation cover are presented. The methodology employed in the experiments and some results on the wind field modeling, fire behaviour, fire safety and smoke dispersion are presented. These field experiments involve activities from several research projects funded by the European Union.

1 INTRODUCTION

The need of experimental data on fire spread and related phenomena in order to check modeling hypothesis or to validate existing models is commonly felt among the scientific community. In order to fulfill this need in its research on wind and slope effects on fire behaviour the University of Coimbra team organized a set of field experiments on shrub vegetation on inclined terrain in the Centre of Portugal every year since 1998. These experiments were designed to fulfill the objectives of a research program Inflame in which the possibility of generating accurate input data to be used in fire behaviour models and data to support the development of new models test and to validate them was considered. In each year different aspects were considered inside this general scope. From one year to another the interest for these experiments grew among the European research community and the number of participating teams increased continuously as well as the amount and variety of data collected.

As was said the initial objective of these experiments was to study the effects of vegetation, type of ignition, slope and wind on fire behaviour. From the beginning the need to develop new fire monitoring methodologies was felt. Methods to characterize vegetation cover as a fuel, models to predict wind field near the surface, estimators of smoke emission and smoke dispersion near the fire were also included in the first set of objectives along with the analysis of fire retardant efficiency assessment studies. The multi-disciplinary character of these experiments – that is the very nature of forest fire research – was very clear and it materialized in the participation of different teams in the successive experiments with objectives so different as fire detection, fire safety, use of explosives for fire suppression and fire ecology.

Preliminary reports describing the experiments of 1998 and 1999 were presented in Viegas (1998, 1999).

The aim of this article is to present a general view of the experimental program, of the test site and conditions, on the type of experiments and data acquired. More detailed descriptions of methodologies and results are left to forthcoming articles.

2 SITE DESCRIPTION

2.1 *Topography*

The study area is located in Central Portugal in Lousã range (40°15'N, 8°10'W). Most of the area is composed by the lythologic complex (*Xisto-grauvaquic*) and the soils are Cambi soils. Annual average temperature is 11 °C, January being the coolest month (average 2.5 °C) and August the warmest (average 18°C). Annual mean precipitation is 760 mm, a water deficit in the soil exists from July to September. Following Thornthwaite climatological classification, the climate in the region is moderately humid, mesotermic, with water deficit during summer and superavit in winter time .

Experimental burning plots were established in public lands that are owned by the local communities but their management is under the jurisdiction of the Forest Service lands. The experimental plots were located along two slopes with an average inclination of 60%, oriented to SW and to SSW. A digital terrain map that was available in which the constant level lines were separated by 10m was acquired to support fire analysis.

The plots were established in each year of the experiments in the same area. The general layout of the experimental plots is shown in figure 1. All plots were numbered in succession during the first four years. In 2002 the plots were numbered from 501 to 560 to indicate that those were the plots prepared on the fifth year of experiments. Not all plots were burned in each year. Some were left as control to analyse vegetation recovery after fire. Plots that were used in the 1998, 1999 and 2000 experiments were adjacent to each other. In 2001 some plots were established on the other side of the mountain. One of these (plot G62) was particularly interesting given its canyon configuration. The area of 2002 experiments was separated from the others and it was situated in a sort of large canyon with a U shape configuration.

The general dimensions of the plots that were actually used in the experiments as well as their average slope and other data are given in table 1.

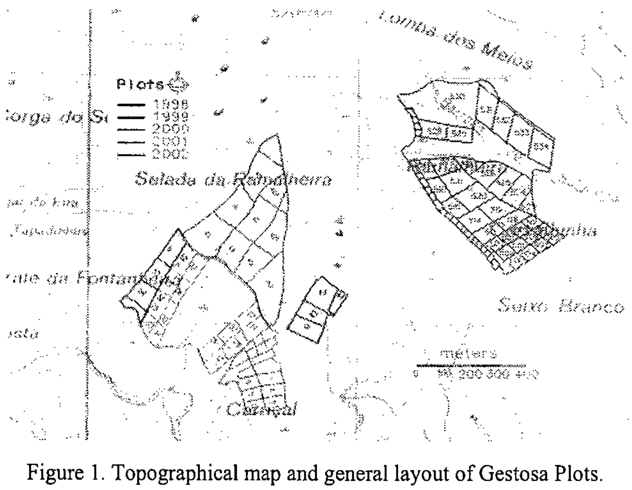

Figure 1. Topographical map and general layout of Gestosa Plots.

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2.2 *Vegetation cover*

In order to characterize fire behaviour, structural assessment of the vegetation was made through the employment of double sampling techniques in which destructive sampling of some specimens was made to determine fuel load - by size classes and states - bulk density and porosity of the fuel complex. These results were compared with pre-established relationships for similar complexes in order to assess their applicability to this specific situation.

The linear intersect method was used for the determination of percent cover, height and bio-volume by species for each plot. Three transepts of 50 meters each were established in each plot with a configuration that tried to capture the vegetation patterns along the plot.

Linear measurements were made of the intercepts of vegetation through which the vertical plane of the line passed. These gave estimates of the shrub density and composition of the fuel complex. From height measurements it was possible to estimate the volume of the shrubs that was then used as an independent variable to estimate fuel load.

The vegetation cover of the entire study area consists in a continuous shrubland with some isolated *Pinus pinaster* trees. It is rather homogeneous in relation to the shrubs composition. Three species are dominant, *Erica umbellata, Erica australis* and *Chamaespartium tridentatum,* corresponding to 85% of the total percentage cover. Nevertheless there is some heterogeneity in respect to the shrubs height. In general, near the top of the hill, the shrubs are lower and more disperse. Some fuel breaks exist. Almost immediately the vegetation gets more dense and very high and near the bottom, we can find shrubs 2m high.

Average values of fuel load and vegetation height for each one of the sampled plots are given in Table 1.

2.3 *Meteorological conditions*

All the experiments were performed at the end of Spring, during late May or early June in order to have the burning conditions as similar to those found during the fire season as possible, without incurring in the risk of making the burns during the fire season itself, that would not be well accepted by the public. In Portugal the weather during May is very variable: very warm days can be followed immediately by rain and cold. This brought some difficulties in each year for the planning and even for the preparation of the experiments. With the support of the very accurate weather forecast that was provided by the Portuguese Institute of Meteorology it was nevertheless possible to overcome this difficulty and to plan the experiments with confidence at least during a period of four days.

Given the type of vegetation and the exposition of the site to wind and to Sun it was found that even after an important rainfall one or two days were sufficient to have acceptable or good burning conditions.

Some weeks before the experiments a set of four automatic weather stations were installed in the study area in order to gather data on meteorological conditions. Particular attention was given to wind field: the possible existence of local wind patterns and the ability of our wind models to predict them was looked with care. One meteorological station equipped with precipitation, air temperature and relative humidity sensors was placed at the top of the hill and used as reference during all the years. The other stations were placed near the test area and therefore their positions changed from one year to another. Data was acquired every minute but only average hourly values were recorded normally. During the days of the experiments wind data were recorded every minute in order to cope with possible quick changes of wind field that might affect fire behaviour.

All experiments were made in good weather conditions. If wind was above a certain threshold that would make the burns unsafe the experiments were not started or were stopped in the case conditions changed during the day. In two occasions the experiments were discontinued due to high moisture content and to rain.

Table 1. General dimensions and Time Table of GESTOSA Plots

Year	Plot	Date	Time		Total Cover (%)	Medium height (m)	Fuel Load (kg.m-2)	Slope (°)	Dimensions (m)		Area
			Start	End					Width	Lenght	Ha
1998	3	08-Jun	16:19	16:31	91	0.75	2.3	19	49	89	0.436
	4	08-Jun	14:00	14:41	88	0.62	1.9	18	48	85	0.408
	5	08-Jun	11:00	11:28	96	0.69	2.1	20	53	80	0.424
	8	09-Jun	14:52	15:12	100	0.92	2.7	22	46	80	0.368
	9	09-Jun	12:26	12:44	100	0.89	2.8	19	49	77	0.377
	10	09-Jun	10:50	11:21	63	0.69	1.3	17	54	72	0.389
1999	20	09-Jun	11:20	12:35	98	1.2	3.6	22	61	130	0.793
	22	09-Jun	11:00	11:15	98	0.9	2.9	18	48	111	0.533
	23	20 May	16:30	16:45	97	1.1	3.1	21	49	98	0.480
	24	20 May	10:50	12:10	96	0.8	2.1	21	62	97	0.601
	25	21 May	17:15	17:30	99	1.0	3.1	19	55	96	0.528
	26	21 May	16:35	16:40	-	-	-	19	40	102	0.408
	27	20 May	15:35	15:45	-	-	-	18	47	91	0.428
	28	21 May	12:13	12:40	97	1.1	3.3	23	59	102	0.602
	30	09-Jun	12:05	12:10	-	-	-	10	37	107	0.396
	32	21 May	11:10	11:20	97	0.9	2.0	17	57	89	0.507
2000	40	19 May	11:37	12:01	99	0.75	1.9	14	102	165	1.683
	40a	19 May	18:19	18:30	-	-	-	11	80	100	0.800
	41	19 May	15:28	15:39	100	0.69	2.4	19	98	136	1.333
	42	19 May	17:14	17:44	99	0.55	1.6	16	90	162	1.458
	42a	20 May	10:45	11:20	-	-	-	18	-	-	
	43	20 May	12:57	13:01	97	0.87	2.1	22	125	142	1.775
	44	20 May	17:07	17:15	98	1.06	2.6	25	90	138	1.242
	45	20 May	17:35	17:41	100	0.64	1.9	23	82	143	1.173
	45a	20 May	15:30	16:30	-	-	-	-	-	-	
2001	51	08-Jun	10:00	10:30	95	1.02	2.9	22	61	130	0.793
	52	15-Jun	10:00	10:30	98	1.2	3.6	22	53	110	0.583
	53	08-Jun	11:30	11:45	99	1.01	2.6	16	69	102	0.704
	54	08-Jun	15:00	15:30	98	0.73	1.9	14	86	94	0.808
	55	15-Jun	11:00	11:30	98	1.1	2.9	12	55	103	0.567
	61	09-Jun	11:00	11:30	99	0.91	2.8	31	69	120	0.828
	62	09-Jun	11:40	12:00	100	1.10	2.8	32	58	109	0.632
	63	15-Jun	12:00	12:40	100	0.87	3.7	31	-	-	
	64	09-Jun	10:00	10:40	100	1.00	3.8	29	36	96	0.346
2002	502	19 May	09:50	09:55	-	-	-	15	50	56	0.275
	506	19 May	10:40	10:45	-	-	-	17	50	52	0.261
	507	19 May	12:30	12:40	-	-	-	19	48	56	0.270
	510	19 May	13:10	13:20	-	-	-	19	47	54	0.254
	513	30 May	10:19	10:44	89	1.15	6.32	21	58	97	0.560
	514	30 May	13:11	13:30	97	1.09	9.9	21	85	90	0.765
	515	30 May	16:20	16:39	98	0.83	5.38	27	87	53	0.461
	516	30 May	12:21	12:28	88	1.08	8.66	22	101	51	0.508
	517	30 May	11:26	11:44	100	1.32	11.12	24	86	52	0.440
	518	30 May	17:04	18:05	97	1.64	11.05	17	58	108	0.626
	519	31 May	14:32	14:51	98	1.19	7.75	21	89	91	0.805
	520	31 May	13:45	14:03	95	1.15	5.73	18	89	109	0.965
	521	31 May	12:00	12:30	100	1.27	6.56	19	87	99	0.856
	522	31 May	11:00	11:30	100	1.16	7.23	18	68	90	0.604

The dates of the burns are indicated in Table 1 with the approximate time of ignition start and of the end of each test.

3 METHODOLOGY

3.1 *Test development*

3.1.1 *Site preparation*

In each the experiments were prepared with an extensive field campaign that started usually several months in advance. After designating the test site and having obtained the necessary approval from the Forestry Service the layout of the plots was designed taking into account the terrain configuration, safety conditions and other practical considerations. The plan of the plots and of the fire breaks was submitted to the Fire Chief of Castanheira de Pera that was in charge of the overall command of safety conditions during the experiments. Adjustments to the plan were made following his suggestions also during the preparation phase of the plots. Given the size of the plots and the difficulties of the terrain and of its slope and vegetation cover a machines was normally used to create the fire breaks and the necessary accesses to the fire trucks and to personnel and equipment. Hand tools to cut shrubs and to move soil were also used in order to minimize the impact on soil and adjacent vegetation.

The plots were marked using GPS and their dimensions and slope were measured. Vegetation cover was sampled in each plot. At least once a week samples of fuel were collected in order to evaluate its moisture content.

Reference marks or beacons were placed at the corners of each plot to assist in the fire monitoring process. During the first years metallic poles of 1.5 m were placed along the edges of the plots at every 5 or 10m to assist the measurement of the rate of spread. A thread was extended between every pair of poles across the plot and above the vegetation following a horizontal line. Given the vegetation height in the majority of the plots this operation was very time and labour consuming. The rate of spread was evaluated from the registered time steps that the fire took to cut each thread. Later with the improvement of the fire monitoring technique based on the image analysis this process was abandoned.

Other specific preparations were made in each year in accordance with the specific objectives and conditions of the experiments.

3.1.2 *Personnel deployment*

The experiments were carried out during one or two consecutive days. Besides the preliminary preparation and planning meetings with the various parts involved in the early morning of each day there was a general briefing with all the personnel in order to recall the plan of the day, to revise tasks and positions, to make the necessary safety advertisements to distribute radios or mobile phones and to synchronize the watches and clocks of all recording material. After this all the members of research teams deployed to their respective places and prepared to be ready for start in the given schedule.

A similar meeting was held by the first author with the chiefs of the various trucks in order to check their deployment and mission. Typically there were around 80 members of research teams and around 50 or 60 fire fighters during these experiments.

A catering service provided by the local Fire Brigade looked after the food and drink needs of the personnel. Two small breaks were made at mid morning and at mid afternoon to distribute water and sandwiches to every body. A major break for lunch was made at noon; at this time everybody joined in a pine stand near the site to have this meal. This break was normally used to assess the plan and to make any changes if necessary. It was also used as an opportunity to explain to the fire fighters and to other observers or invited persons the purpose of the experiments and to present the participating groups and their specific objectives. These meetings were very appreciated by the personnel and helped to motivate them in the experiments.

3.1.3 *Safety issues*

Safety of the persons involved in the experiments and of the forest surrounding the test area was always a major concern of the organizers of these field experiments. This attitude was justified first of all to preserve the integrity of the personnel, to promote the issue of safety among the personnel and finally to maintain the good public and institutional acceptance of these field experiments.

Taking into account that there are some villages and important and very extensive pine and eucalyptus plantations in the whole mountain in the close vicinity of the test area any fire escape could be disastrous. The difficulty of the terrain would make the suppression of a major fire escape almost impossible so all precautions to avoid them had to be taken.

All experiments were assisted by one or more teams of fire fighters with fire trucks and other equipment to prevent fire escape and to suppress the fire after each experiment in order to avoid any rekindlement. These experiments were also seen as an opportunity for training and to provide contact with the fire for firefighters. For this reason there was no difficulty in getting the participation of one or more teams of the fire brigades of the nearby towns. It was normal to have ten or twelve trucks from six to eight different corporations. The overall command and communications were assured by the local Fire Brigade and this also provided the fire fighters with an opportunity to work together and to test their ability to act as a coordinated team and to move in difficult terrain.

All fire fighters were instructed to intervene only if necessary in order to not disturb the normal spread of the fire and also to avoid disturbance to the test area in the perspective of the fire impact studies.

Given that the responsibility of safety during these experiments was in the hands of the Fire Chief the ultimate decision to start an ignition was taken by him. The research team of the University of Coimbra was in charge of the ignition pattern and process but the burns were only initiated after the agreement of the Fire Chief in each case.

As was mentioned before written safety instructions and procedures were given all the participants in the experiments. For many scientists these experiments were their first contact with a "forest fire" and most of them were impressed by the intensity of the fire and of the heat fluxes. In some instances the start of a test was delayed in order to reallocate persons that were in potentially dangerous places.

During the many tests that were held there were some difficult situations of short distance spots or of potential fire escapes due to wind shifts but they were all solved immediately by the fire fighters without problems to safety and without injuries to the personnel.

3.1.4 *Preliminary burns*

In order to improve the safety conditions during the experiments in many cases some preliminary burns were carried out in the buffer zone between the test area and the surrounding vegetation.

These burns were carried out normally several days before the main burns with the support of a small group of firefighters if possible on days of low fire danger. Prescribed fire techniques were used in these burns in order to avoid intense fire fronts.

In 2002 a safety belt of some thirty small plots (20x40m^2) was built surrounding the top of the test area. Given their large number they were burned in two days. In spite of the small size of the plots the steepness of the terrain and the large vegetation height brought some problems during the initial burns. Initially each burn was started with a linear ignition on the top, followed almost immediately by downslope ignition of the sides and then a linear ignition at the bottom. This procedure was adopted to minimize the potential problems created by wind shifts that might make any corrective action impossible given the small size of the plots and the very high flames that were produced. It was found that the converging fire fronts created very high flames and potential danger of spotting. Although we had no problems we modified the ignition pattern to proceed more slowly and make use of the tendency of the fire to align with the slope or wind direction and proceed with the fire as a flank fire with much less intensity.

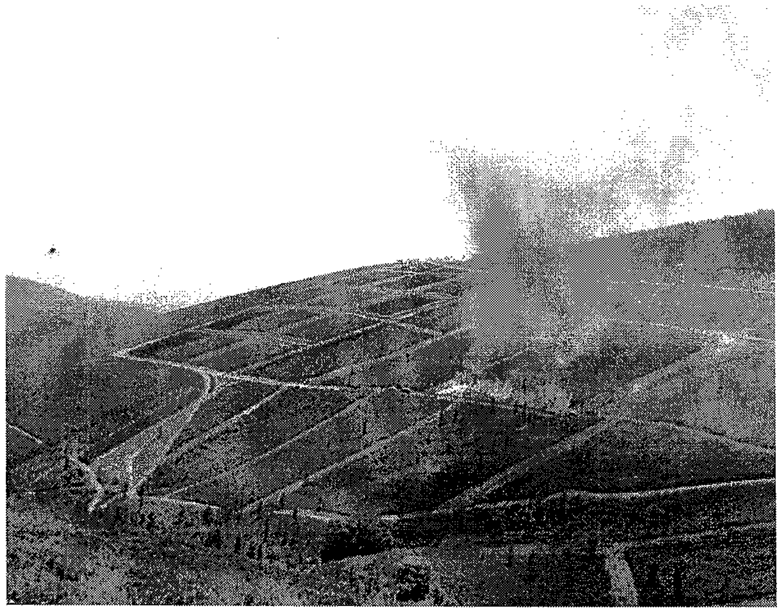

Figure 2. General view during burn of plot G 520 in 31st May 2002.

3.1.5 *Test procedure*

In each experiment an ignition pattern was defined a priori according to the purpose of that particular test. Sometimes due to safety reasons or to some change in the overall conditions this plan had to be revised or changed.

A very common pattern was to burn a line on the top of the plot and to allow the fire to go downslope for about five to ten meter in order to increase the buffer zone on the top of the plot and to improve safety for the main ignition that was usually made as a line at the bottom of the plot. The downslope spread was also used to determine the basic rate of spread R_o of that particular fuel. This parameter was then used as a reference to present the rate of spread results obtained in the same conditions. In some cases when there was no danger for fire to escape laterally or on the top a single ignition line at the bottom was made. A general view tank during the 2002 experiments is shown in figure 2.

Some experiments were made using point ignitions in order to analyse the joint effect of wind and slope on fire spread. In 2002 pyrotechnics were used to produce one or more instantaneous linear ignitions. These proved to be particularly useful to make intermediate fire lines in the middle of the vegetation. Given the height of the shrubs it would be very dangerous to make these burns manually.

In some cases the sides of the plot were also burned either before or after the main ignition in order to prevent fire escape to adjacent plots. This was made especially at the plots situated near the edges of the test site.

During the experiment the various teams present on the site recorded different sorts of data. Extensive video and photographic recording was made from different angles on the ground and in the air with the support of a helicopter from the Fire Brigade Service that was allocated to the experiments in each year (during the first two years we had the support of a helicopter from the Portuguese Air Force). The principle of redundancy in the measuring process was applied extensively during the entire program. Whenever possible more than one sensor or apparatus was installed to gather essential data for the risk of failure of some of them. In several occasions this principle showed its value both in the positive and the negative sides.

When the test was concluded the fire fighters checked for the need of mop up or to conclude some burning to avoid future problems, before moving to the next experiment.

3.2 *Fire behaviour analysis*

3.2.1 *Direct measurement*

Measurements of the fire rate of spread for various vegetation, slope and wind conditions were one of the main aims of the present experimental program. Adapting the very simple but reliable technique that we use at the fire laboratory experiments threads were extended across the plots as explained above. Given the orientation of these threads the upslope (or downslope) component of fire-spread velocity was usually measured. Two independent teams measured the time delay for the fire to cut each thread and it was found that both sets of measurement agreed very well.

Given the complex pattern of wind it was observed that quite often fire did not progress as a horizontal line throughout the plot. This could be easily observed from the aerial images that provided some other features of the fire development namely the rotation of the fire front when it existed. After confirming that the results obtained from image analysis were in good agreement with direct observations this method was abandoned given its practical difficulties as was mentioned above. Two examples of fire advance evaluation using both the direct method and the image analysis process are shown in figure 3 for plots G 23 and G 28 that were burned in Gestosa 1999 experiments.

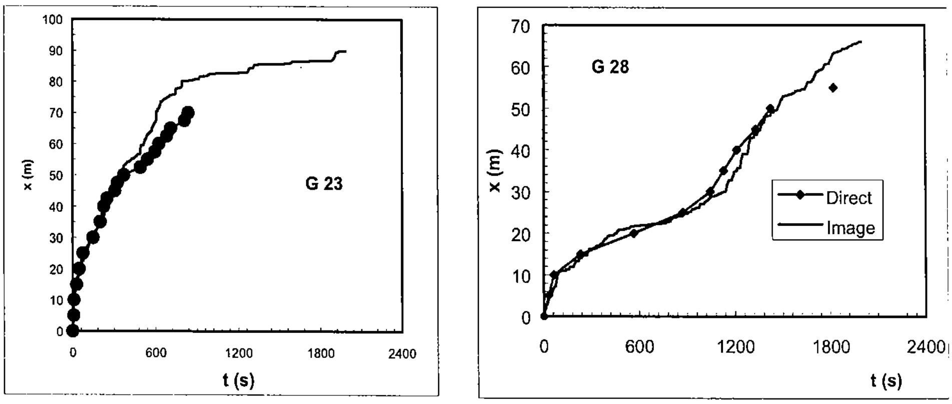

Figure 3. Direct and image analysis results of fire front advance during tests G 23 and G 28.

Air and soil temperature at different places in the plots was measured in some experiments in order to evaluate the residence time of the flaming combustion or the impact of fire on the ground. Heat flux sensors were also extensively used in some experiments in order to measure the total and the radiative fluxes at different levels above the ground. Pressure probes to measure the horizontal and vertical components of the convective flow inside the fire were also used in association to these measurements.

3.2.2 *Video monitoring and image analysis*

In each experiment images from side and frontal views were registered with photographic and video cameras. One fixed infrared camera and another one embarked in the helicopter were also used systematically in order to localize the fire front advance. The helicopter was equipped with a high precision GPS and its data were recorded during each flight. With the knowledge of the exact position of each camera and of the terrain configuration using an original algorithm (cf. André et al, 2002) the three-dimensional features of the fire front were reconstructed with reference to the actual terrain. Two simultaneous frames collected during the burn of plot G 28 picked from the helicopter with the video camera and with the infra-red camera respectively are shown in figure 4.

Furthermore, the use of different views at different position helps to obtain more accurate results. The smoke may occlude the view of the fire for one view. However if another point of view is available together with the infrared sensor that is no affected by the smoke, it will be possible to keep reconstructing the fire and computing its parameters.

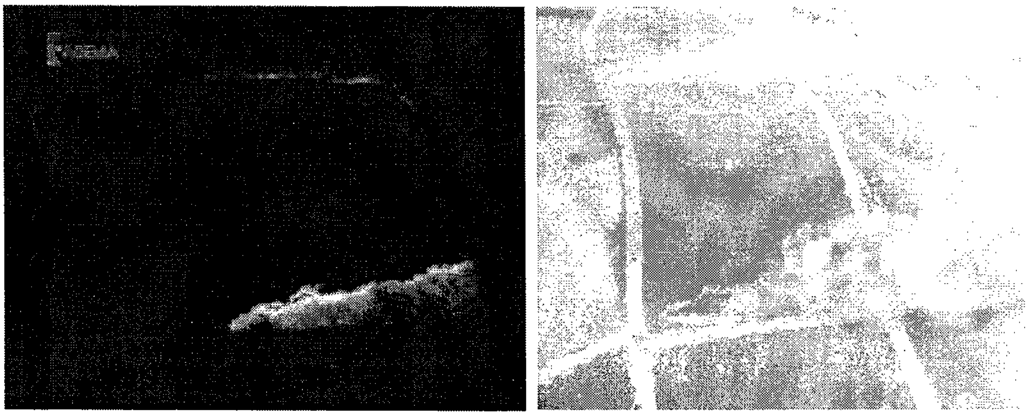

Figure 4. Infrared and video images of fire front advance during test G 28.

3.3 *Smoke dispersion analysis*

Smoke dispersion analysis was carried out through an experimental and a modeling approach. Air pollutants concentrations have been measured during the Gestosa prescribed fires and a clear evolution of measurements approaches and techniques aiming to optimise the procedures is noticeable from the 1st field campaign, in 1998, till the last one, in 2002 (Miranda and Borrego, 2002). In 1998 and 1999, automatic air quality equipment was used allowing to continuously acquiring nitric oxide (NO) and nitrogen dioxide (NO_2) concentration in the air. Figure 5 presents the measured values of nitrogen oxides (NO_x) concentration and wind direction values during the second day of Gestosa98 experiments. Particulate matter was collected in quartz filters and submitted to physical and chemical tests in order to determine organic and black carbon, in 1998 and 2000. In Gestosa 2000 and 2001 the passive sampler technique was tested to measure nitrogen oxides (NO_x), which allowed a larger spatial cover and the possibility to obtain distribution patterns of this pollutant.

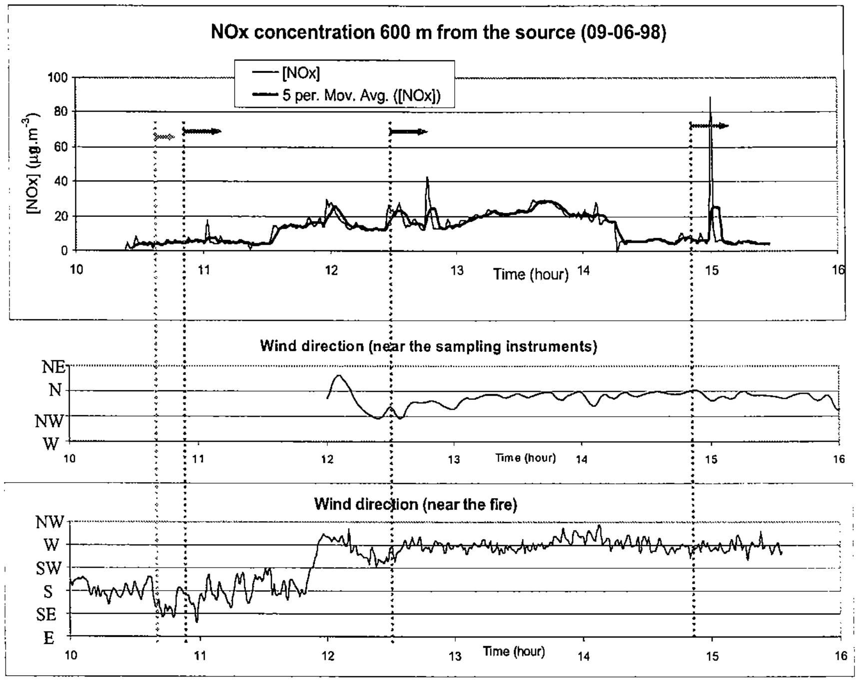

Figure 5. Meteorological data and NO_x concentration evolution, 600 m from the source – Gestosa 1998. The red lines represent the start of the burning of each plot and the green one represents the start of the security line.

In order to improve the air quality knowledge a modelling approach was also adopted, allowing obtaining spatial patterns of pollutants concentrations during the experiments. Smoke dispersion modelling implies the combination of several related features: (i) forest fire emissions; (ii) atmospheric flow; (iii) fire progression; and (iv) dispersion of pollutants. Aiming to obtain concentration patterns of smoke pollutants, smoke dispersion from Gestosa 98 and 99 burns was simulated using the DISPERFIRE (Viegas, 1999) system of models, which integrates a wind module and a dispersion module. In figure 5 it is possible to observe the nitrogen oxides surface concentration field estimated 15 minutes after the beginning of G23 ignition. Smoke concentration prediction compared favourably with measured values in the majority of cases.

The effect of the topography on the NO_x concentration field is quite evident from figure 6 analyses. In these simulations the topography plays a very important role because the wind carried the pollutants in the direction of the valley situated in the SE of the domain, reaching also the East side of this valley where concentration ground levels values are higher. It is also interesting to note that the plume disperses in a very straightway, which is related to the almost constant wind direction during all the fifteen minutes of simulation.

In summary, the Gestosa experiments allowed to conclude that smoke from forest fires can have a significant impact on the air quality and consequently on the human health, namely on the fire-fighters that are affected by very high concentration values of air pollutants.

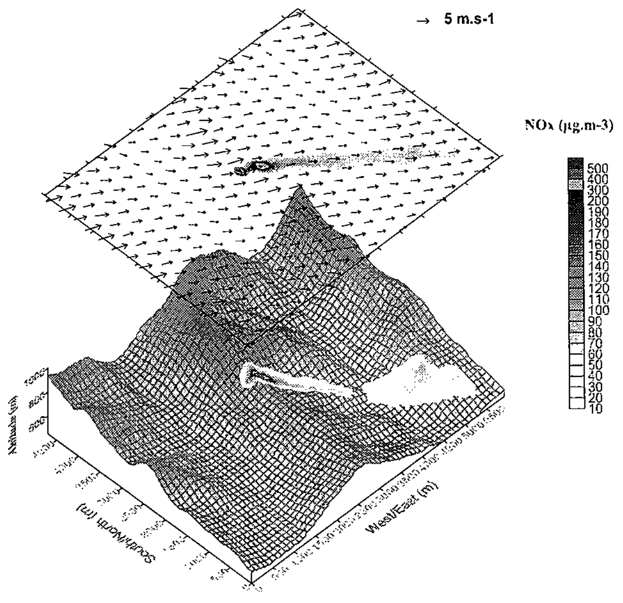

Figure 6. Smoke concentration simulation for plot G23, 15 minutes after ignition (Gestosa 1999).

3.4 *Other studies*

As was said above the Gestosa field experiments were used to test different methods, to measure different parameters and to observe different processes related to fire management and fire ecology. It is not possible to give a detailed account of all of them here so only a brief mention of the most relevant or meaningful is given below.

In 1998 a low angle radiometer was used to characterize the radiometric properties of vegetation in order to calibrate satellite data obtained for that area in the same day before and after the burns. This radiometer was based both on a ground platform and also on a helicopter.

In the scope of a research project on fire retardant efficiency tests with three different chemical products were carried out during the first three years of experiments. An extension of 10 meter was treated with the retardant near the top of the plot and the fire spread was monitored before and after reaching the treated area. It was found that the rate of spread decreased dramatically when the fire reached the retardant treated area although in the majority of cases it went through and propagated to the upper part of the plot. This effect can be clearly observed in figure 3a for plot G23. The advance of the fire front evaluated from the IR image analysis show that the fire took some time to go through the retardant treated area. Fire retardant performance was assessed by the ratio of both rates of spread before and during the treated area.

The possibility of using a lidar to detect forest fires was demonstrated by Utkin et al (2002). This research team of the Technical University of Lisbon participated in the 2001 experiments with their experimental lidar to test the algorithms that were developed to detect the smoke plume with the back scatter of the laser beam by smoke particles. Very good results were obtained during these experiments in which the detector was placed at a distance of about 4 km from the fire. During one experiment in which fog prevented the visual observation of the smoke plume the lidar sensor picked its signal very clearly (cf. Utkin et al, 2002).

In the scope of Fimex Project an explosive device that can be used to suppress high intensity fires that was proposed by Wagner is being developed and tested. In Gestosa this consortium had the opportunity to test this product under quite extreme conditions of steep terrain and very high vegetation. Three different tests were carried out under very intense fire fronts and the explosive hose was able to stop the fire with great success.

In the scope of Spread project an extensive research on fire effects on vegetation recovery and on soil degradation is being carried out. For the Gestosa 2002 experiments a set of twelve plots was prepared for this purpose. A very intense field work was carried out during the weeks prior to the burns of May 2002 by the teams of the University of Castilla-La-Mancha and the University of Barcelona. Four plots were burned on the 19^{th} of May and four other will be burned in the autumn of 2002 in order to analyze the effect of fire season on the recovery of vegetation and soil.

In the scope of Comets Project unmanned aerial vehicles (UAVs) will be used to gather data to manage disasters. Their application to forest fires is particularly envisaged in the project and it is the intention of its consortium to use the Gestosa experiments as a test ground for their equipment and concepts. Radio controlled helicopters and blimps shall be used for this purpose. In 2002 some members of Comets consortium participated in the experiments in order to assess the operational conditions and to prepare a full participation in future experiments.

4 CONCLUSIONS

The Gestosa field experiments were carried out successfully in five consecutive years since 1998 in Central Portugal. Some 48 plots covering an area of 30 Ha of tall shrub vegetation in steep slopes were burned during these experiments. Given the scale of the experiments, the local support that has been obtained for them and the good working conditions that are provided these experiments have become a sort of reference for many European research teams and are being used to develop and test different methods and models in various disciplines related to forest fire management.

The results so far obtained are being explored in several research projects and shall be reported in future publications.

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