SEGURIDAD y Medio Ambiente
Year 32 N128 Fourth Quarter 2012
FUNDACIÓN MAPFRE

Fire effects on soil properties and spectral behaviour

Environment

Ascertaining the effects of fire on the soil is crucial for application of remedial measures. The trouble is, however, that current fire-severity estimation methods are usually costly, subjective and imprecise. The Fire Research Centre (Centro de Investigación del Fuego: CIFU) has assessed the potential of VNIR radiometry for rapid and efficient determination of the effects on soil properties of fires of varying duration and intensity.

By **L. A. ARROYO.** Doctor in Silvopastoralism from Universidad Politécnica de Madrid; research fellow of the *Centro de Investigación del Fuego.* lara.arroyo@uclm.es.
M. B. HINOJOSA. Doctor in ecology from Universidad de Jaén; research fellow of the *Centro de Investigación del Fuego.*

Accurate estimation of soil changes after a forest fire is a sine qua non of efficient restoration measures afterwards. Post-fire management and palliative treatment (reforestation, logging, erosion protection, priority action maps, etc) are not always the same; their particular character in each case depends on the fire severity and post-fire soil effects. Furthermore, fire severity and concomitant effects are often patchily distributed. It is therefore also important to find out the spatial distribution of fire severity over the whole affected area.

The Centro de Investigación del Fuego (CIFU) has assessed the potential of VNIR radiometry for rapid and efficient determination of the fire effect on soil properties

Despite the importance of assessing fire effects on the soil, the current fire-severity estimation methods are usually costly, subjective and imprecise (1). Prompted by the need to fill this methodological gap, the Fire Research Centre (*Centro de Investigación del Fuego: CIFU*) has conducted a study to weigh up the potential of VNIR radiometry for rapid and efficient determination of a fire's effect on soil properties. To this end a study has been made of which heat shock treatments are important for assessing the effects of real fires and how to put such treatment into practice in a methodologically robust manner (i.e. ensuring that measurements are comparable in each case). The study involved a combination of traditional techniques for ascertaining the fire effect on soil (by means of laboratory physicochemical analysis) and the most recent VNIR radiometry methods (using an ASD FieldSpec 3 spectroradiometer). This 12-month, *FUNDACIÓN MAPFRE*-financed research project analysed and ascertained the fire effect on soils and also the precision of VNIR radiometry in detecting and identifying these effects.

VNIR radiometry

Radiometry in general is a set of scientific techniques for measuring electromagnetic radiation. VNIR radiometry in particular measures electromagnetic radiation in the visible (VIS) and near infrared (NIR) ranges of the spectrum (350 to 750 nm and 750 to 2500 nm respectively). These spectrum regions take in the wavelengths in which soil components show a distinctive spectral behaviour, allowing for their identification and quantification (2). This technique represents a rapid and precise alternative for assessing soil property changes after a forest fire.

VNIR radiometry offers several advantages over other analytical techniques. First and foremost it is a very quick analysis (<

1s). This analytical speed is a crucial factor for soil study since soil type distribution is usually very patchy. The ability to make only a few high-precision readings is therefore usually a worse option than being able to make hundreds of somewhat less precise readings (3). Secondly, using this method, spectra can normally be obtained without needing to make extractions with chemical reagents or any other time-consuming process. There is no need for pre-treatment of the soil sample, which is scanned just as it is. Thirdly, the method is so simple that there is no need for specialist-sample scanning personnel. The spectrum-obtaining cost is therefore minimal. Practically the only instrument that needs to be amortised over time is the spectroradiometer. Another of the advantages of this technique is the multi-analysis aspect; once the spectrum has been obtained it can then be used for estimating several parameters at the same time (4). Last but not least, it is a non-destructive technique. There is no physical contact with the sample to be measured and ipso facto no alteration thereof.

This study represents the start of a line of research of great interest for the restoration of burnt areas, such as the use of remote-sensing techniques for studying the severity of forest fires

Conversely, there are many factors impinging on the spectral and spatial variability of a soil sample, so it is no easy matter to establish a cast-iron relationship between the soil properties and spectral curves (5). There was therefore little takeup of radiometry as an analytical technique until computers' calculation capacity became powerful enough to deal with it (1). Each VNIR radiometry spectrum is made up by hundreds or thousands of data and calls for relatively complex calibrations for its analysis. Until recently this analysis was unaffordable or technically impractical.

Fire Severity

When speaking about fire effects it is important to distinguish between fire intensity and fire severity, which are often not the same thing at all (6). The term intensity is used to describe the speed at which the fire releases heat energy (7). It is usually quantified in terms of fireline intensity, since this variable is bound up with flame length and is therefore easily measurable (8). Fire severity, for its part, is a more qualitative concept, referring to the fire's effect on ecosystems. High-intensity fires might therefore lead to significant soil changes, in which case they would be classed as high-severity fires. This is not always the case, however. Latent, low-intensity fires, for example, can turn out to be of high severity if they bring about significant changes in the heated soil or even nearby soil. In this case the decisive fire-severity factor would not be so much its intensity but rather the temperature exposure time. Finding out fire severity is therefore crucial for describing the fire's effects on the ecosystem's soil (9).

Study Methodology

The study methodology is summed up in figure 1. First of all two types of soil with sharply contrasting edaphic properties were selected and sampled. Soil 1, taken from a Spanish Fir (*Abies pinsapo*) wood in *Parque Natural Sierra de las Nieves* (Málaga), is limestone soil with a high content of organic matter. Soil 2, in contrast, taken from *Cistus* (rockrose) and heather scrub in the hunting grounds of Quintos de Mora (Toledo), is siliceous soil with a low organic matter content.

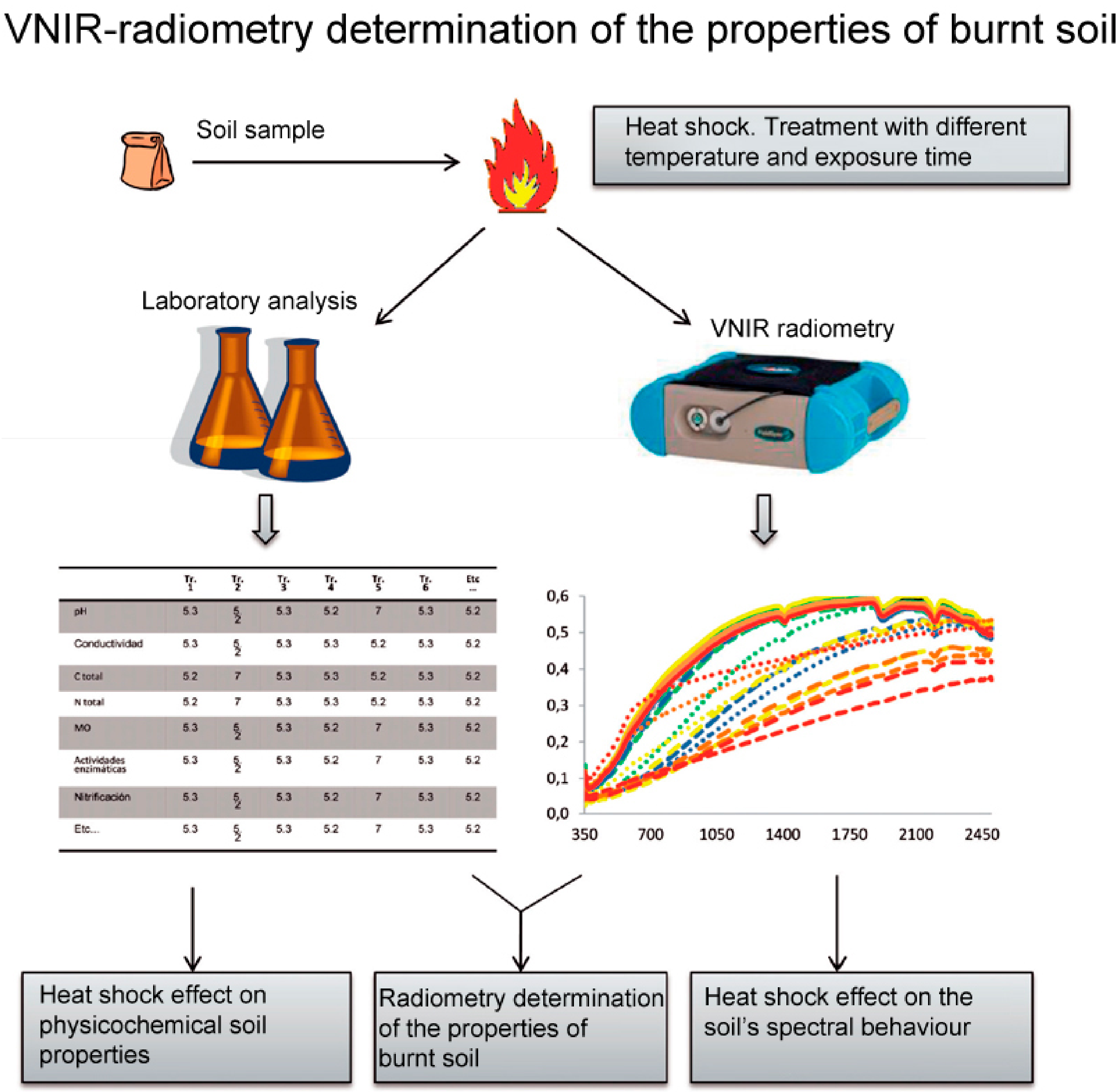

Figure 1. Working methodology for the project «VNIR-radiometry determination of the properties of burnt soil».

Table 1. Conditions (temperature and exposure time) of the heat shock treatments to which the soil samples were subjected (Tmnt. = Treatment; T = Temperature in °C).

Tmnt.	T	Time	Tmnt.	T	Time	Tmnt.	T	Time	Tmnt.	T	Time
100-1	100	1 min	100-5	100	5 min	100-10	100	10 min	100-30	100	30 min
200-1	200	1 min	200-5	200	5 min	200-10	200	10 min	200-30	200	30 min
300-1	300	1 min	300-5	300	5 min	300-10	300	10 min	300-30	300	30 min
400-1	400	1 min	400-5	400	5 min	400-10	400	10 min	400-30	400	30 min
500-1	500	1 min	500-5	500	5 min	500-10	500	10 min	500-30	500	30 min
600-1	600	1 min	600-5	600	5 min	600-10	600	10 min	600-30	600	30 min
700-1	700	1 min	700-5	700	5 min	700-10	700	10 min	700-30	700	30 min

Figure 2. Treatment of the soil samples: heavy-soil sampling aliquots ready for treatment; heat shock treatment in muffle furnace and post-treatment appearance of the samples

All the treated samples (plus the control samples) were then analysed. Traditional laboratory analyses were conducted alongside VNIR radiometry analysis. Given the importance of soil fertility for post-fire regeneration of the vegetation, the traditional physicochemical analyses centred on those variables that are typically bound up with soil fertility. The following variables were hence assessed: organic matter content, total nitrogen, available inorganic phosphorous, cation exchange capacity, exchangeable Ca, Mg, Na and K content, pH, texture and total carbonates. The laboratory analyses allowed us to assess and determine the soil effects as a result of the test processes and also to study the relationship between these effects and the VNIR radiometry results.

The spectral analysis, using an ASD FieldSpec 3 radiometer (Analytical Spectral Devices Inc., Boulder, CO, USA), was conducted on the same samples used for the traditional laboratory analysis. A measurement protocol was designed for the radiometric readings. This protocol involved preparing the samples for measurement, fitting out the measuring room (minimising problems of diffuse reflectivity), the spatial layout of the lighting sources in relation to the sensor and sample (figure 3) and the configuration of the radiometric readings properly speaking. These readings allowed us to assess the heat shock effect on the soil's spectral behaviour.

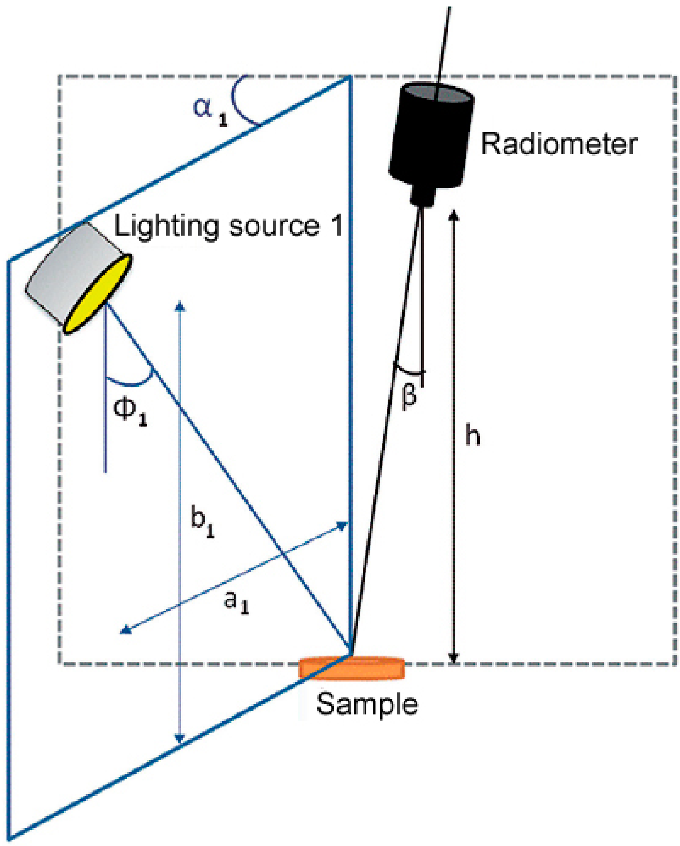

Figure 3. Layout of the VNIR radiometer measurement system (β = 0°; h = 20 cm; α1 = α2 = 45°; φ1 = φ2 = 60°; a1 = a2 = b1 = b2 = 42 cm).

Results

Heat shock treatment produced colour changes appreciable to the naked eye (figure 4). These colour differences show the fire's effect on the soil's spectral behaviour, affecting at least the visible zone of the spectrum (up to 750 nm). Radiometry was then used to evaluate quantitatively the changes in the spectral behaviour of the treated soils, and also to assess changes in the NIR region (not visible to the naked eye).

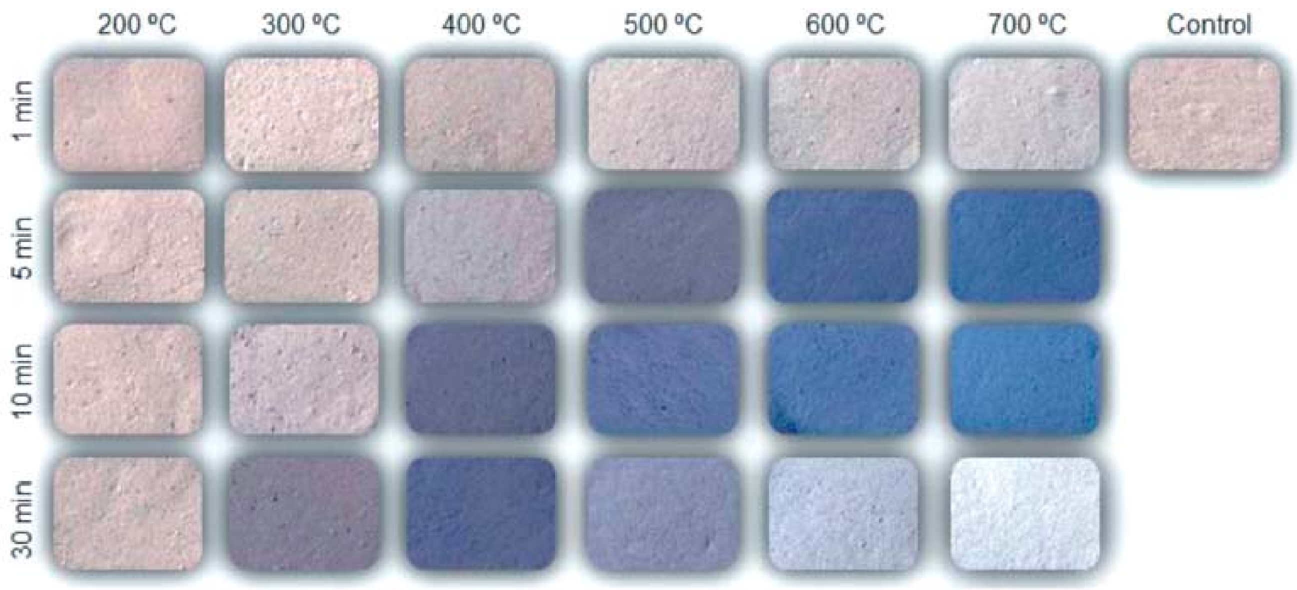

Figure 4. Aspect of the soil 2 samples after heat shock treatment. Rows and columns show, respectively, treatment of the same time and exposure temperature. The control sample is shown to the right.

Precise calculation of post-fire soil changes is a sine qua non for efficient programming of subsequent restoration tasks

The spectral response of the studied soil (without heat shock treatment) is shown in figure 5. The radiometric measurement spectra comprised 2150 individual reflectivity readings. For the statistic analyses a selection was made of 11 wavelengths representative of the complete spectra (selected wavelengths are shown in figure 5). Wavelengths were selected on the following criteria: a visual analysis of the spectra obtained, the statistical analyses themselves and the position of the spectral bands present in the TM sensor of the Landsat satellite.

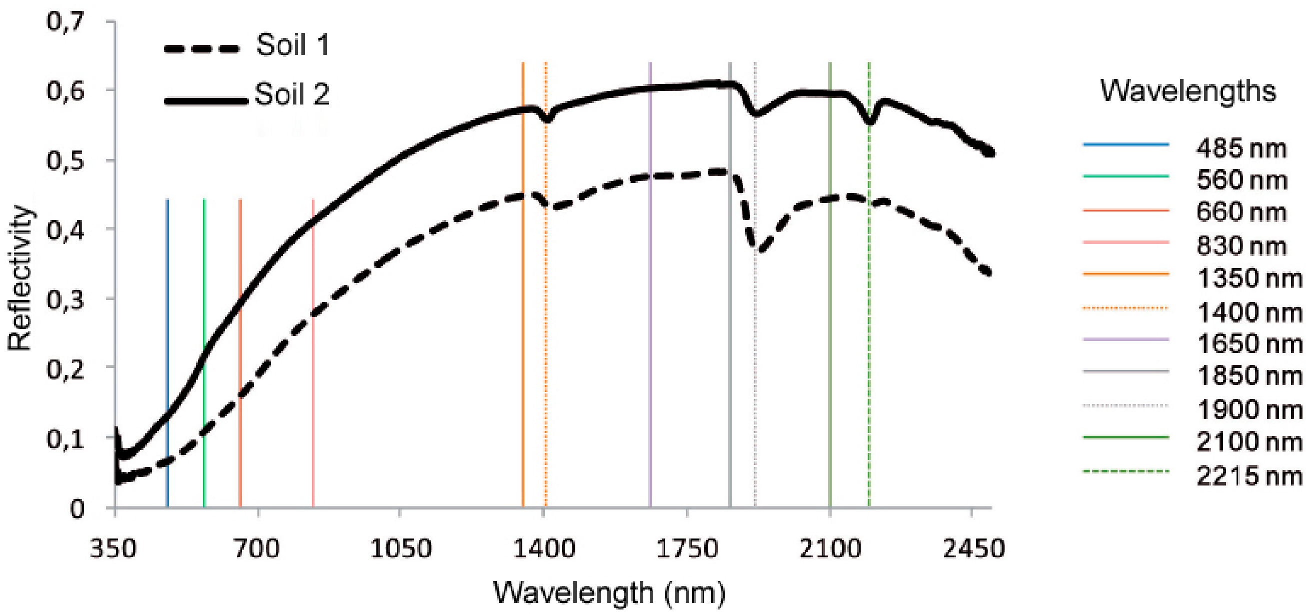

Figure 5. VNIR spectra of the untreated soil samples (control samples) and location of the wavelengths selected for the statistical analysis

Study results show the capacity of VNIR radiometry for

The spectra obtained from the samples treated with heat shock (figure 6) show a decline of reflectivity values throughout all spectrum regions analysed, as well as lower water absorption peaks (for wavelengths of 1400, 1900 and 2200 nm).

estimating the effects of forest fires on soils

Both processes occur gradually as temperature and exposure-times increase. Thus, water absorption peaks fall away completely at the highest temperature and exposure times. Changes in the spectral behaviour associated with the presence of water in the sample occur mainly in the NIR region (in the water absorption peaks); as such they are not visible to the naked eye. As for the fall in reflectivity values, this trend is inverted for treatments of greater severity (i.e., longer time and higher exposure temperature). In the treatments of greatest severity, reflectivity values increase, especially in the spectrum region corresponding to red and NIR. This behaviour shows the same general pattern for all soils studied. According to the statistical analyses carried out on the 11 selected wavelengths, the differences found in reflectivity values were statistically significant (α=0.01). VNIR radiometry is therefore a very sensitive technique for detecting post-fire soil changes.

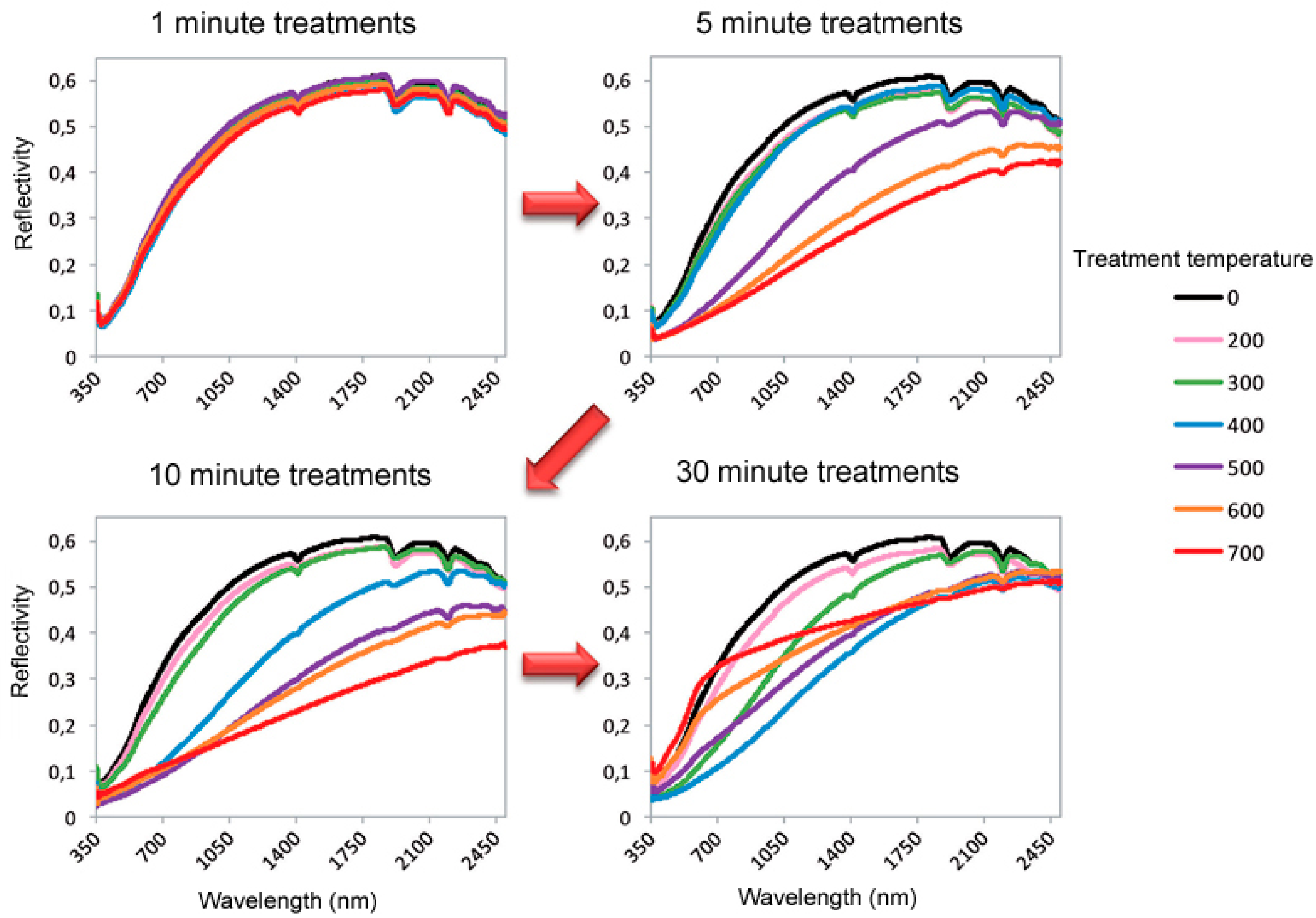

Figure 6. Spectral response of soil 2 samples after heat shock treatment.

These advances are particularly important in the current scenario of climate change

The laboratory-conducted physicochemical analyses, for their part, showed up a decline in the content of organic matter, in the cation exchange capacity and clay percentage. These changes were not significant in general for the least severe treatments (for example treatment at 200°C or less than 1 minute). The laboratory physicochemical analyses also detected a significant increase (although in general only for treatment at more than 200°C and 1 minute) in pH, assimilable phosphorous content and exchangeable forms of Ca. As for exchangeable K, there was an initial fall in the concentration of this exchange base (for treatment of intermediate severity), but this trend inverted at 5 minutes duration for treatment at 700 °C and at 10 minutes for treatment at 600° C. No significant differences were detected or a clear pattern in the behaviour of total nitrogen concentration or exchangeable forms of Na and Mg. Table 2 sums up the general trends observed in this group of variables in terms of the increase of exposure time or temperature reached during the treatment.

Table 2. General trends observed in the laboratory-analysed physicochemical variables. Summary of results obtained for a two-factor ANOVA test (α=0.01).

	Temperature increase From 200 to 700°C	Increase in exposure time From 1 to 30 min.	Temperature x time interaction

	Temperature increase From 200 to 700°C	Increase in exposure time From 1 to 30 min.	Temperature x time interaction
% M.O.	D-	D-	IN
Total N	D-	D-	NO
Asimilable P	D+	D+	IN
CIC*	D-	D-	IN
Mg	IG	IG	IN
K	D-	D-	NO
Ca	D-	D-	IN
Na	NO	NO	NO
pH	D+	D+	IN
% clay	D-	D-	IN
% silt	D+	D+	IN
% sand	IG	IG	IN

*CIC =

D+ = There are significant differences and most increase. D- = There are significant differences and most decrease. IG = There is no clear behaviour pattern and no clear differences. IN = There is interaction between factors of temperature and time. NO = There are no significant differences.

Conclusions and proposal of future lines of research

These study results demonstrate the usefulness of VNIR radiometry for calculating the effects of forest fires on soils. A solid methodological base has also been laid down for VNIR-radiometry measurements of burnt soil. The advantages of this non-destructive methodology (quickness, cheapness and precision) make VNIR radiometry a tool of great potential for estimating fire severity. The radiometric method developed has also proven to be more sensitive to fire effects than estimations made by traditional laboratory techniques.

It should be noted here that the tests for this study were conducted in the laboratory under controlled conditions, cancelling out external factors (constant lighting source, minimum diffuse dispersion, eliminated interference, etc.). These study results are therefore not directly applicable to measurements made in the field or on real fires. Many aspects remain to be examined before this technology can be transferred from its current state to possible final use in real fires. Results to date, however, have laid down the necessary base for a thoroughgoing study of field radiometry for determining the properties of burnt soils.

The use of remote-sensing techniques would offer, among other advantages, the chance of finding out and studying the spatial distribution of fire severity throughout a whole territory

These advances are particularly important in the current scenario of climate change. According to the forecasts of the Intergovernmental Panel on Climate Change future conditions are likely to be even more adverse: longer summers, more droughts and heat waves. Witness, indeed, the increase in the number and size of forest fires in recent years in the Mediterranean area (10), and this trend is thought likely to hold steady or even worsen in coming years. The study of forest fires, including their effects and post-fire regeneration processes, is therefore increasingly important to ensure proper fire management.

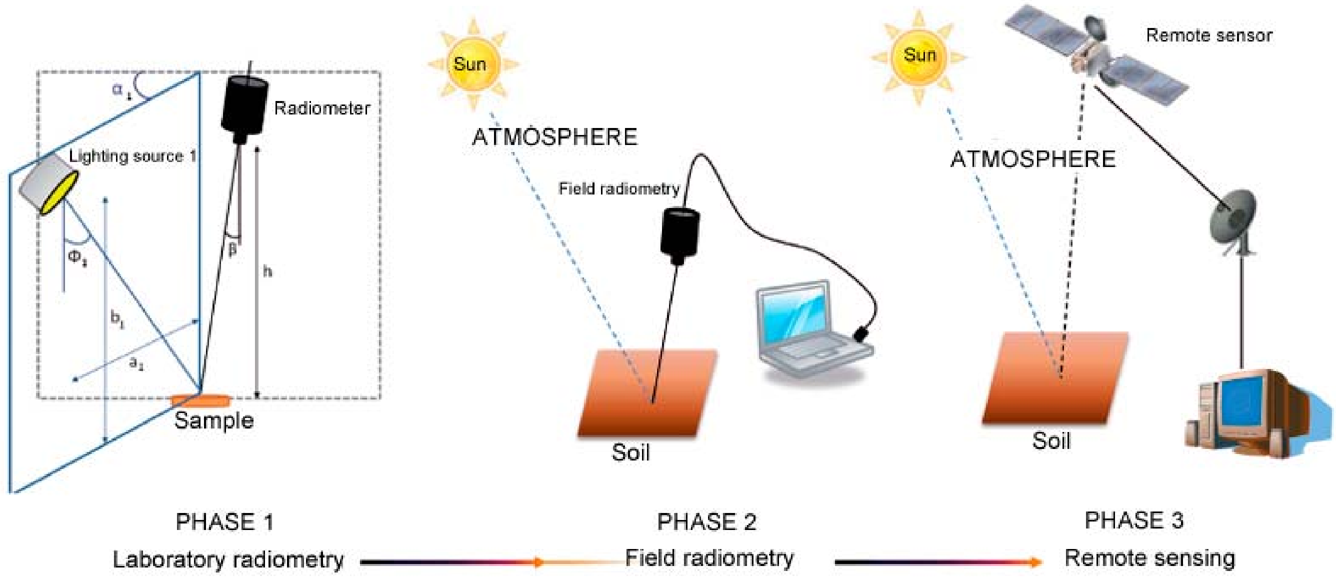

Figure 7. Proposed research phases on the basis of results to date. The work presented herein corresponds to phase 1.

In light of the promising results of this project, the authors consider that the following research phases should now be tackled (figure 7). The second phase would involve setting up a field VNIR radiometry methodology for in situ assessment of fire severity in a quick, precise and efficient way. Phase 3 would then investigate the possibility of using remote sensing techniques and remote-platform images for building up forest fire severity maps. In the first phase (carried out in this project) all the radiometric measurement parameters were well known and even established by users themselves, thereby maximising measurement efficiency. In the second phase of field radiometry, however, factors come into play that are beyond our control (e.g. the amount of radiation falling on the sample, cloud cover on measurement days or the angle of solar inclination). In this phase the knowledge acquired in the experimental laboratory phase (phase 1) would help to offset the drawbacks of this lack of control over the measurement conditions. Likewise, the knowledge acquired in phase 2 would help to offset the greater restraints of phase 3.

The use of remote sensing techniques would offer, among other advantages, the chance of finding out and studying the spatial distribution of fire severity throughout a whole territory. The research carried out in the Centro de Investigación del Fuego, therefore, not only inputs results of great interest per se (in relation to the fire's effects on the soil and the potential for estimating these effects with radiometric techniques), but also paves the way for future research within the blueprint proposed here. The findings of this study and also the advances in terms of methodological aspects represent the start of a line of research of great interest for the management of burnt areas. Indeed, precise determination of a fire's severity is crucial for taking decisions and the application of palliative measures.

TO FIND OUT MORE

1. Guerrero, César. Espectroscopía de infrarrojo cercano (NIR) para la estimación de las temperaturas alcanzadas en suelos quemados, en: Actualización en métodos y técnicas para el estudio de los suelos afectados por incendios forestales. A. Cerdá y A. Jordán, Editors: Valencia. 2010. p. 261–88.
2. Demattê, J. A. M.; Campos, R. C.; Alves, M. C.; Fiorio, P. R.; Nanni, M. R. . Visible- NIR reflectance: a new approach on soil evaluation. Geoderma 2004; 121(1-2): 95–112.
3. McBratney, A. B.; Minasny, B.; Rossel, R. V. Spectral soil analysis and inference systems: A powerful combination for solving the soil data crisis. Geoderma 2006; 136: 272–78.
4. Ben-Dor, E.; Banin, A. Near-infrared analysis as a rapid method to simultaneously evaluate several soil properties. Soil Science Society of America Journal 1995; 59: 364–72.
5. García Rodríguez, M. P.; Muñez León, C. . Utilización de la teledetección y Sistemas de Información Geográfica en la cartografía de suelos. Boletín de la Sociedad Española de la Ciencia del Suelo 1997; 4: 95–105.
6. Hartford, R. A.; Frandsen, W. H. . When it's hot, it's hot … or maybe it's not (surface flaming may not portend extensive soil heating). International Journal of Wildland Fire 1992; 2: 139–44.
7. Chandler, C. P; Cheney, P.; Thomas, P.; Trabaud, L.; Williams, D. Volume I: Forest fire behavior and effects, en: Fire in Forestry, John Wiley & Sons, Inc: New York. 1991. p. 450.
8. DeBano, L. F. The effect of fire on soil, en Management and productivity of western-montane forest soils, Harvey. A.

E. y L. F. Neuenschwander, Editors. 1991, U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: Ogden, UT. p. 32–50.

9. Simard, A. J. Fire severity, changing scales, and how things hang together. International Journal of Wildland Fire 1991; 1: 23–34.
10. Moreno, J.M.; Rodríguez- Urbieta, I.; Zabala, G. Cambio climático y riesgo de incendios forestales en Castilla-La Mancha, en: Impactos del Cambio Climático en Castilla-La Mancha. Primer Informe, Junta de Comunidades de Castilla la Mancha, Editor. 2009.
11. Palm, C. A.; Swift, M. J.; Woomer, P. L. . Soil biological dynamics in slash-andburn agriculture. Agriculture Ecosystems and Environment 1996; 58: 61–74.
12. Ketterings, Q. M.; Bigham, J. M.; Laperche, V. Changes in soil mineralogy and texture caused by slashand- burn fires in Sumatra, Indonesia. Soil Science Society of America Journal 2000; 64: 1108–17.