Capacity of the Nearby Infrared Spectroscopy (NIRS) Red for the Prediction of some Properties of Burned Soils in a Semi-Arid Area of Western Algeria

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Abstract: The forestry sector in Algeria is confronted for the years 1965 to a resurgence of the fires that destroy averaged 48 000 ha per year, or 12% of forest areas. As a result of repeated fires, a pyrophyte vegetation develops on degraded soils and from which the spontaneous regeneration of forest stands and reforestation are very difficult. The Algerian forest sustainable management must therefore be informed by an assessment of the physico-chemical quality of burned soils and the vulnerability of microbial activities in this disturbance Any rehabilitation or regeneration of the burned forest ecosystems program must take into consideration the impact of the fires on the ground [1] and therefore evaluate a large number of soil properties [2]. The main objective of this study was to evaluate the ability of spectroscopy in the near infra-red to predict the time since the last fire and burned some microbiological characteristics of soil. This study is interested in the pine forests of the Algerian semi arid floor Aleppo pines. Promising results have shown a prediction rather senssible of the time since the last fire. The advantages of the SPIR are many. This method is fast, inexpensive and non-destructive.

Keywords: Fire, forest, vulnerability, soil, NIRS.

INTRODUCTION

The vulnerability of ecosystems is defined as their sensitivity to global change (changes in land-use, stress and disruption of climate change...) and also considers the impact of the risk of loss of ecosystem services on human societies. The vulnerability of ecosystems also results in a loss of stability (i.e. resistance and resilience) face additional environmental disturbances fires or stress (i.e. water stress). Resistance and resilience to perturbations are two measurable components of the stability of the ecosystem functions [3].

The landscapes of the Algerian semi arid area are generally considered degraded, vegetation dynamics being affected by disturbances, anthropogenic or not, and the stress of desertification processes.

Forest fires are the first of the list among these disturbances and are old and recurring phenomena which largely shaped the evolution and dynamics of the forest and wildlands. They affect the physical integrity of the environment and the availability of resources, and modify the structure of populations, communities and the ecosystem [4]. Environmental stress (droughts, heat waves, salinity...) are internal factors or external to the ecosystem. Intensity affects life history traits (growth, reproduction and longevity...) and the behaviour of organizations and by those responses, affect all levels of ecological Organization (individuals, populations, communities, and processes) [5].

Despite trademarks visible adaptation of plant species to the climate of this region and the natural recurrence of fires, forests of Algerian semi-arid areas can be weakened by a change in fire regimes and mouth-watering become are potentially vulnerable to climate change expected [6]. These semi arid vegetation are admittedly in decline but they try to use survival mechanisms to overcome the effect of fire and climatic hazards they suffer for thousands of years. The vulnerability of soils and ecosystems more broadly depends to some extent on our ability to assess and anticipate a loss of resilience or degradation of these attributes to protect them as well. This recquiere unfortunately vulnerability assessment knowledge thorough of these soils and ecosystems and thus the acquisition of a large number of data costly in time and money.

In this study, our overall objective was to study the ability of near infra-red spectroscopy (NIRS) for the prediction of the time since the last and some soil

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properties. The specific objective of this research was to develop a mathematical model linking the time since the last fire and some microbiological characteristics of soil (basal respiration, microbial biomass and enzyme activity FDA hydrolase) to spectra near infrared. It should be noted the importance of mathematical and statistical methods to view, retrieve and process information in the development of the NIRS. Thus the near infrared spectroscopy has proven its usefulness in types varied as agriculture, food industry, pharmaceutical, chemical and petroleum. By its speed and its non-destructive nature, the NIRS is a method of choice for the analysis of industrial processes online. This tool already widely used in agri-food to also these proven science soil and especially for predicting physico-chemical and microbiological fire South of the France Mediterranean soil properties [7]. The establishment of an analytical application using the NIRS requires a set of multidisciplinary knowledge. This is why has spent a good part of this article to the presentation of the NIRS, its instrumentation and the approach to develop a quantitative analysis.

MATERIALS AND METHODS

1) Presentation of the Study Area

The study area is located in the forest of Fenouane (34^o 45 ' 11.38 N 0^o 02 ' 54,16 O) (Figure **1**); It extends over an area of 2 537 ha and is located in the commune of Sidi M' barek. This forest of the southern foothills of the tellian atlas is located at an average altitude of 850 m, whose climate is of the Mediterranean type belonging to the semiarid bioclimatic floor fresh Variant. The area is characterized by an annual average rainfall of 348 mm with a seasonal rainfall of type HPAE; average annual temperatures are 16.5 ^{o}C with a 3 ^{o}C "m" and "M" of 32 ^{o}C inducing a significant thermal amplitude of 29 ^{o}C [8].

2) Choice of the Chronosequence Post-Fire and Sampling of Soils

A survey of regional and local forest services allowed to accurately determine the dates of the fires in the forest of Fenouane on a 20-year period from 1990 to 2009. The choice of observation sites (Figure **1**) was imposed by areas where fires themselves are repeated, therefore a sampling led. Five Plots, depending on the number of fires they have undergoes in 20 years were selected. A repository (witness) of plots having suffered no fire during the chosen period constitutes another component to serve as a comparison. I have chosen five (05) stations on the basis of the last fire (modality I. 2009, modality II. 200, modality III. 2003, mode IV. 1998, modality T. witness).

To statistically validate the results, each modality of time since fire was replicated five times. On each plot sampling, five soil samples were collected randomly, after eliminating the litter at a depth between 0 and 5 cm corresponding to the surface horizon organo-mineral 'A '. Five soil samples were then mixed to obtain a composite sample (1 kg). Composite samples were sieved to 2 mm and air-dried.

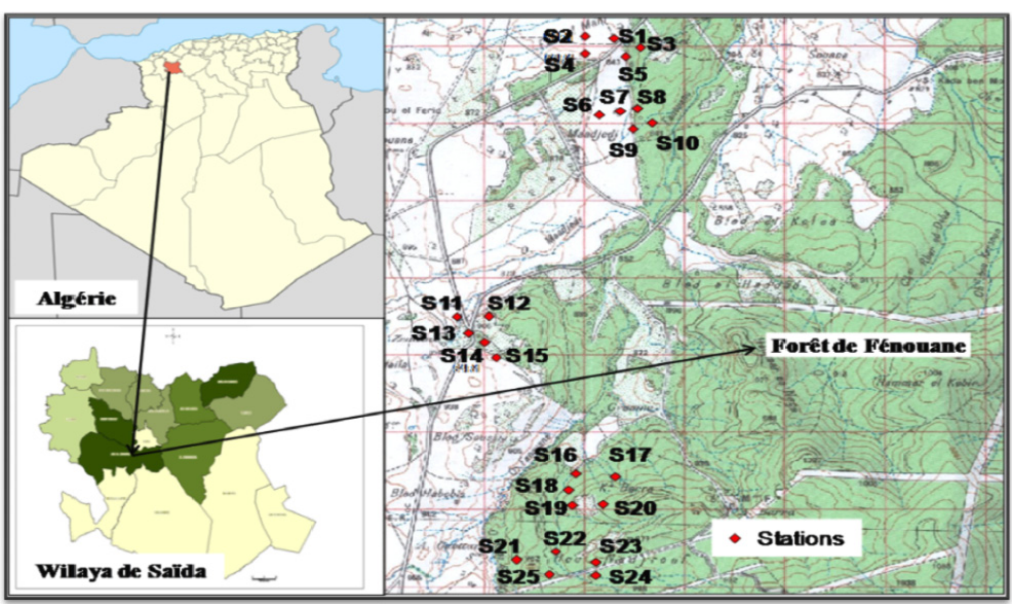

Figure 1: Location of the study area.

3) Microbiological Analyses Selected for the NIRS

Basal Respiration

Basal respiration (µg C-CO2/g dry soil) was measured according to the Protocol described by Anderson & Domsch (1978) [9], to evaluate the physiological state of the soil microbial communities. Ten (10) grams (dried equivalent) of fresh soil stored at 4 ° C were weighed in a (117 mL) glass bottle. The vials have been closed with a sealing cap immediately after replacement (4 minutes) from their internal atmosphere by a stable CO2 concentration atmosphere, then incubated 4 hours at 25 ° C. After incubation, an aliquot of atmosphere of the vial (1 mL) was injected with a syringe in a chromatograph gas (Chrompack CHROM 3 - CP 9001). The gas chromatograph was equipped with a TCD detector and a packed column (Porapack) in which circulates from helium to a flow of 60 mL.h-1. The values have been adjusted to 22 ° C in accordance with the law of perfect Q10 = 2 gases. Ambient CO2 concentrations have been subtracted at CO2 concentrations measured after incubation for the amount of CO_2 produced by heterotrophic microorganisms contained in the sample.

Microbial Biomass

A mixture of talc and glucose (1000 µg C g - 1 soil) has been added to the ten grams (dried equivalent) of soil. Microbial biomass was estimated by the method of respiration induced by addition of glucose [9]. 100 minutes of incubation was carried out to achieve a maximum induced respiration rates. The vials have been closed with a sealing cap immediately after replacement (4 minutes) from their internal atmosphere by an atmosphere of stable CO2 concentration, and then incubated 90 minutes at 22 ° C. Bottles CO2 concentration was analyzed by chromatography gas and corrected in the same manner as described previously for the basal respiration. Induced respiration rates were converted to microbial biomass value using the equation given by Beare *et al.* [10].

Measurement of the Activity of the Hydrolases of Fluorescein Diacetate (FDAse)

The FDA hydrolase activity allows to evaluate the activity of a wide range of enzymes (e.g., esterases, proteases, lipases, cutinases) involved in the hydrolysis of carbonaceous molecules. FDAse activity was measured according to the modified method of Green *et al.* [11]. Four mL buffer phosphate potassium to 60 mM (pH 7) more 50 µL of fluorescein diacetate (2 mg/mL of acetone) solution were added to 1 g of soil cool and incubated at 30 ° C for 1 hour. The reaction was stopped by adding 2 mL of acetone and the mixture was immediately centrifuged for 2 minutes at 12,000 g (4 ° C). Fluorescein liberated from the FDA was measured in the supernatant at 490 nm. For each sample, a witness is done in identical conditions by replacing the buffer containing the substrate by buffer alone. The FDA hydrolase activity is expressed in µmol of fluorescein released per minute (U) and per gram of dry soil (U.g - 1).

4) Spectrometric Analysis of Soils in the Near Infrared (NIRS)

Spectroscopy near infrared (NIRS) is a non-destructive analytical technique based on the interaction between light radiation in the near infrared (10,000 - 4000 cm-1 or 800-2500 nm) and the molecules of the sample. Links C - H, N - H, O - H, S-H, C = O and O — H, constituent of most molecules biological [12], have strong polarization and a great mass imbalance and are therefore most likely to be implemented with vibration.

The NIRS thus measured intensities of absorption of electromagnetic radiation by the organic matter of the soil. However, in the area near infrared, removals are not due to basic molecules, but harmonic vibrations vibration and vibration of combinations.

Thus, and because the various chemical bonds of a soil absorption bands may overlap, the absorption spectrum collected is complex and very difficult interpretation.

The NIRS appears as a valuable tool to predict the levels of C and N in soils [13, 14] and estimate the process of decomposition of organic matter in soils and litter. It is also more and more applied to the prediction of microbial activities in soil. The acquisition of Spectra of air-dried and sieved soil samples was carried out at the Institute of Sciences molecular de Marseille with spectrometer Nicolet Antaris with of an integrating sphere. Data recorded in reflectance (R) are automatically converted to absorbance (A) by the relationship A = log (1/R). Spectra acquired software Omnic 2.1 between 4500 and 10 000 cm–1 with a nominal resolution of 4 cm - 1. Each spectrum is obtained by accumulating 100 interferograms [14].

The predictive ability of microbial activities and parameters of fire by the NIRS was analyzed by regression of partial least squares (RMCP) [15]. The RMCP is to fit a linear statistical model linking a matrix of variables explanatory X (descriptors, here the values of absorbance PIR matrix) to a matrix of response variables Y (e.g. properties of soil measured by conventional methods of reference). During the process of modeling the RMCP summarizes descriptors (matrix X) into a series of components (also called factors) two orthogonal.

Unlike the principal components analysis and other multivariate linear regression methods, these components are constructed to explain better the matrix Y, and the information contained in this response matrix is taken into account for the calculation of the coefficients B (matrix B). In the same way, the response variables are summarized in a series of components uh (scores Y, no constraint of orthogonality). The series of factors (uh, th) are constructed by the RMCP so their covariance is maximum. The number of components may not exceed the number of explanatory variables.

The RMCP being empirical modelling procedure, it is essential to determine an optimal number of components (h) ensuring a proper complexity while avoiding a sur-ajustement of the model and therefore a very low predictive power or zero [16]. On the other hand, being built in a predictive purpose regression models, it is important to be able to reliably test their robustness.

Different methods used to evaluate the robustness and to validate the models by specifying their predictive power. Some methods use the initial data set to achieve a cross-validation of the model (case of data with few individuals), others validate the model on one set of data specially acquired for independent validation (case of datasets with many individuals).

In this research, the samples were divided into two distinct sets: the first, composed of three quarters (chosen randomly) samples, serves as a calibration model construction, while the second, made up one-quarter of the remaining samples, serves at the calibration by prediction model validation. The number of selected components was determined by examination of the PRESS curve (Predicted Residual Error Sum of Squares).

The PRESS value is an indicator of the error of prediction in an RMCP. Whenever it adds a component representing a useful information for calibration model Multivariate, the values of the error of the model and the PRESS are reduced. The value of the PRESS at a minimum for a given number of components. This number is then used for the construction of the final model. The R2 of the calibration model and the standard error of calibration (ESC) were calculated and tested by full cross-validation ('full cross validation').

In addition, the calibration model was built by selecting the most appropriate wavelength obtained by the method of projection of the variables important . The evaluation of the performance of the prediction has been estimated by the value of the R2 of the model's prediction, the standard error of prediction (ESP) and predictive gap of residues (DPR for residual predictive deviation'). The RPD is the ratio of the variance prediction data measured on the error type. ESC and ESP were analysed with regard to the standard error of measurement (ESM). To improve models, mathematical pretreatments such as the "multiplicative scatter correction" (MSC), the "standard normal variate» (SNV) or the first derivative, have been applied to spectra.

Each RMCP model was built with the software Unscrumbler 9.2 (Camo Process AS, Norway) to minimize the ESC and maximize the R^2 of calibration and the children.

RESULTS AND DISCUSSIONS

1. Microbial Properties of Soils

No significant differences in basal respiration, microbial was measured on this post fire chronosequence (Figure **2A**). The only significant difference from microbial biomass has been measured between the non-burned 2 years and soils not burned for 8 years (Figure **2B**).

Two years after the last fire, activities FDA hydrolases are 40% more low ($P < 0,01$) in a soil not burned for at least 20 years (Figure **3**). Four years were enough to get this activity up to the level measured in soils not burned for at least 20 years. However, a significant increase in FDA hydrolases activities occurred 8 years after the last fire compared soil not burnt 2 years [1].

2. Prediction of Certain Properties of the Soil and the Time Since the Last Fire by the Close Infrared Spectroscopy Red (NIRS)

From Spectra acquired in the near infrared, we constructed multiple regression models to evaluate the predictability of certain microbial properties (basal

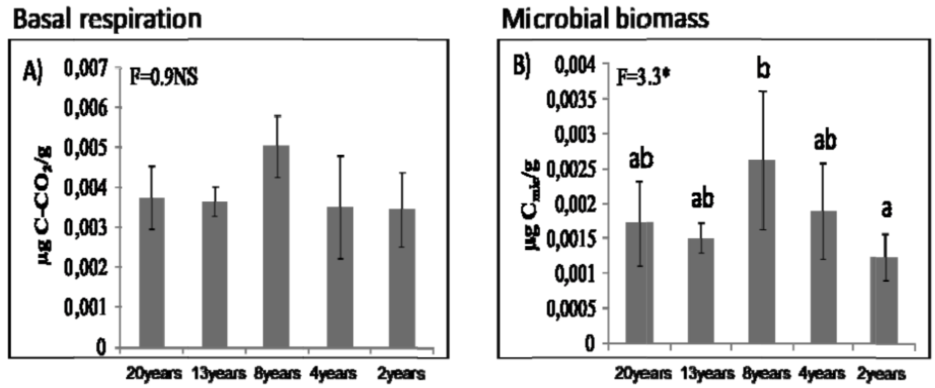

Figure 2: Basal Respiration (**A**) and microbial biomass (**B**) soils collected along a chronosequence postincendie. The value F of ANOVA is presented with its significance threshold (*: P < 0,05; not significant).

respiration, microbial respiration and FDA hydrolase) and the time since the last fire by ' using this destructive, fast and not expensive tools. Our choice fell on these parameters because it was the only ones available for 50 samples (minimum number of samples needed for the construction of robust models). The number of samples used for the construction of the calibration models and prediction, the number of factors considered during this construction, as well as the parameters for evaluating the quality of models (i.e., R2 correlation coefficients, cross-validation ETVC, deviation of prediction FTES deviations, predictive residual deviations RPD and the values of bias) are recorded in Table **1**.

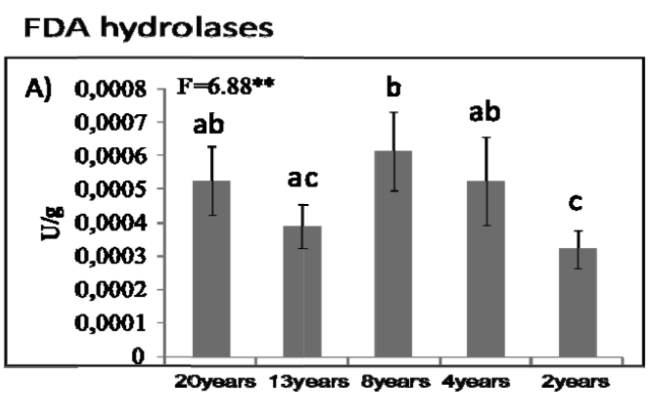

Figure 3: Dynamics of return postincendies enzyme activities FDA hydrolases. The value F of ANOVA is presented with its significance threshold (**: P < 0,01).

Our results indicate that the prediction is the most accurate for the time since the last fire (R2 = 0.93, ETP = 1, 94, RPD = 3.84). This prediction model is considered satisfactory with an accuracy which is about 1 year and half (bias = 1.61). For basal respiration, microbial biomass calibration models present satisfactory qualities (R2 = 0.98, 0.97) but predictive models can be improved (RDP between 1.1 and 1.4), in particular their accuracy that could be increased by the use of a larger number of samples.

FDA hydrolase presents different models of calibration and unsatisfactory prediction (R2 = 0, 6 and RDP = 1, 16). This result can be explained either by the low number of samples taken into account in this analysis, either by the inability to predict enzyme activity that is indirectly correlated to chemical soil characteristics and in particular the evolution of the carbon content. An ecosystem, or a compartment of the ecosystem becomes automatically less vulnerable to fires if the consequences of disturbances can be anticipated. This expectation is based on our capacity, both technical and financial, to characterize the properties of soil before and after fires and this in situations pedoclimatic the more diverse possible. Spectroscopy of the nearby infra-red is a tool which would, by its low cost and the acquisition speed analytical, replace the soil measures traditional costly in time and money.

The objective of our study was therefore here to test the predictability by spectroscopy of the nearby infra red microbial characteristics of forest soils in burned Algerian and a characteristic parameter of the fire regime; the time since the last fire. Spectra in the nearby infra red and conventional microbiological analyses have therefore done on soil collected during the two campaigns of levies (i.e. 2009 and 2010), on 50 samples, to ensure a certain robustness to predictive models, both statistically and in terms of the heterogeneity of the levies. Our results showed that the information contained in the spectra of infra-red soil can be used to predict the time since the last fire with an error that comes close to a year and a half. These results are consistent with those obtained by Guénon *et al*. [7]. The quality of the models explained in part by

Table 1: Model Parameters of Calibration and Prediction of Time Since Fire and Microbial Activities by the Close Infrared Spectroscopy Red

	Calibration					Prediction				
Variables	N	transformation	F	R^2	ETVC	N	R2	ETP	RDP	Bias
Time since the last fire	30	SNV	10	0,93	2,45	12	0,93	1,94	3,84	1,61
Basal respiration	30	None	12	0,98	0,00026	8	0,73	0,0012	1,43	0,00027
Microbial biomass	31	None	12	0,97	0,000019	9	0,82	0,00074	1,15	$-6{,}9510^{-5}$
FDA hydrolase	31	MSC	06	0,62	0,00022	10	0,69	0,00025	1,16	$-3{,}410^{-5}$

N: Number of soil samples used for calibration and prediction models.
SNV: Standard normal variate.
MSC: Multiplicative scatter correction.
ETVC: Standard deviation of cross validation.
F: Number of axis of ACP retained.
R^2: Correlation coefficient between measured and variables predicted for calibration and prediction models.
ETP: Standard error of prediction.
RPD: Residual predictive deviation.

the strong correlation on the one hand between the spectral signatures and the carbon content of the soil, and between the evolution of these levels and the time since the last fire. For the restoration of the soil microbial properties, although average quality Spectra could be improved.

Indeed of similar to the our report a high efficiency of the NIRS to predict these microbial properties after disturbance [7, 17] also showed that the predictions of basal respiration and microbial biomass were satisfactory but could be improved.

The number of samples used in this study remains low compared to the studies cited above. If this tool looks promising and very great interest to predict and therefore to anticipate the effects of fire on soil quality, we suggest to increase sampling in particular effort to take into account the very strong spatial and temporal heterogeneities, pedoclimatic and functional Algerian forests created by fire.

CONCLUSION

The pressure exerted by man on Mediterranean soils is a reality since ancient times, it has increased over the past century by the steady increase in natural resource needs. According to Yaalon [18], Mediterranean soils would be part of the anthropogenic soils of the planet.

The Mediterranean regions accumulate natural factors conducive to the deterioration in their quality [19] and are often fragile indeed. Indeed, the soils are often thick, cover of vegetation is often sparse, under regimes of small but violent precipitation, erosion accentuated by an often sharp relief mechanisms.

These natural degradation in addition to population growth in poor rural areas which leads to overfishing of a judged non-renewable resource (labour marginal slope areas highly susceptible to erosion, overgrazing, over-exploitation of firewood).

In this research work which has benefited from a robust experiment design on it faced some difficulties especially for the prediction with the NIRS tool because a low variety of stories known fire and the low number of harvested sample.

Neaumoin our results indicate that the close infrared spectroscopy red may be a tool that would allow traditional costly in time and money, and to establish robust models for prediction of the quality of the burned soils by its low cost and the acquisition speed analytical, to replace the soil and therefore their vulnerability. This work represents a promising and can be generalized to the various disturbance currently Algerian forests.

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