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Unravelling remote sensing signatures of plants contaminated with gasoline and diesel: An approach using the red edge spectral feature

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ABSTRACT

Pipeline systems used to transport petroleum products represent a potential source of soil pollution worldwide. The design of new techniques that may improve current monitoring of pipeline leakage is imperative. This paper assesses the remote detection of small leakages of liquid hydrocarbons indirectly, through the analysis of spectral features of contaminated plants. Leaf and canopy spectra of healthy plants were compared to spectra of plants contaminated with diesel and gasoline, at increasing rates of soil contamination. Contamination effects were observed both visually in the field and thorough changes in the spectral reflectance patterns of vegetation. Results indicate that the remote detection of small volumes of gasoline and diesel contaminations is feasible based on the red edge analysis of leaf and canopy spectra of plants. Brachiaria grass ranks as a favourable choice to be used as an indicator of HCs leakages along pipelines.

1. Introduction

Pollution by petroleum and petroleum byproducts is a worldwide threat to the environment. One of the sources of contamination is the pipeline systems used to transport petroleum products from production to consumption areas. Although environmental and operational variables are taken into consideration when those pipelines are designed and installed, the weathering of material in older pipes, collapses of terrain, sudden changes in pressure and temperature, among other reasons, can originate clefts and consequent leakage of petroleum hydrocarbons (HCs). Therefore, monitoring pipelines and the nearby landscape features crossed by them is important from the economy, environment and health perspectives. However, this is not a trivial task, especially at countries of great dimensions, such as Brazil, which has a pipeline system with a structure of 11 000 km of pipes running all across the country. In this context, remote sensing technology can be a very useful tool.

The red edge is a spectral feature defined as the wavelength within the 690–740 nm interval that corresponds to maximum slope in the reflectance profile of green vegetation (Lamb et al., 2002). The low reflectance in the red wavelength (∼690 nm) and the high reflectance in the near infrared (∼740 nm) results from chlorophyll absorption and leaf intercellular light scattering, respectively (Campbell, 1996). Remote sensing within the red edge region is usually explored in studies aiming to identify, differentiate and estimate several parameters of vegetation. Examples include the estimation of vegetation chlorophyll content, biomass, hydric status (Filella and Penuelas, 1994) and biochemicals concentration (Mutanga and Skidmore, 2007); and the identification of varied stresses in plants (Carter and Miller, 1994; Carter and Knapp, 2001; Zarco-Tejada et al., 2003). The red edge is normally used as a plant stress indicator because variation in chlorophyll is often observed in response to stress. Red edge parameters, such as position and slope, vary as healthy leaves absorb less radiant energy due to the loss of chlorophyll pigments.

HCs leakages can cause geobotanical and biochemical changes in vegetation growing in areas with contaminated soils (Schumacher, 1996). Consequently they may change considerably the chlorophyll concentration of affected plants, potentizing the indirect detection of HC leakages based on analyses of the vegetation's red edge. This hypothesis is based on the fact that changes in the chlorophyll content of a plant cause its red edge to shift towards

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longer (red shift) or shorter (blue shift) wavelengths (Boochs et al., 1990).

Aiming to detect HC leakages, red edge remote sensing has been used in the spectral characterization of wheat plants in oil-bearing areas in China (Yang et al., 1999); in the identification of stress in grass, wheat and beans as a consequence of gas leaks (Smith et al., 2004); in the identification of the effects of natural gas, methane and ethane upon maize spectra (Noomen et al., 2006); in studies of anomalies in vegetation growing near benzene transportation pipelines in Netherlands (van der Werff et al., 2008; van der Meijde et al., 2009); and more recently in a study of vegetation patterns in a seepage area in the United States (Noomen et al., 2012). These studies have reported promising results, but they were performed in countries of temperate climate, usually evaluating high levels of contamination, and focussing mainly on gaseous HCs.

A field experiment conducted under tropical weather is used here to analyse spectral modifications within the red edge region as small amounts of gasoline and diesel are gradually dropped into the soil cultivated with brachiaria (*Brachiaria brizantha* H.S.), perennial soybean (*Neonotonia wightii* Am.) and maize (*Zea mays* L.), after the plants are well established. The objective is to verify whether it is possible to remotely detect small leakages of liquid HCs based on the analysis of the red edge feature (in leaf and canopy spectra); and to identify which of the three plants analysed is most suitable to be used as a plant indicator of contaminations.

2. Methods

2.1. Plant species analysed

Brachiaria brizantha (Hochst) Stapf is a perennial grass plant of easy adaptability that presents resistance to drought and to cold temperatures, grows effortlessly in humid or dry soils, and has low demands as to soil fertility (Brito and Rodella, 2002).

Neonotonia wightii (Arn.) usually known as perennial soybean, is a leguminous plant of African origin that has a high agronomic value as a forage plant. It is a climbing plant of perennial cycle that spreads through seeds, cuttings or roots. The main characteristics of this species are its capacity to produce new shoots during the drought season, its persistence, palatability, propensity to mingle with grass plants, and its good yield as forage.

Maize (*Zea mays* L.) is a plant of the Poaceae family native of the Americas. The species has an annual cycle and adapts to widely different environment conditions. Its grains are consumed as food by human beings and animals, and the plant is used both as green forage and silage.

The idea was to test plants commonly cultivated in Brazil which have different characteristics (annual versus perennial, monocotyledons versus dicotyledons) to found out which type of vegetation would be more suitable to be utilized as a contamination indicator. Also the plant should present a root system not very deep; otherwise the roots might reach the pipeline and cause damage to it.

2.2. The field experiment

The field trial was conducted in an experimental area of the University of Campinas (UNICAMP), in Paulínia – SP, Brazil. The experiment had one control treatment (CTR) – plants grown on soils not contaminated by HCs; and two HCs treatments – plants developed on soils contaminated with diesel (DSL) and gasoline (GSL). The soil used in the experiment is a eutroferric red latosol with 65% of clay. This type of soil is commonly found throughout Brazil and is fairly representative of the areas where the pipelines are found. For each one of the plant species analysed there were four repetitions (parcels) per treatment (i.e. CTR, DSL and GSL) (Fig. 1a). Each parcel (with 3 m length and 5 m width) corresponds to an area of 15 m^3 of soil. After the plants were well developed, diesel and gasoline leaks were performed into the cultivated soil through a dripping system placed over the soil surface (Fig. 1b). Along a period of one month seventeen leaks of gasoline and diesel were done. The first HC leak comprised up to 2 L of GSL/DSL per cubic metre of soil. Subsequent contaminations amounted to approximately 0.7 L of GSL/DSL per cubic metre of soil. Spectral measurements started prior to the first contamination and ceased after the last contamination.

2.3. Plant samples for biochemical analyses

Samples of brachiaria, perennial soybean and maize plants from the three treatments (CTR, DSL and GSL) were collected in four dates along the course of the experiment: Collection 1 in April 17th (before the first contamination), Collection 2 in April 30th, Collection 3 in May 14th, and Collection 4 in May 28th (after contaminations had finished). Those samples were later tested for their biochemical (chlorophyll *a*, chlorophyll *b*, carotenoids, total sugar and starch) and nutritional contents (nitrogen, phosphorus and potassium). The comparison between treatments for biochemical and nutrient contents was performed based on the ANOVA test ($p < 0.05$). When significant differences were observed among the three

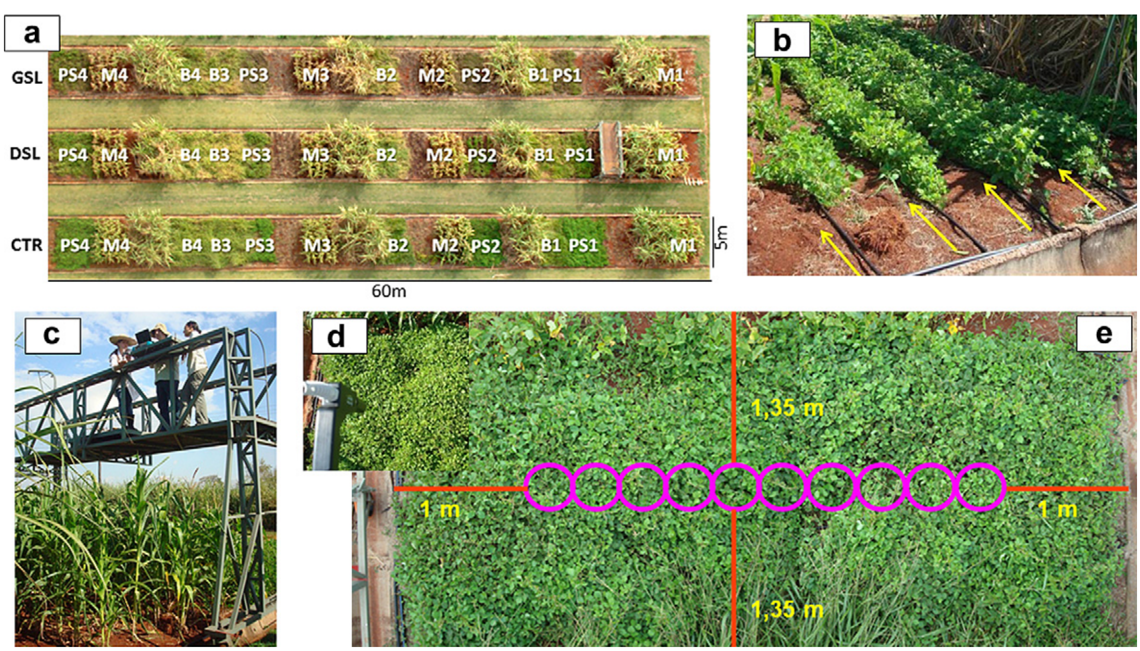

Fig. 1. Photos of the experiment: (a) aerial view of the experiment area showing the plots of brachiaria (B), perennial soybean (PS) and maize (M) in for repetitions/parcels (e.g. M1, M2, M3 and M4) for the treatments CTR (plants not contaminated), DSL (contaminated with diesel) and GSL (contaminated with gasoline); (b) side view of one perennial soybean parcel, showing the hoses (yellow arrows) used to drip the hydrocarbons in the soil; (c) mobile platform used to acquire spectral measurements of canopies; (d) view of a perennial soybean canopy from the platform (e) showing a draw of 10 circles in the central part of the plot representing the spots measured from the platform to acquire the canopy spectra. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)