Hyperspectral Remote Sensing for Detecting the Effects of Three Hydrocarbon Gases on Maize Reflectance

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Abstract - Natural gas in the soil is known to affect vegetation reflectance. Remote sensing can be a tool for monitoring vegetation along pipelines, providing information on possible leaks. In this study we tried to understand how natural gas, methane and ethane affect the development of maize and its reflectance by applying continuum removal of the red absorption pit. Natural gas and methane in small concentrations did not affect plant development and reflectance. Ethane caused a decrease in plant height and an increase in reflectance between 575 and 600 nm. The reflectance of maize growing in large concentrations of natural gas showed a red edge shift towards shorter wavelengths. The combination of plant development and reflectance characteristics will be a key to find gas leaks in pipelines.

Keywords: natural gas leakage, hyperspectral remote sensing, vegetation reflectance

1. INTRODUCTION

Gas pipelines that are buried in the soil leak for several reasons of which aging and accidents are most common. If these leaks are large or undiscovered for a long time, large quantities of explosive gases can develop in the soil thus giving rise to potentially dangerous situations. It is known that natural gas in the soil affects vegetation health and reflectance (Pysek, 1989; Yang, 1999; Smith, 2004). Changes in vegetation reflectance could serve as an indicator for gas leakage. Although it is known that vegetation is affected by gas in the soil, it is not known how the reflectance is affected. In general, it is assumed that gas in the soil displaces the oxygen present in the soil pores, which hampers root respiration (Hoeks, 1972). It is not known if natural gas itself or one of its components affects plant reflectance. In this research, we studied the *direct* effect of natural gas and its two main components methane and ethane on maize leaf reflectance and plant growth, as well as the *indirect* effect of natural gas on maize canopy. We focused on the red absorption pit, which was analysed using continuum removal.

2. MATERIALS AND METHODS

Two experiments were carried out in order to test the influence of natural gas on plant development. The first experiment focused on the influence of gas in the soil on individual plants, whereas the second experiment was carried out to study the effect of gas on the canopy. The same species was used for both experiments to be able to make a comparison between the two experiments.

2.1 Greenhouse experiment

The first experiment was carried out in a greenhouse of Wageningen University, The Netherlands. The aim of the experiment was to measure the influence of the natural gas, methane and ethane on the plants, and to avoid possible indirect effects, like oxygen shortage. Therefore, a small amount of each gas was mixed with normal air before use, which was delivered to sealed pots. In this way the plants would not experience any oxygen shortage in the soil. Natural gas, methane, and ethane gas-air mixtures are explosive so all the gas was mixed up to 50% of the Lower Explosive Level (respectively 2.49%, 2.5%, and 0.73% of natural gas, methane and ethane in air).

The gas cylinders were attached to pots by 3 m long plastic hoses, which had an internal diameter of 1 mm. The hoses were attached to a gas flow meter so that the flow of the incoming gas could be measured. The pots were randomly placed in the greenhouse such that one gas cylinder was connected to two pots.

Each pot was sealed with plastic through which 4 maize plants were growing. During 51 days, 7,5 litres of gas were delivered to each pot per day.

2.2 Field experiment

The aim of the second experiment was to study the indirect effects of gas in the soil -such as oxygen shortage- on canopy reflectance. The experiment took place close to The University of Nottingham, UK. Natural gas was delivered to two maize plots of 2.5 by 2.5 m, with two additional maize plots being gas-free. The gas was delivered by pipelines that ended in the centre of each gas plot 1 meter under the surface. The gas and oxygen concentration in the soil were measured by means of four plastic pipes of 4 cm diameter that collected the soil air 50 cm below the surface. The gas concentration was measured by attaching a GMI Gasurveyor gas detector on the outflow side of each pipe. The Gasurveyor instrument measures methane and oxygen in a range of ppm, Lower Explosive Level, and volume %. During 59 days 1000 l of gas was delivered to both plots.

2.3 Height measurements

The height of the plants was measured once a week in both experiments. In the greenhouse, each plant was measured, while in the field experiment, 12 random plants from each plot were chosen for the height measurements.

2.4 Reflectance measurements

The reflectance was measured weekly. In the greenhouse, the measurements were done with a GER3700 spectroradiometer, which has 704 channels ranging from 1.5-9.5 nm bandwidth.

The sensor, a fiber optic of 10º field of view, was held directly above the leaf that was measured. A halogen lamp mounted on a tripod was used to illuminate the plants from 10 cm above the plants. From each plant in one pot, 5 measurements were taken on individual leaves. Afterwards the mean of all spectra from one pot was calculated to average out differences in leaf angle.
In the field, canopy reflectance measurements were made using an ASD Fieldspec Pro spectrometer. Its 1.5 m long fibre optic cable with 25° field of view was held approximately 1 meter above the plant surface to view an area of 50 by 50 cm. All spectra of one plot were averaged to get the average canopy reflectance of 2.5 by 2.5 meter.

2.5 Data analysis

To compare the effects of the different gases on leaf and canopy reflectance, we focused on the red absorption pit. The reflectance in the red region is characterized by strong light absorption due to chlorophyll. Changes in plant health due to stress are usually accompanied by a decrease of leaf chlorophyll content, which causes an increase in the red region reflectance. The red edge position (REP) – which is the inflection point on the slope between the red absorption and near infrared reflectance - is also used to correlate chlorophyll content with reflectance (eg. Collins, 1978; Horler, 1983; Boochs, 1990; Curran, 1995). Decreasing chlorophyll causes the red edge position to shift towards shorter wavelengths (Collins, 1978). To enhance the comparability between the spectra, we applied continuum removal of the red region between 550 and 750 nm.
Continuum removal normalizes spectra by applying a hull over that part of the spectra that will be analyzed (Fig. 1).

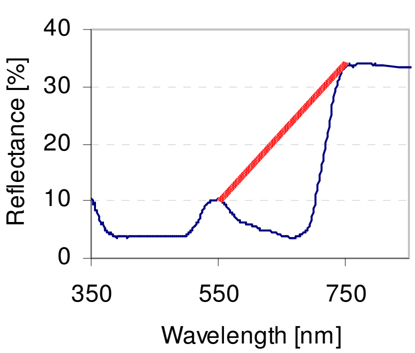

Figure 1. Continuum removal on the red absorption feature

Dividing the reflectance at a certain wavelength in the absorption feature by the value of the hull at that wavelength gives a relative value for the absorption pit between 0 and 1 (Clark, 1984).
After continuum removal was applied, the band depth (D) of each band in the absorption feature was calculated by subtracting the continuum removed reflectance (CRR) from 1 (Kokaly, 1999):

$$D(\lambda) = 1 - CRR \quad (1)$$

The continuum removed red region was also used to calculate the red edge position. There are several ways to calculate the location of the red edge (eg. Guyot, 1988; Clevers, 1991), of which calculating the first derivative of the reflectance is common for high resolution spectra (Demetriades-Shah, 1990). We calculated the first derivative of the continuum removed spectra of the red region. The maximum in the first derivative is the red edge position.

We used the one-way ANOVA (with $p \leq 0.05$) test to compare the band depths and red edge position of the different treatments. When the null-hypothesis (= all groups are equal) was rejected, the LSD post-hoc test was used to test which groups were significantly different from each other.

3. RESULTS

3.1 Height

Ethane had the strongest influence on plant growth. The plants growing in ethane were always 10 to 15 cm smaller than the control plants (Fig. 2). The natural gas and methane plants were approximately the same height at all dates. They were also smaller than the control, but not more than 5 to 10 cm. All differences in height between the treatments and the control were significant ($p \leq 0.05$).
The height of the canopy in the field was affected in a similar manner. There was a clear range visible within the gassed plot of high plants at the side of the plot towards very small plants in the centre of the plot (where the gas entered the soil and the oxygen concentration was lowest).

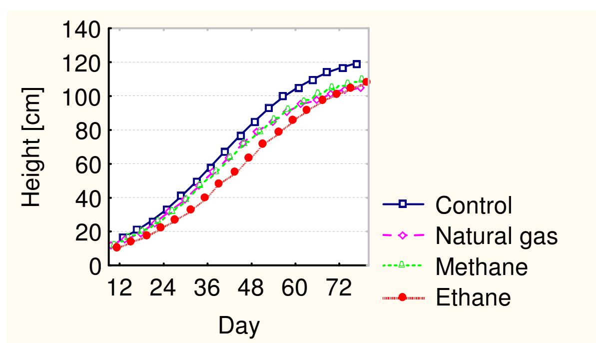

Figure 2. Height of maize plants in time (logistic curve fitted through the data)

3.2 Band depth analysis

Continuum removal of the red absorption pit did not result in any significant differences between the control, natural gas and methane treatments in the greenhouse. Ethane however caused significant ($p \leq 0.05$) lower band depths (= higher reflectance) in the yellow/orange region between 576 and 603 nm, mainly after t = 30 (Fig. 3).
The band depths of the canopy growing in natural gas were significantly less deep than the control band depths in the whole red region.

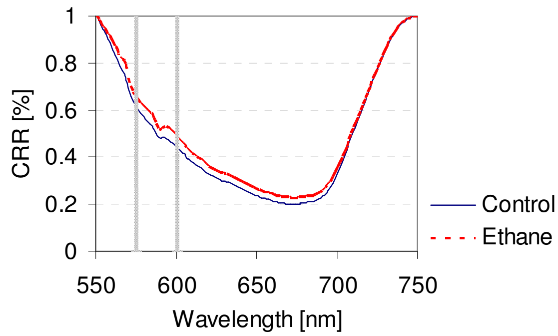

Figure 3. Continuum removed reflectance (CRR) of ethane and control treatments. The grey lines indicate the edges of the yellow area where ethane caused significantly lower band depths.

3.3 Red edge

The red edge of the continuum removed greenhouse spectra does not show any significant difference between the control plants and the gassed plants (Fig. 4). The red edge position of the control canopy was on average located at 1 nm higher wavelength than the red edge of the gassed canopy (Fig. 5).

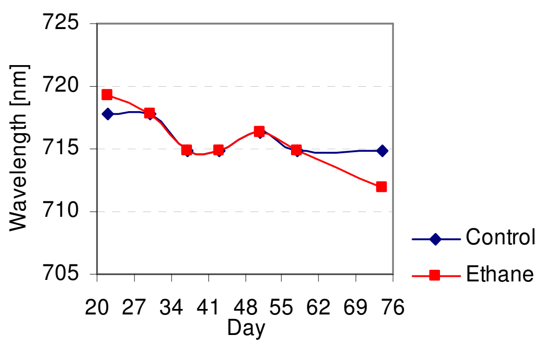

Figure 4. Location of red edge position of control and ethane treatments in time

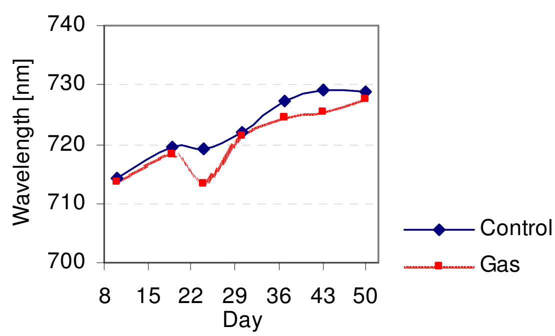

Figure 5. Location of red edge position of the canopy in time

4. DISCUSSION

The difference between the height of the control plants and the gassed plants in the greenhouse is a direct result of the gas itself, since care was taken that oxygen shortage would not occur. Ethane caused the largest decrease in plant height even though the ethane concentration in the soil was lowest of all. We assumed that the decrease in height was a sign of plant stress. As plant stress goes often together with a decrease in chlorophyll (Carter, 1993), we assumed this would be noticeable in the band depth and red edge of the continuum removed reflectance. This was not the case for natural gas and methane; both band depth and red edge were not affected by the gases. The red edge of the plants growing in ethane was not affected either. However, after t = 30, ethane had a higher reflectance in the yellow region. It is not clear what caused the higher reflectance. Higher reflectance in the yellow region could be a sign of chlorophyll shortage (Adams, 1999), but in that case, the red edge position would be located at shorter wavelengths compared to the control. We assume therefore that the higher reflectance in the yellow region is caused by something else than chlorophyll shortage. The red region is not only characterised by chlorophyll, but also by foliar pigments such as catonenes and xanthophylls. Research is underway to find out if these pigments contributed to the increased reflectance in the yellow region.

In the field, oxygen shortage occurred which caused a large decrease in plant growth. This was noticeable in the canopy reflectance as a decrease in band depth in the red region as well as a shift of the red edge position of about 1 nm towards shorter wavelengths. This is accordance with research by Smith (2004), who found an increase in reflectance in the visible light, and a change of shape of the red edge position after delivering natural gas to beans and winter wheat.

Although natural gas itself stresses maize growth, this is not visible in the reflectance. Methane does not affect maize growth or reflectance whereas ethane affects both. Since natural gas contains approximately 95% of methane and 5% of ethane, it was expected that the effects of natural gas would resemble those of methane. This is indeed the case. The amount of ethane in natural gas is too low to have an effect in the small concentrations used in this experiment. When the soil contains larger concentrations of natural gas, ethane is expected to affect plant growth in a similar way as in this experiment. However, when too large concentrations of natural gas build up in the soil such as in our field experiment, oxygen shortage will occur, which most likely blurs the effects caused by ethane.

5. CONCLUSION

The effect of gas leakage on plant growth and reflectance was effectively split in a direct and indirect effect. Ethane gas causes a decrease in growth and an increase in continuum removed reflectance in the yellow region of the visible light. Natural gas and methane cause a small decrease in growth, but no changes in the red region reflectance. Natural gas in large concentrations causes oxygen shortage in the soil. This in turn causes a decrease in plant height, which results in an increase of continuum removed reflectance in the whole red region, as well as a shift of the red edge towards shorter wavelengths. This research has given new insights in the effects of natural gas leakage on plant growth and reflectance. The combination of plant height and continuum removed reflectance in the red region of the visible light will be useful when monitoring gas pipelines for gas leaks.

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