Comparative Analysis of Spectral Responses of Varied Plant Species to Oil Stress

Ebele J. Emengini, Francis C. Ezeh, Njike Chigbu

Abstract- Plants are susceptible to oil pollution, and require constant and accurate monitoring to ensure their sustainment and that of the ecosystem in general. Remote sensing technology has this capability yet, there is the need to understand how oil affects the spectral reflectance of different plant species. A deciduous shrub called forsythia (*Forsythia suspensa*) and ornamental fountain grass (*Pennisetum alopecuroides*) were grown in pots and were subjected to low, medium and high dose oil treatments. Spectral measurements were undertaken in laboratory every four to five days using a field portable GER 1500 spectroradiometer. Development of stress symptoms was visually observed every week. Results show that stress symptoms including stunting, leaf chlorosis and shoot mortality were observed in grass one week after oil treatments while the forsythia showed stress symptoms at later stage. The spectral reflectance of the two plant species significantly increased in the visible region of the spectrum. However, in the NIR, contrary to forsythia, there was significant decrease in spectral reflectance of grass treated with high dose levels. Also, at longer wavelengths in the NIR, all treatment doses had a significant effect on grass spectral reflectance unlike in forsythia where no significant difference was found at all treatment doses. This indicates that the spectral reflectance, particularly in the visible region, is a viable indicator of oil stress that could be applicable across different plant species.

Index Terms- Oil stress, Plants, Remote sensing, Spectral reflectance

1 INTRODUCTION

Contamination of soils with crude oil and refinery products is becoming an ever-increasing problem, especially in the light of several breakdowns of oil pipelines and wells reported recently (Wyszkowski *et al.,* 2004). For safety and security reasons, oil pipelines are kept constantly under surveillance. This is done by several ways such as foot patrol by appointed officials and intermittent aerial surveillance particularly the critical sections of the pipelines using manual observations from aircraft. The overall aim is to guard the pipeline from damage and to look out for possible leaks.

Despite the security and safety measures in place, reports of oil pipeline leaks and spills with disastrous effects continue to rise rapidly, especially in some countries such as Nigeria. The aerial surveillance is costly and has flight risks associated with low level aircraft and rely absolutely on the accuracy of the pilot (Smith *et al.*, 2004). Foot patrol is tedious and time consuming and cannot cover a large area. It is also practically difficult to use in inaccessible areas and hostile environments. If not detected and stopped early, oil leaks can develop into massive spills, leading to fire outbreak which can be very disastrous. This has safety, health, economic and environmental implications including soil contamination, destruction of vegetative ecosystem and arable crops/lands, contamination of surface and underground water, air pollution and extinction of endangered species.

- *Ebele J. Emengini is a Lecturer with the Nnamdi Azikiwe University, Awka, Nigeria, E-mail: scholaphine@yahoo.com*
- *Francis C. Ezeh is a Lecturer with the Nnamdi Azikiwe University, Awka, Nigeria.*
- *Chigbu Njike is a Lecturer with Abia State Polytechnic, Abia, Nigeria.*

Thus, given the severe limitations and demonstrable ineffectiveness of current surveillance approaches, it is imperative that a technique is developed for frequent, accurate and spatially-comprehensive monitoring and detection of oil pipeline leaks. Today, there is a growing and considerable interest in the study of plant stress caused by biotic and abiotic stress factors using remote sensing techniques. Previous investigations have found that soil and vegetation are influenced considerably by hydrocarbon pollution. For example, changes have been observed in biochemistry and reflectance in vegetation growing near natural hydrocarbon seeps (Bammel and Birnie 1994, Yang *et al.*, 1999) and leaking gas pipelines (Pysek and Pysek, 1989, Smith *et al.*, 2000, Smith 2002). Furthermore, vegetation change around the area of gas leaks has been reported from visual observations by helicopter pilots and pipeline engineers (Smith, 2002). Thus, there is some potential for bio-detection of oil pollution using remote sensing approaches.

Remote sensing is a valid alternative to traditional ground-based methods to detect plant stress, especially since the emergence of high spectral resolution imaging sensors. Remote sensing instruments measure radiance reflected from the leaf and canopy surfaces. The spectral differences in these reflectances are derived from leaf optical properties related to the physiological and biophysical status of the plants. Leaf optical properties are a function of leaf cellular structure, water content and biochemical composition (cellulose, lignin, starch, proteins, sugars, etc) and pigment concentrations (Asner, 2004; Ustin et al., 1999, 2004; Wessman, 1990; Woolley, 1971). Alterations in plant biochemistry and cellular composition

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imposed by environmental stressors produce changes in the reflectance characteristics that can be detected using remote sensors. However, there is poor understanding about how different plant species such as deciduous shrub called forsythia (*Forsythia suspensa*) and ornamental fountain grass (*Pennisetum alopecuroides*) could respond to oil stress as these pants are commonly found in the area of oil and gas exploration and exploitation. Hence, the primary aim of this study was to investigate the effects of oil pollution on the spectral reflectance properties of two different plant species, with two specific objectives: (i) to examine how oil pollution at varying levels affect the spectral properties of individual plant species and (ii) to examine how different plant species respond to oil pollution.

2 MATERIALS AND METHODS

2.1 Plant Materials and Treatments

A deciduous shrub called forsythia (*Forsythia suspensa*) and ornamental fountain grass (*Pennisetum alopecuroides*) plant species were used for the experiment. Plants were up to six months old before the experiment studies begun. Four treatments, each comprised of ten replicates were established for each of the plant species. These include the control and three dose levels of oil treatment. Systematically, 20%, 40% and 60% of soil WHC were chosen to represent low, medium, and high dose levels respectively. Pots were kept outdoors under natural and uniform environmental condition except when plants were taken into a dark room for spectral measurements. The plants were watered on a regular basis to avoid water deficiency stress.

2.2 Spectral Measurements and Analysis

Plants were transferred in their pots from outside to a laboratory for measurements. This was to control the influence of other factors on the spectra not related to plant vigour, such as change in illumination angle, atmospheric effects (Luther and Carrol, 1999; Mutanga *et al.*, 2003; Vaiphasa, *et al.*, 2005) and areas of shadow (Blackburn, 2007). The relatively dense canopy structure formed by the plants also controlled the effects of even more controlling factors such as soil/litter surface reflectance, % canopy ground coverage, and presence of non-leaf elements (Blackburn, 2007). A field portable GER 1500 spectroradiometer was used for all reflectance measurements. The GER 1500 uses a diffraction grating with a silicon diode array that has 512 discrete detectors that provides the capability to read 512 spectral bands. Thus, it scans the spectrum at approximately 1.5 nm intervals and covers a portion of the Ultraviolet (UV), the Visible, and the Near-infrared (NIR) wavelengths from 350 nm to 1050 nm. However, the sensor was mounted in a fixed position at about 1.5 m above the canopy at the nadir position with a standard 4^{o} field of view fore-optic. Spectral measurements were undertaken every four to five days and development of stress symptoms was visually observed every week.

Wavelengths considered for analysis were based on systematic selection of different spectral regions that is, the blue (400-500nm), green (500-600nm), red (600-700nm), near infrared (700-800nm) and far infrared (800-900nm). With respect to these spectral regions, the wavebands at which the reflectance difference between the treated plants and controls was high were selected for statistical analysis. This was to ascertain whether change in their spectral reflectances were statistically different. The hypotheses tested were:

(i) There is no significant difference between changes in spectral reflectance of plants treated with oil at different doses.

(ii) There is no significant difference between change in spectral reflectance of different plant species (i.e. grass and forsythia) treated with oil.

ANOVA comparisons were used to test the first hypothesis. Where the spectral reflectance of control and treated plants was statistically different, further analysis was carried out using Post hoc multiple comparisons to ascertain which samples were different. The second hypothesis was tested using Wilcoxon signed-rank test. Although, scale level of measurement was used for data acquisition, the Wilcoxon signed-rank test was used because the sample size is small and they are also related.

3.0 RESULTS

3.1 Visual Stress Symptoms

Treated plants of both grass and forsythia were visually affected by oil pollution as shown in figures 1 and 2 respectively. A variety of visible stress symptoms ranging from stunting, leaf chlorosis and shoot mortality were generally observed in all treated plants as summarised in table 1. While stress symptoms were observed in grass one week after oil treatments, the forsythia showed stress symptoms after two weeks. However, the control plants flourished throughout the experimental period.

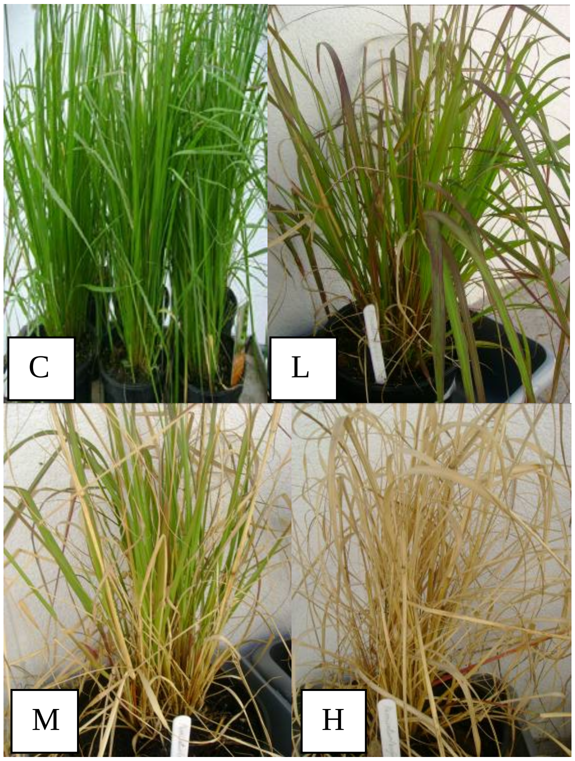

Figure 1 Visual symptoms of grass according to treatment levels of engine oil. C = control, L = low, M = medium, H = high.

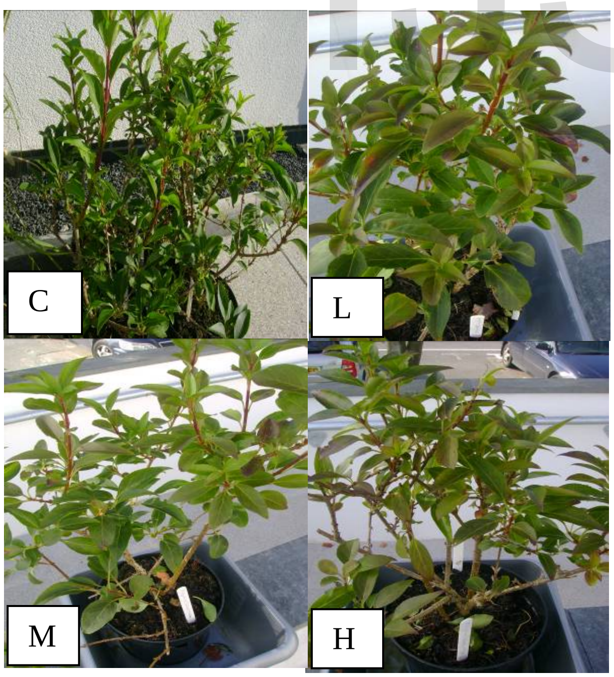

Figure 2 Visual symptoms of forsythia 28 days after treatments with engine oil at varied doses. C = control, L = low, M = medium, H = high.

Table 1 Visual stress symptoms of grass and forsythia contaminated with engine oil at varied doses. C = Control, L = Low, M = Medium, H = High.

Plant specie	**Treat-ments**	**Visual stress symptom**				
		Day 0	Day 7	Day 14	Day 21	Day 28
Grass	**L**	same as above	growth rate declined while some leaves dehydrate	few leaves were dehydrated	few leaves were partially dehydrated while some change to reddish brown	few leaves partially dehydrate while some change to reddish brown
	M	same as above	growth rate declined while some leaves dehydrate	same as low but involves more number of leaves	same as low but higher rate	same as low but with an increased rate
	H	same as above	same as low and medium but at relatively higher rate	almost all leaves were affected	leaves completely dehydrated	plant death
Forsythia	**L**	same as above	same as above	still green	very few leaves appear pale	very few leaves appear pale while others remain green
	M	same as above	same as above	chlorosis affecting very few number of leaves	similar symptoms as low	similar symptoms as low but affecting more number of leaves
	H	same as above	same as above	same as the medium but with an increased rate	similar symptoms as low but involves more of leaves	wilted reddish brown, leaves shoot mortality occurred

3.2 Spectral Response to Stress

The spectral reflectance of the two treated plant species generally increased in the visible and decreased in the NIR region of the spectrum relative to control. Figures 3 and 4

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show the mean reflectance of the treated plants and controls on the final day of the experiment. The pattern of reflectance changes generally follows the dose level except in forsythia where medium dose level had highest reflectance in the NIR (Figure 4).

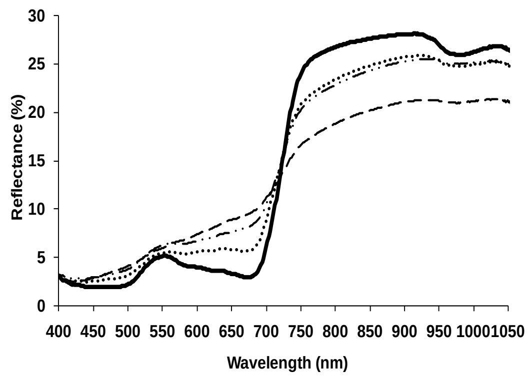

Figure 3 Mean reflectance spectra of oil treatments and control in grass 28 days after treatments commenced. C = control, EL = engine oil low dose, EM = engine oil medium dose, EH = engine oil high dose.

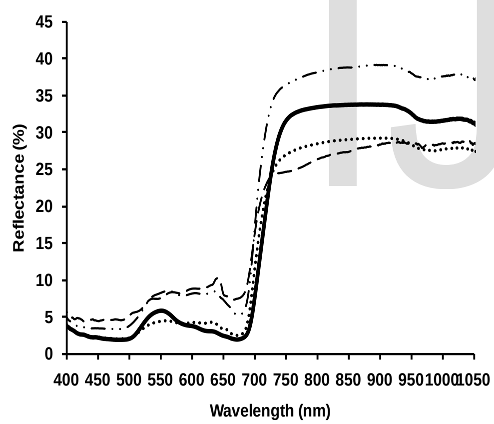

Figure 4 Mean reflectance spectra of oil treatments and control in forsythia 28 days after treatments commenced. C = control, EL = engine oil low dose, EM = engine oil medium dose, EH = engine oil high dose.

Table 2 shows a summary of ANOVA testing for significant differences between the spectral reflectance of control and treated plants. Grasses treated with high dose of oil showed a significant change in reflectance in the blue region. In the same region (blue), high treatment doses significantly affected forsythia's spectral reflectance. In the green region, high treatment doses significantly affected the spectral reflectance of grass. Similarly, medium and high treatment doses had a significant effect on forsythia in the green region. In the red region, medium and high treatment doses significantly affected the spectral reflectance of grass and forsythia. In the NIR, high doses significantly affected grass spectral reflectance. However, medium and high doses had no significant effect on forsythia spectral reflectance in the same region (NIR). At longer wavelengths in the NIR, all treatment doses had a significant effect on grass spectral reflectance unlike in forsythia where no significant difference was found at all treatment doses.

Table 2 ANOVA showing significant difference in spectral reflectance changes of grass and forsythia treated with oil at different treatment doses. In the wavelength column, subscripts G and F refer to grass and forsythia respectively.

Wavelength (nm)	Treatments	Plant species	
		Grass	Forsythia
494.7_G, 401.2_F	Low	0.951	0.972
	Medium	0.541	0.681
	High	0.001*	0.000*
598.6_G, 550.8_F	Low	1.000	0.022*
	Medium	0.621	0.837
	High	0.001*	0.000*
681.1_G, 698.6_F	Low	0.087	0.159
	Medium	0.000*	0.000*
	High	0.000*	0.000*
700.2_G, 798.5_F	Low	0.887	0.246
	Medium	0.300	0.832
	High	0.001*	0.899
800.1_G, 877.7_F	Low	0.000*	0.068
	Medium	0.000*	0.237
	High	0.000*	0.976

n = 20, G = Grass, F = Forsythia, * = significant difference at 0.05.

There is a significant difference between changes in spectral reflectance of grass and forsythia treated with oil at different levels at all waveband regions. Except in the NIR where the ANOVA test showed no significant difference between changes in spectral reflectance of forsythia treated with oil at different levels. Thus, the hypothesis that there is no significant difference between changes in spectral reflectance of plants treated with oil at different doses was rejected at all wavelengths for the grass and accepted in the NIR for the forsythia only. A Wilcoxon signed-rank test showed no significant difference ($p = 0.109 > 0.05$) between changes in spectral reflectance of grass and forsythia treated with oil. Thus, the hypothesis that there is no significant difference between change in spectral reflectance of different plant species (i.e. grass and forsythia) treated with oil was accepted.

4 DISCUSSION

Earlier studies using a wide range of plant species and stresses discovered the first visual signs at different times such as 6, 7, 8, 14, 15, 30 days after inducement (Schollenberger, 1930; Arthur *et al.,* 1985; Pysek and Pysek, 1989; Ketel, 1996; Smith *et al*., 2004; Smith *et al*., 2005). This is similar to the result of this study which also shows variation in time of visual stress symptoms in the two plant species. Thus, this suggests that the time of first visible stress symptom is a function of plant species, type and degree of stress. The visible stress symptoms progressed in a way similar to that observed in oilseed rape leaves affected by natural gas elevation in the soil and other stresses (Smith *et al.,* 2005).

For the two plant species, the reflectance spectra increased in the visible and decreased in the NIR regions of the spectrum. It has long been known that stress generally increases reflectance in the visible region due to a decrease in the dominant absorption features such as the photosynthetic pigments. Thus, light reflected by vegetation in the visible region of the spectrum is predominantly influenced by the presence of chlorophyll pigments in the leaf tissues (Haboudane *et al*., 2002). Similar to the result of this study, Carter (1993) noted that for individual leaves; increased reflectance at visible wavelengths (400 – 700nm) is generally the most consistent response to stress within the 400 – 2500nm range.

A decrease in the NIR reflectance is similar to the results of Pickerill and Malthus (1998). Pickerill and Malthus (1998) found that the NIR reflectance was lower for wheat crops growing over the leaks from rural aqueducts than the surrounding canopy due to the reduced plant biomass and the presence of standing water and wetter soil. The NIR reflectance is influenced principally by the internal cell structure of the leaf (Ceccato *et al*., 2001; Tilling *et al*., 2007). Well-hydrated, healthy spongy mesophyll cells strongly reflect infrared wavelengths (Gates *et al*., 1965). Leaf turgor is associated with cellular growth and function (Graeff and Claupein, 2007). When turgor becomes zero due to stress, the cells collapse and the leaf wilts and this has implications for leaf reflectance. The leaf internal structure of the plants may have been damaged by oil which could explain the increase in reflectance found in the NIR region. Similar reflectance changes found in the present study in both species conforms to the findings of numerous studies that used a wide range of plant stresses such as water logging, natural gas, nutrient stress, heavy metal toxicity and soil oxygen deficiency (Woolley, 1971; Horler *et al.,* 1983; Milton *et al.,* 1989; Carter, 1993; Carter and Miller, 1994; Anderson and Perry, 1996; Smith *et al*., 2004). This suggests that changes in reflectance spectra of plants to stress are the same irrespective of the type of plant specie.

Significant spectral reflectance change was found mainly in the red-edge region of the spectrum particularly across 650nm to 720nm. A study by Carter (1993) found that increased reflectance in the 685 to 700nm wavelengths range was constantly sensitive to different stresses across species. Changes in the spectral reflectance were not significant towards the longer wavelengths of the near-infrared, particularly as dose levels decreased. Carter (1993) found that the infrared reflectance shorter than 1400 nm was comparatively unresponsive to stress. Also, Emengini (2010) found that the NIR (R_{750}, R_{850}, R_{950}) of maize (*Zea mays*) did not perform very well in their response to oil pollution irrespective of the dose level. This suggests that the spectral reflectance at the longer wavelengths may not be a good diagnostic measure for monitoring oil pollution in leaves.

Significant changes in leaf spectral reflectance as a result of oil pollution were found mainly in the red-edge region of the spectrum, between 650 and 720 nm (Emengini *et al*. 2013). This is consistent with a study by Carter (1993) who found that reflectance in the red-edge increased in response to a range of stress agents for a range of plant species, with the region 685 to 700 nm being particularly sensitive. This observation was similar to findings of Smith *et al.* (2005) where the ratio increased rapidly in the gas and herbicide-stressed plants. This could be related to increases in reflectance in the strong chlorophyll absorption region due to a decrease in pigment contents and high reflectance in the green region resulting from a weaker absorption of the pigments.

5 CONCLUSIONS

Based on the stress symptoms observed visually, forsythia appears to be more resistant to oil pollution than grass. This could possibly be attributed to its strong root system that may have stored sufficient resources needed to sustain plant growth. Plants have different levels of sensitivity to stress, but can generally respond quickly to high dose of oil pollution and slowly if contaminated at a sub lethal level. Overall, spectral reflectance, particularly in the visible region, appears to be a potential indicator of oil stress that could be applicable across different plant species. This indicates that the use of spectral reflectance as an indicator of oil-induced stress is worthy of further investigation, that may be focused particularly on identifying appropriate analytical methods for quantifying spectral changes that are most sensitive.

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References

Anderson, J. E., and Perry, J. E., 1996. Characterization of wetland plant stress using leaf spectral reflectance:

implication of wetland remote sensing. *Wetlands*, 16 (4), pp. 477-487.

Arthur, J. J., Leone, I. A., and Flower, F. B., 1985. The response of tomato plants to simulated landfill gas mixtures. *Journal of Environmental science and Health*, 20, pp. 913-925.

Asner, G. P., 2004. Biophysical remote sensing signatures of arid and semiarid ecosystems. In: Ustin S.L. (Ed.), Remote sensing for natural resources management and environmental monitoring: manual of remote sensing, John Wiley & Sons, Inc., vol. 4, pp. 53-109.

Bammel, B. H., and Birnie R. W., 1994. Spectral response of big sagebrush to hydrocarbon-induced stress in the Bighorn Basin, Wyoming. *Photogrammetric Engineering and Remote Sensing*, 60, pp. 87-96.

Blackburn, G. A., 2007. Hyperspectral remote sensing of plant pigments. *Journal of Experimental Botany*, 58 (4), pp. 855-867.

Carter, G. A., 1993. Responses of leaf spectral reflectance to plant stress. *American Journal of Botany* 80, pp. 239-243.

Carter, G. A., and Miller, R. L., 1994. Early detection of plant stress by digital imaging within narrow stress-sensitive wavebands. *Remote Sensing of Environment*, 50, pp. 295-302.

Ceccato, P., Flasse, S., Tarantola, S., Jacquemond, S, and Grégoire, J. M., 2001. Detecting vegetation leaf water content using reflectance in the optical domain. *Remote Sensing of Environment*, 77 (1), pp. 22-33.

Emengini, E. J. 2010. Hyperspectral and thermal remote sensing of plant stress responses to oil

Emengini, E. J., Blackburn, A. G., and Theobald, J. C. 2013. Early Detection of Oil-Induced Stress in Crop Using Spectral and Thermal Responses. *Journal of Applied Remote Sensing*, 7 (1).

Gates, D. M., Keegan, H. J., Schelter, J. C., and Weidner, V. R., 1965. Spectral properties of plants. *Applied Optics*, 4 (1), pp. 11-20.

Graeff, S., and Claupein, W., 2007. Identification and discrimination of water stress in wheat leaves (*Triticum aestvum* L.) by means of reflectance measurements. *Irrigation Science*, 26, pp. 61-70.

Haboudane, D., Miller, J. R., Tremblay, N., Zarco-Tejada, P. J., and Dextraze, L., 2002. Integrated narrow-band vegetation indices for prediction of crop chlorophyll content for application in precision agriculture. *Remote Sensing of Environment* 81, pp. 416-426.

Horler, D. N. H., Dockray, M., and Barber, J., 1983. The red-edge of plant leaf reflectance. *International Journal of Remote Sensing*, 4 (2), pp. 273-288.

Ketel, D. H., 1996. Effect of low doses of metamitron and glyphosphate on growth and chlorophyll content of common lambsquarters (Chenopodium album). *Weed Science*, 44, pp. 1-6.

Luther, J. E., Carrol, A. L., 1999. Development of an index of balsam fir vigor by foliar spectral reflectance – a measure of tree vigor, *Remote Sensing of Environment*, 69 (3), pp. 241-252.

Milton, N. M., Ager, C. M., Eisworth, B. A., and Power, M. S., 1989. Arsenic- and selenium-induced changes in spectral reflectance and morphology of soyabean plants. *Remote Sensing of Environment*, 30, pp. 263-269.

Mutanga, O., Skidmore, A., and Van Wieren, S., 2003. Discriminating tropical grass (Cenchrus ciliaris) canopies grown under different nitrogen treatments using spectroradiometry. *ISPRS Journal of Photogrammetry & Remote Sensing*, 57, pp. 263-272.

Pickerill, J. M., and Malthus, T. J., 1998. Leak detection from rural aqueducts using airborne remote sensing techniques. *International Journal of Remote Sensing*, 19, pp. 2427-2433.

pollution," PhD Thesis, pp. 69, University of Lancaster, United Kingdom.

Pysek, P. and Pysek, A., 1989. Changes in vegetation caused by experimental leakage of natural gas. *Weed Research*, 29, pp. 193-204.

Schollenberger, C. J., 1930. Effect of leaking gas upon the soil. *Soil Science*, 29, pp. 260-266.

Smith, K. L., 2002. Remote sensing of leaf responses to leaking underground natural gas, Ph.D thesis, University of Nottingham, pp. 4.

Smith, K. L., Steven, M. D. and Colls, J. J., 2004. Spectral responses of pot-grown plants to displacement of soil oxygen. *International Journal of Remote Sensing*, 25 (20), pp. 4395-4410.

Smith, K. L., Steven, M. D., and Colls, J. J., 2000. Remote sensing of vegetation stress due to leaking underground pipelines. *Aspects of Applied Biology*, 60, pp. 209-212.

Smith, K. L., Steven, M. D., and Colls, J. J., 2005. Plant spectral responses to gas leaks and other stresses. *International Journal of Remote Sensing*, 26 (18), pp. 4067-4081.

Tilling, A. K., O'Leary, G. J., Ferwerda, J. G., Jones, S. D., Fitzgerald, G. J., Rodriguez, D., and Belford, R., 2007. Remote sensing of nitrogen and water stress in wheat. *Journal of Field Crops Research*, 104, pp.77-85.

Ustin, S. L., Smith, M. O., Jacquemoud, S., Verstraete, M., and Govaerts, Y., 1999. Geobotany: Vegetation mapping for earth sciences. In: Rencz A. (Ed.), Third edition remote sensing for the earth sciences, John Wiley & Sons, Inc., vol. 3, pp. 189-248.

Ustin, S. L., Smith, M. O., Jacquemoud, S., Zarco-Tejada, S., and Asner, G. P., 2004. Remote sensing of the environment: state of the science and new directions. In: Ustin, S. L. (Ed), third edition, *Remote Sensing for the Earth Sciences*, vol. 4 John Wiley & Sons, pp. 679-730.

ISSN 2229-5518

Vaiphasa, C., Ongsomwang, S., Vaiphasa, T. and Skidmore, A. K., 2005. Tropical mangrove species discrimination using hyperspectral data: A laboratory study. Estuarine, Coastal and Shelf Science, 65, pp. 371-379.

Wessman, C. A., 1990. Evaluation of canopy biochemistry. In: Hobbs, R. J., Mooney, H. A. (Eds.), Remote sensing of biosphere functioning. Springer-Verlag, New York, pp. 135-156.

Woolley, J. T., 1971. Reflectance and transmittance of light by leaves. *Plant Physiology*, 47, pp. 656-662.

Wyszkowski, M. J., Wyszkowska, J., and Ziółkowska, A., 2004. Effect of soil contamination with diesel oil on yellow lupine yield and macroelements content. *Plant Soil Environment*, 50 (5), pp. 218-226.

Yang, H., Zhang J., Van der Meer, F., and Kroonenberg§ S. B., 1999. Spectral characteristics of wheat associated with hydrocarbon microseepages. *International Journal of Remote Sensing*, 20 (4), pp. 807-813.