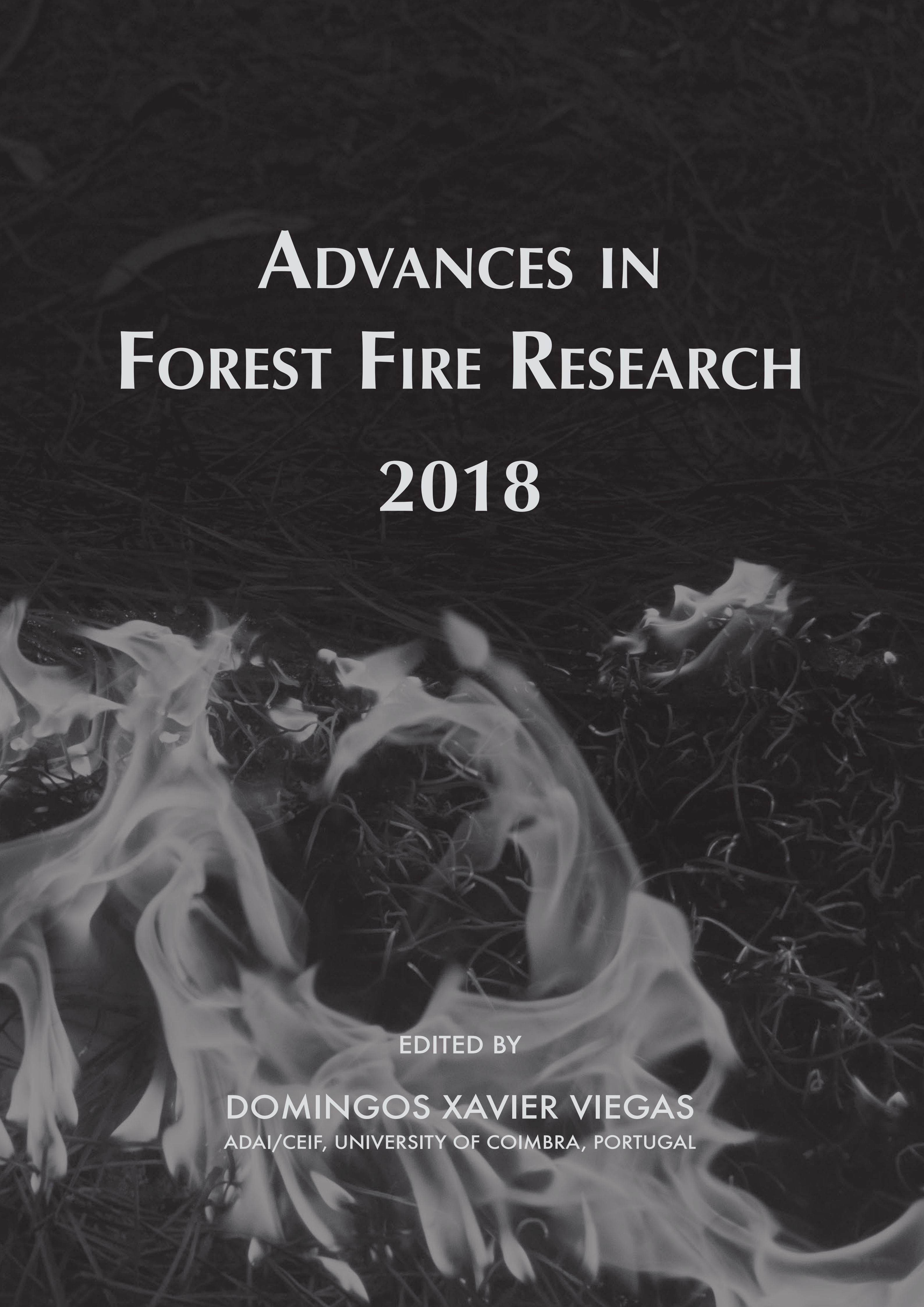

ADVANCES IN FOREST FIRE RESEARCH

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Short contribution – Fuel Management

Bench-scale measurement of pyrolysis products from intact live fuels

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Abstract

Prescribed burning (controlled burning) is used to decrease accumulation of combustible materials and reduce impact of uncontrolled wildland fires. Prescribed fires are often used to burn undergrowth in southern forests of the United States. In order to improve prescribed fire application, accomplish desired fire effects, and limit potential runaway fires, an improved understanding of the fundamental processes related to combustion of heterogeneous fuel beds of live and dead fuels is needed. The initial processes of combustion involve pyrolysis and ignition. During this research, fast pyrolysis of 14 live and dead (biomass) plant species which are native to the southern United States have been studied using a flat-flame burner (FFB) apparatus. The FFB apparatus enables experiments at a high heating rate (~100°C s^{-1}, or ~100 kW m^{-2}) and moderate temperature (~765°C) to imitate pyrolysis during typical fire spread conditions. Pyrolysis products have been analyzed in detail using a gas chromatograph equipped with a mass spectrometer (GC-MS) for analysis of tars, and a gas chromatograph equipped with a thermal conductivity detector (GC-TCD) for analysis of permanent (light or non-condensable) gases. Differences between yields of light gas species were small between plant species. Composition of tars included aromatic compounds with 1 to 5 rings with very few attachments. The pyrolysis products observed at this temperature and heating rate appear to have experienced secondary pyrolysis. The tar composition showed some large changes with plant species. Comparison of products from pyrolysis of live vegetation and dead vegetation of the same plant species showed differences in tar, gas, and char yields, but no major changes in the types of chemical compounds observed.

Keywords: pyrolysis, live shrubs

1. Introduction

Wildland fire is an important component of many North American ecosystems and has been used by humans to accomplish various objectives for several thousand years. Prescribed burning in the southern United States is an important tool used by the Department of Defense and other land managers to accomplish several objectives including hazardous fuel reduction, wildlife habitat management, critical training area maintenance, ecological forestry and infrastructure protection. The vegetation on Department of Defense installations is heterogeneous, unlike the homogeneous fuel beds assumed by current operational fire spread models. These models do not contain fundamental descriptions of chemical reactions and heat transfer processes necessary to predict fire spread and energy release needed for process-based fire effects models. To improve prescribed fire application to accomplish desired fire effects and limit potential escapes, an improved understanding is needed of the fundamental processes related to pyrolysis and ignition in heterogeneous fuel beds of live and dead fuels. The objective of this project is to address several fundamental questions to improve our understanding and modeling capability of fire propagation in natural fuel beds including 1) detailed description of pyrolysis and the evolution of its products for a greater variety of southern fuels than is currently known, 2) how convective and radiative heat transfer from flames to live fuel particles influences pyrolysis and ignition at laboratory and field scales, and 3) more detailed insight into pyrolysis, combustion and heat transfer processes in wildland fire spread through the use of highfidelity physics-based models. This work is part of a larger project which includes trying to measure pyrolysis products in a test bed of vegetation in a wind tunnel as well as in a small field-scale prescribed burn (Weise *et al.* 2018).

2. Experimental Approach

A flat-flame burner (FFB) apparatus was used to study pyrolysis of foliar samples from the plants, as shown in Figure 1. A horizontal fuel sample was attached to a horizontal rod and was suspended in the middle of the glass duct. The rod was attached to a Mettler Toledo XS204 scale. The flat-flame burner structure was placed on wheels which enabled the structure to be moveable. The flat-flame burner was operated under fuel-rich conditions with an equivalence ratio of 1.13, providing a gas background at 765°C with no O_2. The pyrolysis sampling system consisted of a glass funnel connected to stainless steel tubing wrapped with heating tape and insulation with a cold trap to separate the pyrolysis products. Pyrolysis products were analyzed using (1) a gas chromatograph (GC) equipped with, a thermal conductivity detector (TCD), and (2) a GC combined with a mass spectrometer (MS). In the cold trap, the high molecular weight hydrocarbons were condensed and then analyzed by GC-MS after solvent extraction using dichloromethane.

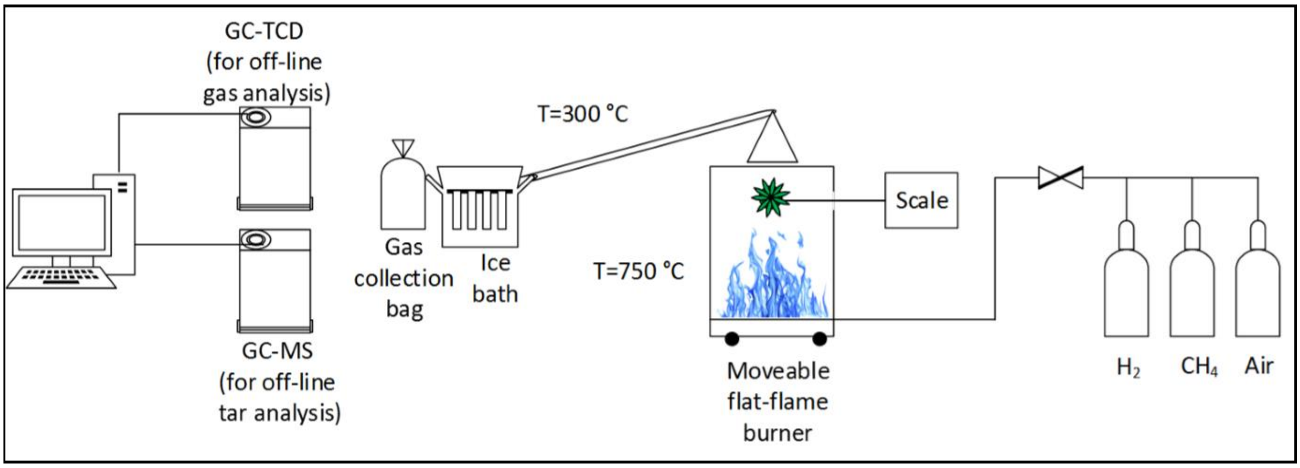

Figure 1 - Flat-flame burner setup used to measure pyrolysis products resulting from heating southern wildland fuels at a high heating rate.

3. Results

Figure 2 shows the yields of tar, light gas, and char from the high-heating rate pyrolysis in the FFB system. The results are the average of three experiments and are shown on a dry ash-free basis. The data showed an excellent reproducibility with the standard deviation of less than 5%. There was not a significant difference in the observed pyrolysis product yields between live and dead samples of a specific plant species.

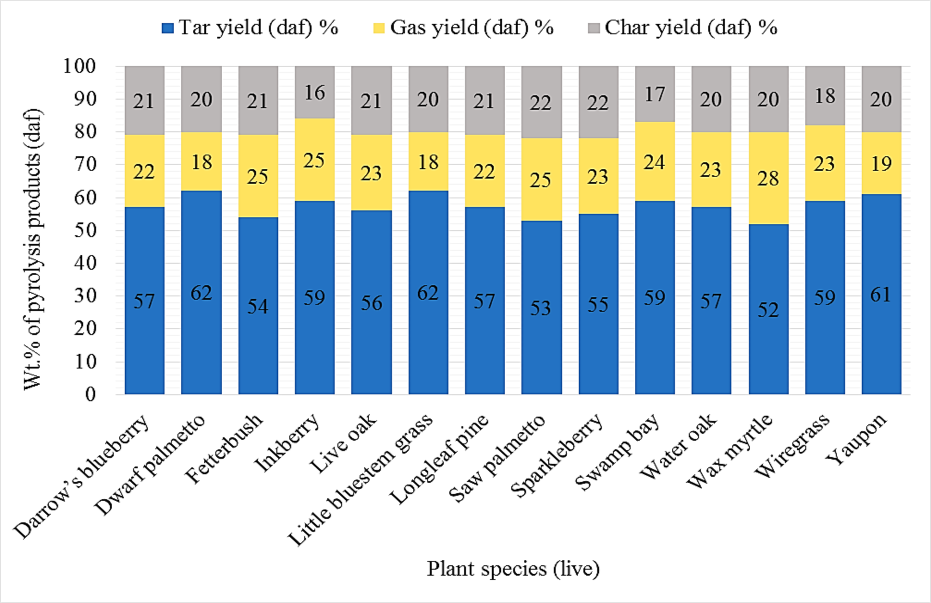

Figure 2 - Yields of tar, gas, and char produced by high-heating rate pyrolysis of live southern fuels (by weight percentage of dry ash-free plant).

Figure 3 shows the species distribution of light gas, presented as wt% of the light gas on a dry basis (with background gases from the FFB subtracted). The major light gas species for all plants was CO, followed by CO_2, then CH_4 and H_2. The CO content varied the most for the Swamp Bay plant. Pyrolysis of dead plant species yielded similar results.

Phenol, naphthalene, fluorene, anthracene, phenanthrene, fluoranthene, and pyrene were the major identified tar compounds, with 1 to 5-ring aromatic compounds. Differences in tar composition were observed for each plant species. The tar species data seemed to lie in four general areas: broad leaf, pine needle, palmetto-type, and grasses. For example, in tar analysis, phenol ranged from 6 mole% in dead little bluestem grass to 36 mole% in live saw palmetto. See Safdari, et al. (2018) for additional details.

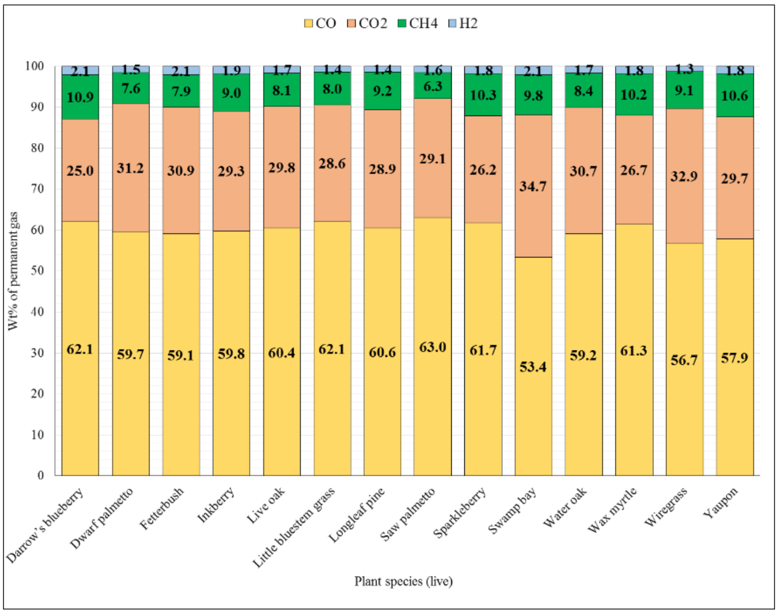

Figure 3 - Composition of permanent (i.e., non-condensable) gas from pyrolysis of live southern fuels (by weight percentage of dry permanent gas).

4. Conclusions

Most plant species from the same type of plant (broadleaf, grass, or needle-like) showed only small differences in yields of the light gas species (CO, CO_2, CH_4, and H_2). Tar compounds consisted of 1- to 5-ring compounds with very few attachments on the rings. Major tar species observed included phenol, naphthalene, fluorene, anthracene, phenanthrene, fluoranthene, and pyrene. Tar compounds from different plant species exhibited a significant difference in the distribution of functional groups.

5. Acknowledgement

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6. References

Safdari M-S, Rahmati M, Amini E, Howarth JE, Berryhill JP, Dietenberger M, Weise DR, Fletcher TH (2018) Characterization of pyrolysis products from fast pyrolysis of live and dead vegetation native to the Southern United States. *Fuel* **229**, 151-166.

Weise DR, Fletcher TH, Johnson TJ, Wao W, Dietenberger M, Princevac M, Butler B, McAllister S, O'Brien J, Loudermilk L, Ottmar R, Hudak A, Kato A, Shotorban B, Mahalingham S, Mell WE (2018) A Project to Measure and Model Pyrolysis to Improve Prediction of Prescribed Fire Behavior. In '8th International Conference on Forest Fire Research'. Coimbra, Portugal