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Fire behavior and heat fluxes for lab-scale burning of little bluestem grass

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ABSTRACT

This paper discusses the physics and fire behavior of grassland fuel using experimental and modeling results. Experimental characterization included intermediate-scale tests to determine the mass loss rates, heat release rates (HRRs), and flame heat fluxes of burning little bluestem (*Schizachyrium scoparium*) grass plants at various fuel moisture contents and external flow conditions. The experiments included single-plant tests, multiple-plant tests with no forced flow/wind, and multiple-plant tests in which a forced flow was directed over the plants to simulate wind. The burning characteristics of single plants and fire spread between multiple plants under various conditions are discussed. The computational tool, Wildland–Urban Interface Fire Dynamics Simulator (WFDS), was then used to model the experiments using both a prescribed HRR and the particle-based fuel element model (predicted HRR). Comparisons are made between the experimentally measured quantities and the results predicted by WFDS. The results of the WFDS simulations with a prescribed HRR are in good agreement with the measured heat fluxes for the multiple-plant tests with no wind. The results of the particle-based WFDS fuel element model are in good agreement with the experimentally measured mass loss rates and HRRs of the single-plant tests. The WFDS fuel element model effectively captures the different stages of burning of the little bluestem plant. For the prediction of heat fluxes in the wind tests, there are limitations in the use of the prescribed HRR model.

1. Introduction

The construction of suburban housing continues to expand into forested and natural environments. The incursion of suburban residential communities into forested areas that can act as fuel for wildland fires occurs at the wildland–urban interface (WUI). Many natural disasters such as hurricanes, floods, and storms have super-real-time forecasting abilities using models and tools that have been developed in recent decades. There is a need to improve such forecasting and warning systems for approaching wildland or grassland fires, and the accurate prediction of fire danger and fire spread at the WUI is necessary to aid in effective community preplanning and disaster response during wildland fire incidents. Most recently, in the southwest US in the state of Texas, 6400 km^2 (1.58 million acres) were burned from December 2005 to April 2006 with more than 700 residential structures destroyed, and 14 000 km^2 (3.46 million acres) were burned from November 2010 to August 2011 with more than 1600 residential structures destroyed [1,2].

Fire spread behavior in wildland fire incidents is typically characterized using three basic categories of predictive models: empirical, semi-physical, and physics-based models. Perry [3] presents several models that were developed in the latter half of the 20th century. Since the availability of computational power has increased tremendously in the past few decades, it is now feasible to incorporate more detailed physics in these predictive models. For example, a study reported by Koo et al. [4] used a two-dimensional model to describe wind-aided fire spread through a bed of porous fuel. Their model takes into account inclination of terrain, convective and radiative heat transfer to unburned fuel packets, and other details. Their results were compared to experimental results from Weise and Biging [5] for flame spread in white birch fuel beds and yielded reasonable results. Morvan et al. [6] reported the interaction of two fire fronts using a two-dimensional physical model (FIRESTAR) and a three-dimensional physical model, Wildland–Urban Interface Fire Dynamics Simulator (WFDS). Comparisons of a single-head fire and two fire fronts were in good agreement between the two models.

Simulations in large-scale computational fluid dynamics models involve length scales in the computational domain that are many orders of magnitude greater than the length scale for the flame thickness (about 0.1 mm) and even the scale of vegetative fuel elements. Attempts at resolving these small scales directly

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would result in computationally intractable simulations. For this reason, the description of wildland fire propagation relies on the rational averaging of physics that occur at small scales into large-scale models on relatively coarse grids. A computational strategy in WFDS and associated codes has been to model the fuel distribution using a boundary (surface-averaged) model [7]. In addition, WFDS has a zeroth-order particle-based fuel element model that seems to be able to capture some aspects of individual plant burning [8]. Between the ability to model individual plants and the desire to model large connected segments of plants, there is a need to test the ability of models to predict the interactions and coupling between a small number of plants at a reduced (intermediate) scale. In a recent study conducted by the authors, reduced-scale experiments on little bluestem (*Schizachyrium scoparium*) grass were used to develop input parameters for WFDS related to fuel properties [9]. In the present study, we describe experiments that were conducted on single- and multiple-grass plants both with and without an external flow/wind. We then characterize and model the single- and multiple-plant fire tests using WFDS with a prescribed heat release rate (HRR) and with the particle-based fuel model. This exercise provides insight into the capabilities and deficiencies in both the prescribed HRR model and the particle-based model predictions of burning grass plants.

2. Experimental methodology

2.1. Plant choice, morphology, and characteristics

Little bluestem grass plants were collected from local plots in Austin, TX, US. The plants had an average height of 1.5 m (standard deviation of 0.14 m). Based on geometric differences of different portions of the plant, three different sections of the little bluestem grass plant were identified [9]: the bunch, stalk, and inflorescence sections, as shown in Fig. 1. From mass measurements of the plant, the lower portion of the plant (region from 0 cm to 20 cm) contained an average of 37% of the total mass (bunch region), and the upper portion of the plant (region from 20 cm to 150 cm) contained an average of 63% of the mass (stalk and inflorescence regions). The surface area to volume (SAV) ratio was calculated by using calipers to measure the dimensions of three sections of the plant. The average SAV ratio of a representative little bluestem plant was calculated as 9270 m^{-1} [9]. The fuel moisture content (FMC) of each plant was determined by measuring the mass of a small plant sample (which included all three regions of the plant) before each test and oven drying the sample. For the oven-drying process, after a 2-h period of drying at 101 °C, the grass samples were weighed at 30-min intervals. If the mass of the samples did not change significantly between weighing intervals, then the dry mass of the sample was calculated as $\mathrm{FMC} = (m_{wet} - m_{dry})/m_{dry} \times 100$.

2.2. Experimental setup

Experiments were conducted within a fire testing structure at The University of Texas at Austin (UT Austin). The fire testing structure had interior measurements of 5.82 m (length) by 4.78 m (width) by 2.44 m (height). The exterior doors were open for all of the tests, except for the multiple-plant no-wind HRR characterization tests, in which all of the doors and vents were closed. The fire testing structure was instrumented with 32 thermocouples (eight thermocouple trees with four thermocouples per tree located at four heights). Two heat flux gauges (directional flame

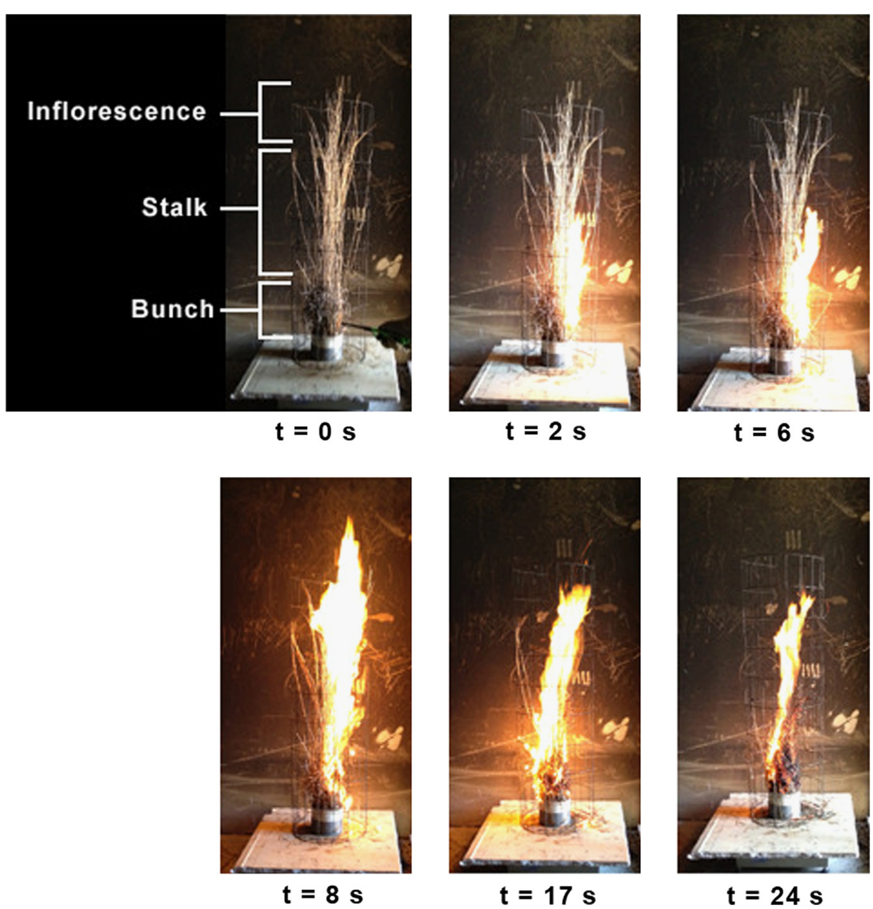

Fig. 1. Time sequence of test with single little bluestem plant [9].