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Flammability characterisation of grassland species of Songhua Jiang-Nen Jiang Plain (China) using thermal analysis

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A B S T R A C T

The aim of this work was to study the flammability of grassland fuels of the Songhua Jiang-Nen Jiang Plain in China. A Pyris Diamond TG-DTG was used, and the grassland materials examined were *Aneurolepidium chinense*, *Chloris virgata*, *Phragmites communis*, *Suaeda corniculata*, *Lathyrus quinquenervius*, *Hemarthria japonica*, *Puccinellia chinampoensis*, *Calamagrostis epigejos*, *Medicago ruthenica* and *Lespedeza davurica*. These species are very common in the Songhua Jiang-Nen Jiang Plain, and are frequently devastated by wildland fires. Mass loss is an important index for modelling wildland fires and for fire hazard studies on biomass fuels. In the TG-DTG curves, evaporation of a moisture peak and two dominating thermal oxidative degradation peaks were recorded. The relative data determined was used to compare the ignitability, combustibility and sustainability of the species. An index of integrated flammability was calculated for the examined species, and the relative flammability was ranked in the order: *Medicago ruthenica* > *Suaeda corniculata* > *Lespedeza davurica* > *Lathyrus quinquenervius* > *Chloris virgata* > *Hemarthria japonica* > *Puccinellia chinampoensis* > *Phragmites communis* > *Calamagrostis epigejos* > *Aneurolepidium chinense*. The flammability ranking of these natural fuels can be used in grassland fire management planning, fire behaviour modelling and fire hazard assessment.

1. Introduction

The effect of fire on grassland ecosystems has been an important field of research in ecological studies for several years. Nevertheless, our ability to predict the impact of a grassland fire is still limited, and this is partly due to the great variability of fire behaviour in different plant communities. Grassland fuel burning during wildland fires initially involves a series of complex processes. The study of the flammability of grassland species is very important for grassland fire management, and flammability is one of the key factors of grassland fire regimes, such as fire behaviour, fire management and fire risk.

Flammability can be defined as how easy it is for a material to catch fire, both spontaneously and through exposure to certain conditions [1]. The flammability of grassland species, according to Anderson [2] and Liodakis et al. [1], includes three components: ignitability, combustibility and sustainability. The ignitability determines how easily the fuel ignites; combustibility is the rate of burn after ignition; and sustainability measures the stability of the burning rate, or how well the fuel continues to burn.

However, the flammability of natural fuels is a complex phenomenon. In the field conditions of wildland fires, it is impossible to control and accurately measure the variable factors that affect fuel flammability [3]. Burning of biomass fuels initially involves the thermal decomposition of their volatile gaseous products during a series of endothermic reactions, and the ignition of these products in air. The heat released from the combustion, when sufficient, causes the ignition of adjacent unburned fuel particles by propagation. Therefore, the thermal degradation process of natural fuels is decisive for wildland fire spread. Many researchers have investigated the flammability of various fuels through testing their thermogravimetric properties in the laboratory, which excluded all external factors. The thermal behaviour of natural fuels is a complex phenomenon that involves both chemical reactions and physical processes (heat and mass transfer). Susott et al. [4] and Susott [5,6] were the first to measure the heat of combustion of organic materials using the methods of linear programmed heating of milligram samples in an inert (non-oxidising) atmosphere. Then, under controlled conditions, laboratory methods were developed to study the effect of material properties and chemical composition of materials on combustibility. Various techniques have been successfully used for the thermal degradation study of fuels, e.g. differential scanning calorimetry (DSC), thermogravimetry (TG) and derivative thermogravimetry

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Nomenclature

Dur	combustion duration
$\left(\frac{dw}{dt}\right)_{max}$	maximum rate of mass loss in each stage
$\left(\frac{dw}{dt}\right)_{mean}$	mean rate of mass loss in each stage
Ign	ignitability of each species
M	mass loss in each stage
S	index of flammability
S_n	index of integrated flammability
T_b	burnout temperature in each stage
T_i	onset temperature in each stage
T_p	peak temperature in each stage

Subscripts

1	first major stage
2	second major stage
3	third major stage

(DTG) [7–9]. In addition, most laboratory experimental studies employ a single fuel property to represent flammability. Among these, the most popular are the temperature of ignition, the time to ignition (ignition delay time) and the heat content [1].

A number of tests have been proposed for the determination of burning characteristics on a laboratory scale. For example, Liodakis et al. [10] measured the ignitability of five Mediterranean forest species with a specifically designed apparatus. Grotkjær et al. [11] conducted an experimental study to determine the ignition temperature of biomass at 21% O_2, both under pulse ignition conditions and under thermogravimetric conditions. Thermal analysis has also been applied to determine the self-ignition of solid fuels, such as wood, coal, etc. [7,12–16]. Based on these references, the characterisation of ignition is complicated since the ignition temperature is not a fundamental parameter of the fuel: it depends on the sample mass, the heating rate of the particle, the surrounding gas and the indicator of ignition. In some studies, many parameters have been produced to represent the flammability. Leroy et al. [8] founded the relationship between energy and sustainability of fuels. The combustion duration was determined to express the combustibility and sustainability by calculating the first derivative of sample temperature versus oven temperature [1].

These studies have confirmed that the thermogravimetric analysis (TGA) method offers many advantages: homogeneous samples are analysed in a controlled environment with constant heating and air flow rates, thus minimising random variations and producing highly reproducible results, and the samples are ground and have approximately the same weight, thus reducing the fuel compaction problem to a minimum. Therefore, differences in the thermal behaviour of various fuels should be attributed to their chemical constituent; TGA does not require pilot ignition. Thus, species ranking based on the TGA results have produced meaningful groups of similar flammability, as verified by field observations [17].

A large number of papers have been published on the pyrolysis of different types of biomass, e.g. different wood types [18–22] and agricultural residues [23–25]. Wesołowski [26] investigated the relationship between the elemental composition of medicinal raw plant materials (44 samples of leaves and flowers) and the thermal decomposition of these samples using principal component analysis (PCA). All of those papers have drawn the conclusion that the thermal analysis technique can be used as a supporting method to determine the differences in plant raw materials in chemical analysis.

Many forest-fire researchers and wildland managers have identified some classification of individual plant species according to their potential flammability using thermal analysis methods so that the classification can be used in fuel hazard rating and fire management planning. However, a few investigators have used these methods on studies of grassland fires. With a thermogravimetric analysis apparatus, pyrolysis characteristic experiments of king grass (*Pennisetum purpureum* × *P. american*) were carried out at different heating rates [27]. Mellon and Sharma [28] determined the relationships between DTG weight-loss parameters of perennial ryegrass and dry matter digestibility.

The main purpose of the present work is to calculate the flammability of common grassland species of the Songhua Jiang-Nen Jiang Plain in China using the methods of thermogravimetric analysis, and to rank them into categories according to ignitability, combustibility and sustainability. The experiments were performed after grinding whole plant litters into a fine, uniform substance. Thus, the study eliminates the influence of plant structure and the external characteristics of combustion, and counts the main intrinsic components of the fuel (hemicellulose, cellulose and lignin). Furthermore, this research can be correlated with fire regime studies of grassland, and the flammability can be used in some applications, such as grassland fire management and fire behaviour modelling.

2. Methodology

2.1. Instrumentation

Thermogravimetric analyses were carried out using a Pyris Diamond TG-DTG, which was supported by a PC and software for control and data handling. The heat of combustion of the grassland samples was determined using an Oxygen Bomb Calorimeter, model PARR 1281.

2.2. Sample preparation

Tests were conducted on ten grass species: *Aneurolepidium chinense* (AC), *Chloris virgata* (CV), *Phragmites communis* (PCT), *Suaeda corniculata* (SC), *Lathyrus quinquenervius* (LQ), *Hemarthria japonica* (HJ), *Puccinellia chinampoensis* (PC), *Medicago ruthenica* (MR), *Lespedeza davurica* (LD) and *Calamagrostis epigejos* (CE). The selected grassland species are common in the Songhua Jiang-Nen Jiang Plain and are often devastated by grassland fires. The location where the samples were collected was at the heart of the Songhua Jiang-Nen Jiang Plain in the northwest of Changling County, Jilin Province, China, with a latitude of 44°45′N, a longitude of 123°45′E and an altitude of 160 m. The climate is semi-arid and semi-humid temperate continental monsoon mode with four clear-cut seasons. Average yearly temperature is about 4.9 °C, annual precipitation is about 400–500 mm and there are 140 days without frost. The main soil type is black soil with calcium, the pH ranges from 7.5 to 9.0 and the dominant species is *Aneurolepidium chinense*. The approximate sum of the fuel load was from 100 to 400 g/m^2, and the fuel depth was from 20 to 40 cm. The dates of collection were 17 and 18 November 2007.

The samples were prepared for thermal analysis and heat of combustion according to the following procedure: the samples were dried at 60 °C, the approximate time of drying the samples