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Fire Dangerous Properties of the Most Common Plants of Grass Ecosystems in Ukraine

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Abstract. The impact of grass fires on environment and grass ecosystems is mainly negative. The fire hazard of herbaceous plants causes the occurrence and spread of fires in herbaceous ecosystems. Various indicators, in particular the humidity of the combustible material, the self-ignition temperature, etc., can estimate it. These indicators depend on the type of plants and the natural conditions that determine the properties of the combustible materials. The goal of the research is to determine the fire hazard indicators of five the most widespread herbaceous plants in Ukrainian ecosystems (*Festuca arundinacea*, *Festuca pratensis*, *Elymus repens*, *Phleum pretense* and *Trifolium arvense*) and to substantiate these indicators due to results of thermogravimetric analysis and values of absolute humidity and self-ignition temperature. Within 5 days, the absolute humidity of the samples as well as the self-ignition temperature were determined by weight method and using the OTP testing device. Complex thermal analysis of samples was also perform using a Q-1500D derivatograph. The results of the research show that absolute humidity and self-ignition temperature of certain types of plants specify differences in their fire-fighting properties. According to the results of complex thermal analysis for each plant species, three stages occur at different temperatures: evaporation of free and bound water, self-ignition of samples and combustion of carbonized residue. The maximum exothermic effect for each plant was characterized by different value of temperature, as well as ash residue, which impedes the combustion process.

Key words: Herbaceous ecosystem, fire hazard, absolute humidity, self-ignition temperature, thermal analysis, ash content.

Introduction

Grass fires make the impact on environment and ecosystems. The soil properties are change after fires. The biodiversity of grass ecosystems is also changes. The most negative impact of fires is on fauna. However, sometimes fires make a positive impact which uses for grassland management (Pereira et al., 2017). There are several types of grass ecosystems in Europe. According to the MAES classification, they are pastures and natural grasslands (Maes et al., 2013). In East Europe there are many abandoned agricultural lands with grass cover which also belong to grass ecosystems with the same fire impact on them (Khanina et al., 2018). In general the processes of occurrence and spread of grass fires in all types of grass ecosystems are very similar and are determined by fuels characteristics. Grassy ecosystems under favorable weather and herbaceous plants'

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conditions are fire hazardous: they may effect on fire, spread of fire and cause the fires of various objects. In 2016 in Ukraine grass and shrub fires covered an area of more than 36,000 hectares, which amounts 48.3% of the total area of natural ecosystems' fires (Center of fire statistics of CTIF, 2018). The fire hazard of herbaceous plants, like other combustible materials of vegetable origin, depends most on their quantity, moisture content, specific combustion heat, surface to volume ratio, the part of minerals (ash) in their composition, as well as the bulk density (Simpson et al., 2016). Moisture content is the most important fire hazard property (Yebra et al., 2018). However, plants on a site may have different states during a given period: long-withered, recently withered, withering and alive (Cruz et al., 2016). These features are due not only to the climatic and weather conditions, but also to the biological features that cause not only the spatial structure but also the flammability of the grasses (Harris et al., 2016).

Vegetable combustible materials were studied in (Keane, 2015). There are well-known studies of the fire risk of individual plant species in the United States (Havill et al., 2015) and Mediterranean countries (Simpson et al., 2016). A review of the literature that deals with the plant flammability and the definition of flame retardant plants are provided in (Bethke et al., 2016). The classification and fire-hazard characteristics of combustible materials of vegetable origin, including herbs, is given in Amer Mehmood et al. (2017). In Ukraine the fire-hazardous properties of herbaceous plants in forest ecosystems have been studied (Kuzyk, 2019). However, by now still there was no research on the fire hazard of herbaceous plants of meadow ecosystems of Ukraine, which necessitates their carrying out.

The ignition characteristics of herbaceous plants in the field conditions are determined mainly by experimental methods, in particular, laboratory study of their fragments in terms of absolute humidity, ignition and self-ignition temperatures (Thakur et al., 2017). Thermogravimetric analysis (Thakur et al., 2017; Hlavsova et al., 2016) is one of the most promising and fast methods of investigating the combustible properties of plants and their fragments, which makes it possible to quickly investigate the processes of mass loss of combustible material upon the application of heat using derivatograph. The output of pyrolysis products depends on the biochemical composition, secondary reactions and the content and composition of the ash (Hlavsova et al., 2016), causing differences in the ability of different types of combustible materials to ignition.

To analyze the fire hazard of grassy ecosystems and to predict the fire spread, it is necessary to evaluate the fire risk of plants of individual species. This can be done using traditional fire safety methods and derivatographic method, which will not only establish the fire risk of plants of meadow ecosystems, but also provide a comparative analysis of the results obtained by different methods.

The article is dedicated to establishment of fire hazard characteristics of the most widespread representatives of Ukrainian grasslands and their justification by the values of absolute humidity, self-ignition temperature and the results of thermogravimetric analysis.

Materials and Methods

The absolute humidity of the samples was determined by weight method. The self-ignition temperature was determined using an OTP device according to the standard (DSTU 8829:2019, 2019) for solid materials. The reaction chamber inside OTP device vas preheated up to 500 Celsius degrees. Chapped and formed like tablets plant samples was putted inside chamber. The self-ignition temperature was identified by chromel-alumel thermocouple putted inside testing sample at the moment of flame apperance. The thermal analysis of the samples was performed on a Q-1500D derivatograph of the "Paulik-Paulik-Erdey" system using a computer to record an analytical signal of mass loss and thermal effects. The studies were performed dynamically with a heating rate of 5°C per minute in air. Thermal stability of the samples was studied in the temperature range of 20-1000°C. The reference substance was aluminium oxide.

The studies were conducted in May 2018. Fragments of the aerial parts of herbaceous plants were selected as the test material on May 16 on the grasslands near Lviv, Ukraine (49°53'42.2"N 24°03'52.5"E). We chose the most widespread representatives of Ukrainian grasslands in Western Ukraine (Baistruk-Hlodan & Khomiak, 2016), Western Forest-steppe (Yarmoliuk et al., 2010), Forest-steppe (Kirian et al., 2018) and widely uses for forage producing (Bugayov et al., 2008) such as: *Festuca arundinacea* Schreb., *Festuca pratensis* Huds., *Elymus repens* (L.) Could, *Phleum pretense* L. and *Trifolium arvense* L. After delivery to the laboratory, part of the material was left for further drying at a temperature of 20±2 Celsius degrees (the samples were formed and weighed) and the other part was used to determine the self-ignition temperature. In total, 18 samples with a weight of 0.05 kg were formed for each of plant species. In the next 4 days, the temperature of self-ignition was determined for the partially dried samples. Self-ignition temperature was determined by conducting 3 experiments for each type every day. Drying lasted 4 days, and on the 5th day the samples were placed in the moisture-testing oven, kept for 3 hours at 105°C and weighed. 3 samples of each plant species were tested. The masses of the samples in an absolutely dry state were used to determine their absolute humidity.

Results and Discussion

Elymus repens had the highest initial humidity and *Festuca pratensis* had the lowest initial humidity. However, on the 5th day of research, the lowest humidity was observed for *Festuca arundinacea* and *Festuca pratensis*, the highest humidity – for *Trifolium arvense* (Table 1).

The self-ignition temperature of samples is given in Table 2. It was determined every day during the drying process as well as for a completely dry condition. The samples were placed to the cylindrical furnace of the OTP device heated to 550°C, and the self-ignition temperature was determined by the thermocouples disposed inside the samples.

On the first day of the studies, the temperature of self-ignition was the highest for all plants and ranged from 432 to 493°C, and further decreased daily. *Elymus repens* had the highest, and *Festuca pratensis* had the lowest self-ignition temperature. On the 5th day of research, the temperature of self-ignition decreased for all species by approximately 100°C and remained the lowest for *Festuca pratensis*, while *Phleum pretense* had the highest self-ignition temperature. For a completely dry condition, the *Trifolium arvense* samples had the lowest self-ignition temperature (265°C), while the *Festuca pratensis* samples and the *Trifolium arvense* samples had the highest auto-ignition temperatures (296 and 298°C).

As can be seen from the results of studies, the fire hazard characteristics of different plants vary differently during drying, which indicates their dependence on the species. To determine the causes of such differences, a complex thermal analysis of the samples was conducted, the results of which are presented on thermograms (Fig. 1). The average weight of the samples was 100 mg.

Table 1. Absolute humidity (per cent) of plant samples during their drying.

Herbaceous plant	Date of test				
	16.05	17.05	18.05	19.05	20.05
Festuca arundinacea	307.46	174.21	108.58	26.71	8.03
Festuca pratensis	382.55	192.09	90.79	16.78	9.00
Elymus repens	630.57	275.51	89.44	45.81	12.37
Phleum pretense	277.56	225.01	134.29	53.41	17.39
Trifolium arvense	471.56	308.97	202.28	76.47	19.59

Table 2. Self-ignition temperatures (°C) of plant samples in the process of drying them.

Herbaceous plant	**Date of test**					**Absolutely dry state**
	16.05	**17.05**	**18.05**	**19.05**	**20.05**	
Festuca arundinacea	451	440	419	395	342	273
Festuca pratensis	432	408	362	346	326	296
Elymus repens	493	481	465	414	374	283
Phleum pretense	457	446	439	421	380	298
Trifolium arvense	490	473	443	414	358	265

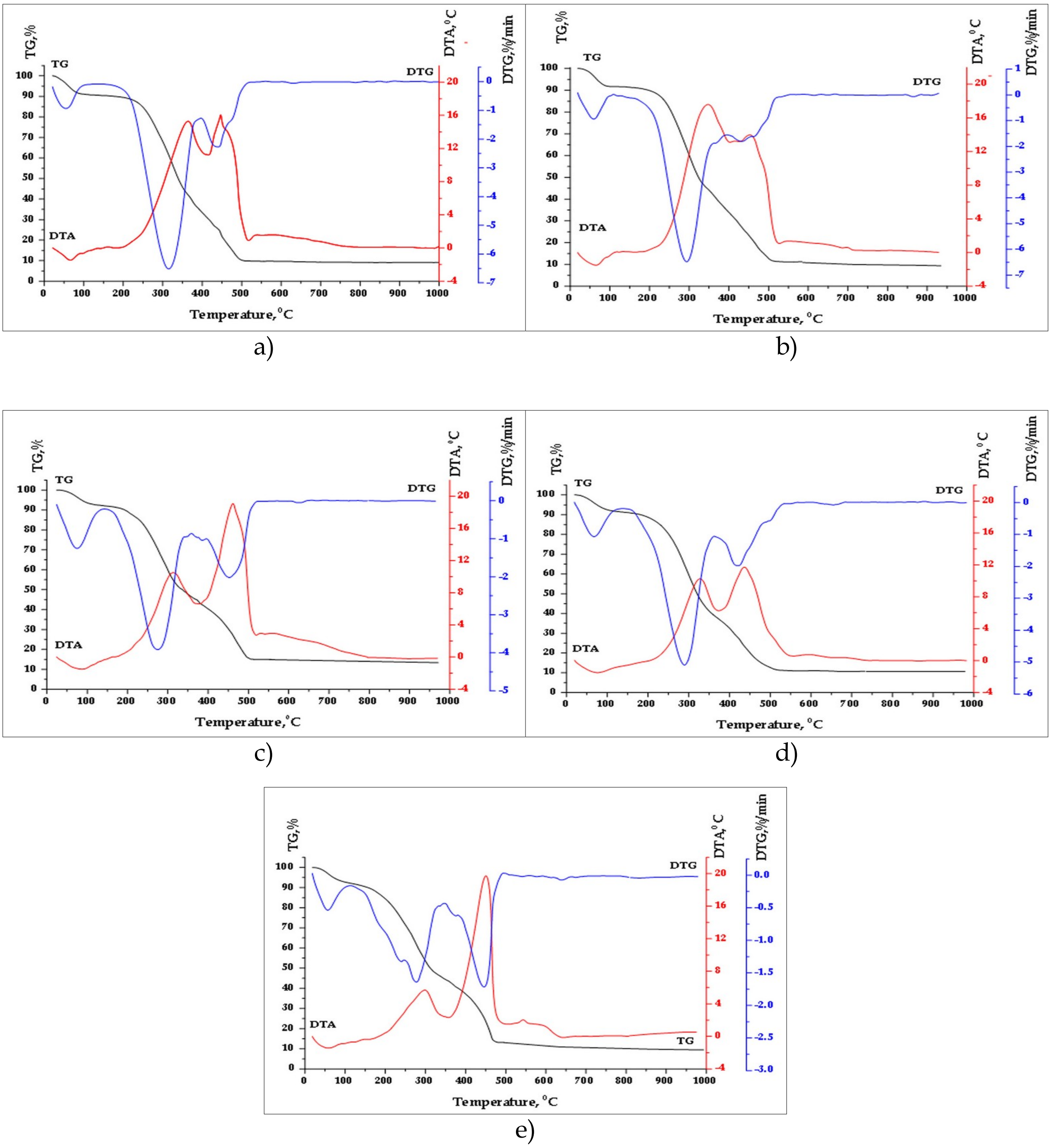
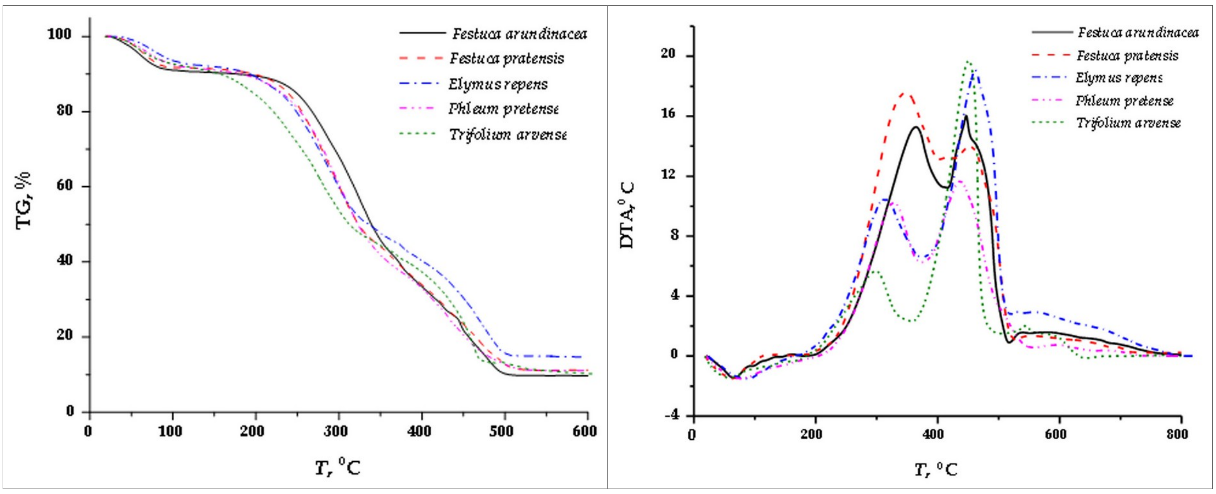


Fig. 1. Thermograms of herbaceous plants of meadow ecosystems: a) *Festuca arundinacea*; b) *Festuca pratensis*; c) *Elymus repens*; d) *Phleum pretense*; e) *Trifolium arvense*.

Thermogravimetric (TG) curves illustrate the weight loss of the samples during the heating process. Differential thermal analysis (DTA) curves indicate the sign and magnitude of the thermal effect of the process. And the curves of differential thermogravimetric analysis (DTG) are the result of differentiation of the TG curves and correspond to the weight loss velocity at the appropriate temperature. In Fig. 2 TG and DTA curves of the samples are shown for comparison.

In the table 3 the results of thermogravimetric analysis of the samples and the maximum temperature of the first exothermic effect (*Tmax*,°C) corresponding to the flame combustion of the samples, are shown. For each of plant species three stages characterizing the corresponding pyrological properties are identified. Their temperature intervals are different for each plant species, which indicates unequal fire hazard characteristics.

In all the tested samples, the endothermic processes occur in the temperature range 20–245°C (stage I). These processes are accompanied by the weight loss of the samples. In this temperature range, the evaporation of unbound water and the release of constitutional water that is part of the plant material has place. It should be noted that the *Trifolium arvense samples* had the highest content of unbound and constitutional water (15.01%), which was lost in the temperature range of 20–197°C.



a) b)

Fig. 2. Thermogravimetric curves of herbaceous plants of grassy ecosystems:
a) TG curves of the samples; b) DTA curves of the samples.

Table 3. Results of thermogravimetric and differential thermal analyzes of the samples.

Herbaceous plant	Stage	Temperature range, °C	Mass loss, %	Maximum temperature of the first exothermic effect Tmax, °C
Festuca arundinacea	I	20 – 183	10.08	364
	II	183 – 397	55.64	
	III	397 – 1000	25.12	
Festuca pratensis	I	20 – 184	10.10	347
	II	184 – 400	56.24	
	III	400 – 1000	26.03	

Elymus repens	I	20 – 195	10.21	316
	II	195 – 366	44.45	
	III	366 – 1000	32.46	
Phleum pretense	I	20 – 211	12.29	333
	II	211 – 373	49.94	
	III	373 – 1000	25.62	
Trifolium arvense	I	20 – 197	15.01	300
	II	197 – 349	40.27	
	III	349 – 1000	35.54	

The samples of *Festuca arundinacea* contain the smallest amount of water (10.08%), which is lost in the temperature range of 20–183°C. Such results are in good agreement with the data on the humidity of the samples obtained during their drying.

Intensive destruction of the samples in the second stage, which is illustrated by rapid weight loss, begins at temperatures higher than 183–211°C. The points of extremum on the DTA and DTG curves of the samples differ significantly, indicating differences in their chemical composition.

In the temperature range of 183–400°C, there are a number of complex processes: along with the endothermic processes of pyrolysis of the samples, exothermic oxidation processes take the place, leading to the combustion of the decomposition products. The DTA curves exhibit clear exothermic effects in this temperature range.

It should be noted that the *Trifolium arvense* samples are characterized by the lowest thermal resistance. The thermo-oxidation processes in this sample flow at lower temperatures (Fig. 1), the maximum of the exothermic effect (300°C), which corresponds to the flame combustion of the decomposition products of the sample, is displaced to the area of lower temperatures in comparison with other samples (Fig. 2).

Samples of *Festuca arundinacea* and *Festuca pratensis* exhibit the highest thermal resistance. The temperature interval of intense mass loss, which corresponds to the combustion of the decomposition products, is displaced to the area of higher temperatures (Fig. 1). The maximums of the exothermic effect of these samples are manifested on the DTA curves at the highest temperatures as compared to other samples (Fig. 2). For the sample of *Festuca arundinacea*, it is observed at a temperature of 364°C, and for the sample of *Festuca pratensis* – at a temperature of 347°C. Samples of *Elymus repens* and *Phleum pretense* demonstrate moderate thermal resistance. The maximums of the exothermic effects of these samples correspond to temperatures of 316°C and 33°C.

The results of thermal analysis are satisfactorily consistent with the data obtained in studies on the determination of self-ignition temperatures of samples.

In the temperature range 349-1000°C (stage III), the carbonized residue formed during the flame combustion of the samples is combusted. On the DTA curves of the samples there is a pronounced exothermic effect, the points of extremum of which, as in stage II, also differs from each other and indicate the difference in chemical composition. After completion of the combustion a small quantity of residue (ash) remains. For samples of *Elymus repens* and *Phleum pretense* this quantity is the largest.

Studies have only been conducted on the 5 most common herbaceous plants since we cannot describe every part of a grassland that can sometimes number more than 150 species. However, the focus of ignition occurs on a small part of the site and therefore is determined by the properties of the dominant plants. In addition, single plants do not significantly affect the spread of fire.

Conclusions

The fire hazard of herbal plants is caused by their physical and chemical properties. It depends significantly on their species and conditions and causes differences in the processes of ignition and spread of fires. Differences in fire hazard of different plants can affect the occurrence of fires, as well as the rate of fire spread in grassy ecosystems. As a result of laboratory thermogravimetric studies, it is established that the highest thermal resistance due to the exothermic effect is peculiar to *Festuca arundinacea* and *Festuca pratensis*. The largest is the ash residue for *Elymus repens* and *Phleum pretense*, which indicates that they have less ability to ignite in comparison with other plant species. Fire hazard by values of self-ignition temperature depends on the humidity of the plants, which decreases in the process of drying, and at high humidity may be lower for some types of plants, in particular the *Elymus repens* and *Trifolium arvense*, and at low humidity – for others types, in particular the *Elymus repens* and *Phleum pretense*.

To evaluate the fire hazard of a particular ecosystem, it is necessary to explore the plants that are part of it. It is advisable to take into account the difference between the fire hazard properties of herbaceous plants in the analysis of the fire danger of the grassy areas, prediction the spread of fires and their extinguishing. Plants with lower fire hazard characteristics should be planted near high-risk objects. For the territories of nature reserves, taking into account the fire-fighting properties of the most common herbs will minimize the risk of fires and their spread to forests. Because it is not possible to change the species composition in grasslands, which has a high fire risk, we have to use grass mowing before the end of a vegetation period where it possible and additionally introduce restrictive measures for mitigate the fire hazard.

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