Fire Technology Transfer Note

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Ignition Thresholds in Grassland Fuels and Management Applications for Public Conservation Land in Canterbury

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Introduction

There is a need to protect important grassland and wetland areas from fire. New Zealand's Department of Conservation (DOC) is responsible for fire protection on significant areas of grasslands, many of which have open access for public recreation (e.g. off-road vehicles, camping, tramping, etc.).

The main objective of this study was to determine the factors that trigger successful ignition in grassland fuels. The study was undertaken as a Masters project (Wakelin, 2010) funded by DOC, to aid fire managers with decisions around activity controls on public conservation land during periods of elevated fire danger.

Ignition of fully cured (dead) tussock and exotic grass fuels was investigated by simulating five different ignition sources: hot metal (hot parts from off-road vehicles), hot carbon emissions (hot particles from vehicle exhausts), metal sparks (from grinding operations), organic embers (smouldering debris dropped onto grass fuels from hot vehicle parts) and open flame (from matches or lighters).

The results have been used to develop decision-support tools that will improve fire management strategies and tactics, as decisions need to be guided and supported by science-based knowledge and tools. Use of these tools will help to mitigate against wildfires before they start through a range of reduction and readiness activities.

Background

Over thousands of years, natural and human influences have resulted in the formation of extensive tussock grasslands. They are now considered to be natural vegetation cover and are maintained by fire and grazing in many parts of the country (Ogden *et al*., 1998; McGlone, 2001). When tussock grasses (e.g. *Chionochloa* spp., *Poa cita* and *Festuca novae-zelandiae*) die the leaf bases and sheaths dry out and build-up around the plant, causing them to be highly flammable, even during the winter. Exotic species (e.g. A*grostis capillaris* and *Anthoxanthum odoratum*) do not have a build-up of cured grass at their base, but remain highly flammable when cured. Wetland vegetation, comprising red tussock (*Chionochloa rubra*), sedges (*Carex* spp.), moss (*Sphagnum cristatum*), and other hydrophilic plants (e.g. *Olearia bullata* and *Bulbinella angustifolia*), is also susceptible to ignition, usually after periods of dry weather.

In Canterbury, grasslands and wetlands are commonly exposed to drought and foehn winds. These conditions, combined with highly combustible fine fuels, increase the likelihood of fires throughout the region. In October 2007, DOC opened Hakatere Conservation Park, located in the Ashburton Lakes basin between the Rakaia and Rangitata rivers. Over 50% of the park is covered by intensive management areas of the Ō Tū Wharekai wetland, which supports unique plants and animals that are vulnerable to wildfire. This high country area features tussock grasses interspersed with exotic grasses.

Fire risk in this area is exacerbated by two key factors: land-use change due to tenure review and increased recreational and occupational users. Greater awareness of recreational areas and increased public access to land are causing more people to visit sensitive grasslands and wetlands, augmenting the fire risk. Furthermore, grassland fuel loads are increasing due to land-use change, meaning less grazing and less controlled burning. These factors, combined with severe fire weather conditions, raise the likelihood of high-intensity fires that are difficult to control.

Research Approach and Methods

A literature review examined previous research that investigated ignition behaviour of grass and other fine fuels, and identified key attributes of the five ignition sources to be tested. Two types of 100% cured grass samples were tested against each of these ignition sources: a native hard tussock (*Festuca novae-zelandiae*), and mixed exotic grasses (mostly brown top, *Agrostis capillaris*, with small amounts of sweet vernal, *Anthoxanthum odoratum*).

Laboratory experiments were conducted across a range of grass fuel moisture levels to determine ignition success resulting from contact between the ignition sources and the grass samples for a specified time period. Field experiments were then used to verify laboratory results. At the end of each test, ignition was classified as either a success (flaming or glowing), or failure (non-ignition).

The experimental design included the following assumptions:

- Experiments tested for fuel ignition only and did not consider fire spread.
- Arrangement of grass in the samples was consistent.
- If an ignition source was present (in the laboratory or the field), it would come into contact with grassland fuels.
- Experiments tested for worst-case scenarios that would exist in the field, including fully-cured grass, moisture content levels lower than 3%, relative humidity (RH) < 50% and ambient temperature > 18ºC.
- Ambient temperature and RH (averages of 21.8ºC and 34.7% respectively) were relatively constant in the laboratory.
- The effect of wind was simulated using a three-speed fan (0, 1, 2 m/s, i.e. 0, 3.6, 7.2 km/h).

Logistic regression was used to model the probability of ignition from each ignition source. The study reported ignition thresholds in terms of 50% (possible) and 70% (likely) probabilities of ignition success. As in the similar study for gorse scrub fuels (Anderson, 2009; Scion, 2009), moisture contents were converted to the equivalent Fine Fuel Moisture Code (FFMC) values from the Fire Weather Index (FWI) System (Van Wagner, 1987) component of the New Zealand Fire Danger Rating System to aid understanding and application of the decision-support tools.

Figure 1. Grass sample held in contact with the copper hot plate in vertical orientation (top) and ignition testing of an exotic sample at the manifold of an ATV (bottom).

Sample Preparation
In the laboratory, all grass samples were arranged to represent their natural orientation in the field (standing up right in a clump, see Figure 1 top). Sample moisture content was varied between 0% and 175% based on oven-dry weight.

Hot Metal Contact
This experiment simulated ignition through contact with hot metal surfaces, such as the exhausts from off-road utility or All-Terrain Vehicles (ATVs), or from other hot equipment such as industrial lawn mowers or brush cutters (Figure 1). This involved a copper hot plate heated to temperatures of 365 – 495°C being held in contact with grass samples in both horizontal and vertical orientations.

Maximum contact time between the sample and the hot plate was five minutes, and wind speed was set at 0, 1 and 2 m/s (0, 3.6 & 7.2 km/h). Field experiments tested actual exhaust systems of an unloaded 2006 4WD Nissan Navara (turbo diesel with manual transmission, where temperatures ranged from 213 to 229ºC), and of an unloaded ATV (Honda Foreman 400, where temperatures ranged from 427 to 512ºC).

Hot Carbon Emissions
This experiment simulated hot carbon particles and hot exhaust gases exiting a vehicle exhaust. This was achieved using a steel pipe with a funnel at the sample end. Hot carbon (ordinary wood pellets heated until glowing) was broken into particles of 1.0 mm diameter and dropped into the funnel every 30 seconds (Figure 2). A hot air gun set at 200ºC blew the hot carbon particles onto the sample. Trials lasted five minutes.

The 4WD Nissan used for the hot metal field experiments was also used for the hot carbon emissions field experiment; however, exhaust gas temperature did not exceed 115ºC, so results were difficult to compare with laboratory findings.

Metal Sparks
This experiment simulated hand-held grinding operations and/or sparks produced by outdoor power equipment and machinery in the field (Figure 3). A hand-held grinder (surface speed of 80 m/s) ground steel for a maximum of 30 seconds, showering the grass sample with sparks. Wind speed was again set at 0, 1 and 2 m/s. Field trials were conducted in the same manner as the laboratory experiments.

Figure 2. Hot carbon emissions experimental set-up in the laboratory (top) and field (bottom).

Figure 3. Metal sparks experimental set-up in the laboratory (top) and field (bottom).

Organic Embers
This experiment simulated heated organic material that falls onto dead grass after accumulating on a moving vehicle (usually encased in dry mud). Grass and soil were pre-moulded into disks that were heated to an average surface temperature of 400ºC. The disks were placed on top of the grass samples and left for five minutes (Figure 4). Wind speed was again set to 0, 1 and 2 m/s. Ignition of samples in the laboratory was not observed, so no comparative field experiments were completed.

Open Flame
This experiment represented careless use of an open flame, for example from a gas cooker being knocked over. A 2 cm sized flame was produced using an ignition apparatus (representing a propane torch or barbeque lighter) and wind speed was again set to 0, 1 and 2 m/s (Figure 5). Maximum contact time between the grass sample and the flame was limited to 20 seconds. Field trials were conducted in the same manner as the laboratory experiments.

Key Findings

No difference was observed between the ignition behaviour of tussock and exotic grasses.

Hot Metal Contact
Hot plate temperature, orientation (horizontal/vertical), and wind speed were the main factors that determined ignition behaviour of the grass samples subjected to contact with heated metal surfaces (such as vehicle exhausts) (Figure 6).

Ignition curves and thresholds were determined for a fuel moisture content of 1%, but in the field fuels are unlikely to dry to this level, with the lowest moisture levels likely to reach 3% under extreme weather conditions (Pyne *et al*., 1996). Hot plate temperatures as low as 390ºC triggered successful grass sample ignitions. Ignitions were also observed at moisture content levels up to 111%, indicating that the hot plate caused samples to dry to their ignition point.

Field experiments showed that contact with the exhaust of the unloaded Nissan 4WD (where temperatures were less than 230ºC) posed little ignition risk in cured grasses. On the other hand, the unloaded ATV was found to pose a high ignition risk, as the exhaust system reached higher temperatures (427 - 512ºC) and all trials were successful in the field.

Hot Carbon Emissions
Grass moisture content was the main factor that determined ignition behaviour of grass samples exposed to hot carbon emissions (Figure 7); however, predictions were better when the ambient temperature and relative humidity were included in the model.

Ignition was possible for samples with grass moisture levels up to 116%, indicating that the exhaust gas

Figure 4. A tussock sample with a disk placed on top (left), and organic embers in moulds (right).

Figure 5. Open flame experimental set-up (left), and exotic grass sample ignition (right).

caused the samples to dry to their ignition point. No ignitions occurred in the field, indicating that the risk of ignition from the well maintained Nissan 4WD vehicle was low, where exhaust gas temperature only reached 115ºC. As a result, further testing using a wider range of vehicle types and models is necessary.

Metal Sparks

Moisture content was the key factor that determined the ignition behaviour of grass samples exposed to metal sparks (Figure 8). Ignition was possible for samples with moisture levels up to 69%. All ignitions were successful in the field, indicating that grinding operations pose a significant rural fire risk in fine grassland fuels.

Open Flame

Both moisture content and wind speed were factors that determined the ignition behaviour of grass samples exposed to open flame contact (Figure 9). Without the presence of wind (0 m/s), ignition was possible for samples with moisture levels up to 32%. The presence of wind (1 m/s) increased the probability of ignition of samples at higher moisture levels, where all ignitions were successful at moisture contents less than 54%.

For higher wind speed (2 m/s), results were variable due to the flame being blown out and requiring it to be relit. As a result, the probability curve for the ignition data obtained with a wind speed of 2 m/s is not reported. All ignitions were successful in the field, confirming that open flame ignition sources pose a significant rural fire risk in fine grassland fuels.

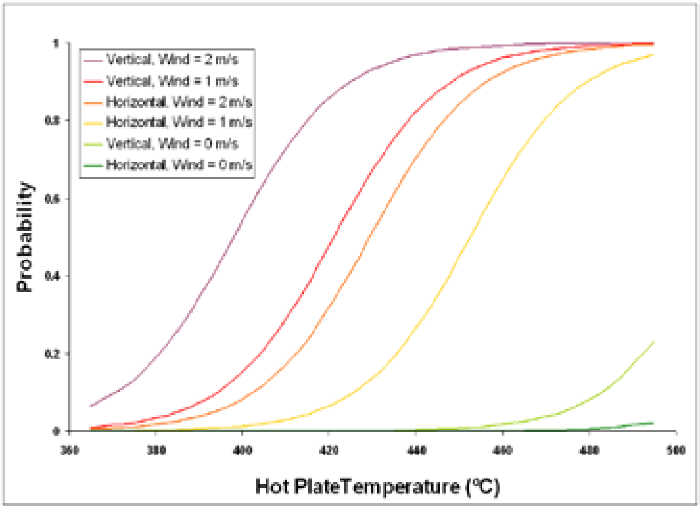

Figure 6. Probability of ignition success of grasses for six different plate orientation and wind speed scenarios tested in the laboratory, with moisture content set to 1%.

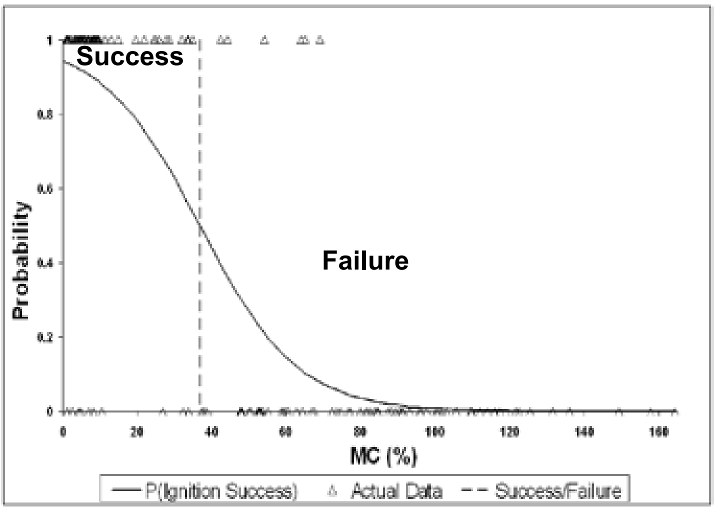

Figure 8. Ignition probability (categorised into success or failure) for grasses from metal sparks, with the probability curve based on grass moisture content.

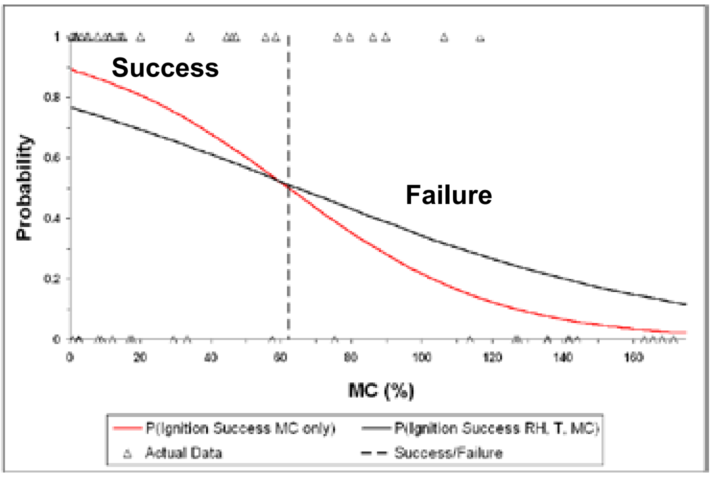

Figure 7. Ignition probability (categorised into success or failure) for grasses from hot carbon emissions, with the probability curves shown based on grass moisture content only (red line) and on ambient temperature, relative humidity and grass moisture content (black line).

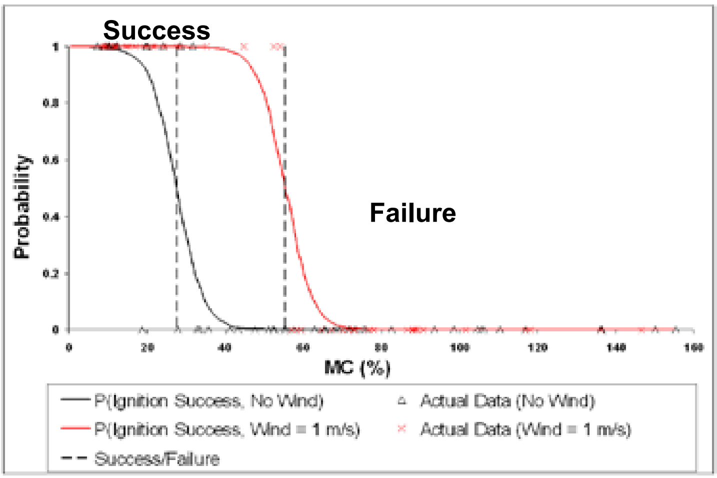

Figure 9. Ignition probability (categorised into success or failure) for grasses exposed to open flame contact, with the probability curves for wind speeds of 0 m/s (black line) and 1 m/s (red line) and the dashed lines indicating the success/failure boundaries.

Management Applications

The results from this study provide useful information for fire managers in Canterbury and other regions of New Zealand. These results also add to the understanding of moisture thresholds for ignition and spread in gorse scrub fuels (Anderson, 2009; Scion, 2009). Grass ignition threshold values, for a probability of ignition of 50%, are provided in terms of moisture content (MC%), Fine Fuel Moisture Code (FFMC) and contact temperature (hot metal only) (Table 1). A series of decision-support tools have also been created for four of the five ignition sources tested (Appendices I to IV).

These decision-support tools can be used to support fire management decisions to mitigate against the four ignition sources reported in the Appendices. Each Appendix includes two decision-support tools: ignition thresholds in terms of a 70% probability of ignition, and a table including different ignition probabilities depending on FFMC and other relevant conditions.

For example, the first table in Appendix I can be used to support decisions around closing certain off-road tracks to vehicle access once the FFMC reaches a certain level. The second table in Appendix I is used to predict the probability of ignition depending on FFMC and hot metal temperature. The predictions are colour-coded for different ignition probability levels:

Colour	Probability range	Likelihood of ignition
Green	0 to 0.49	Unlikely
Yellow	0.50 to 0.70	Possible
Orange	0.71 to 0.80	Likely
Red	0.81 to 1.00	Highly probable

When fire danger is elevated, these tools can support decisions to restrict the use of each ignition source, and can also be used to create guidelines for their safe use in grasslands. The information presented in this study can help educate recreational vehicle users of grassfire risk, and of the need for vehicle maintenance and other fire prevention actions.

It is important that fire managers understand the limitations of this study before using the decision-support tools. The tools should be used with caution if applied to conditions beyond those specified in the assumptions (i.e. degree of curing, ambient temperature, relative humidity, and wind speed). Note that the maximum wind speed at the experiment level was set to 2 m/s (7.2 km/h) due to time and resource constraints, and field conditions are frequently exposed to wind speeds more than five times this speed.

Furthermore, the ignition threshold and probability values only provide indications around the likelihood of ignition success, not fire spread. The New Zealand Fire Danger Rating System (NZFDRS) can be used to help predict the likelihood of fire spread if an ignition is successful. The results of this study are relevant and applicable, but also indicate that there is a significant amount of future work to be undertaken in this area.

Table 1. Summary of ignition thresholds for a **50% probability** for each ignition source under different scenarios.

Ignition source	Predictor variables	Scenario	Ignition threshold *	
			FFMC	MC or ºC
Hot Metal	MC (%), wind speed, hot plate temperature (ºC), orientation (horizontal)	Vertical, Wind = 2 m/s, MC = 1%	100	398ºC
		Vertical, Wind = 1 m/s, MC = 1%	100	421ºC
		Horizontal, Wind = 2 m/s, MC = 1%	100	429ºC
		Horizontal, Wind = 1 m/s, MC = 1%	100	452ºC
Hot Carbon Emissions	MC (%)	N/A	52	65% MC
Metal Sparks	MC (%)	N/A	69	37% MC
Open Flame	MC (%), wind (1 m/s)	No wind	75	28% MC
		Wind = 1 m/s	57	55% MC

* These are different than the 70% probability of ignition thresholds identified in the decision support tools included in Appendices 1-4.

Recommendations for Future Work

Further validation and testing of the methods and results found in this study should be undertaken, including:

- Conducting experiments under a broader range of conditions, especially higher ambient temperatures and lower relative humidity levels.
- Increasing the number of field tests, vehicle types and models, and testing grass samples *in situ*.
- Extending the work to include samples under a range of curing values, different grass types/species, and investigation of fire spread once successful ignition has occurred.
- Validating or, if required, developing new models for predicting moisture content in grass fuels based on weather and/or FWI System components.

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Appendix 1 (Hot metal contact)

Ignition thresholds of grasses from **hot metal contact** (e.g. exhausts of utility vehicles and ATVs), based on metal surface temperature and orientation, windspeed, and Fine Fuel Moisture Code (FFMC) or grass moisture content (MC%).

Managers should assume that all temperatures listed in these tables can be reached by ATVs while driving or idling in the field (maximum exhaust system temperature recorded in this study was 512ºC at the ATV's manifold).

The results of this study indicate that maintained diesel utility vehicles (unloaded, on flat terrain and driving at normal off-road speeds) pose reduced ignition risk in grassland fuels as their exhaust system temperatures are less likely to reach ignition threshold temperatures.

Ignition thresholds for management applications (Probability of ignition = 70%)					
Scenario	FFMC / MC (%)				
	100 1%	91 10%	82 20%	67 40%	55 60%
Vertical orientation - full contact between grass fuels and hot metal. Wind speed = 2m/s	408ºC	411ºC	413ºC	419ºC	424ºC
Vertical orientation - full contact between grass fuels and hot metal. Wind speed = 1m/s	432ºC	434ºC	437ºC	442ºC	448ºC
Horizontal orientation - contact between the tops of grass fuels and hot metal. Wind speed = 2 m/s	440ºC	442ºC	445ºC	450ºC	456ºC
Horizontal orientation - contact between the tops of the grass fuels and hot metal. Wind speed = 1 m/s	463ºC	465ºC	468ºC	474ºC	479ºC

Decision support table of ignition probabilities for grasses from **hot metal** contact such as vehicle exhausts. Ignition success is dependent on Fine Fuel Moisture Code (FFMC) or grass moisture content (MC%), wind speed and hot metal temperature.

Scenario with highest ignition risk: Wind Speed = 7 km/h (2 m/s) AND full contact with grass fuels.															
FFMC	**MC**	**Temperature (ºC)**													
		365	**375**	**385**	**395**	**405**	**415**	**425**	**435**	**445**	**455**	**465**	**475**	**485**	**495**
100	1%	0.06	0.13	0.26	0.44	0.64	0.80	0.90	0.95	0.98	0.99	1.00	1.00	1.00	1.00
96	5 %	0.06	0.12	0.24	0.42	0.62	0.79	0.89	0.95	0.98	0.99	1.00	1.00	1.00	1.00
91	10%	0.05	0.11	0.22	0.39	0.59	0.77	0.88	0.94	0.97	0.99	0.99	1.00	1.00	1.00
86	15%	0.05	0.10	0.20	0.37	0.57	0.75	0.87	0.94	0.97	0.99	0.99	1.00	1.00	1.00
82	20%	0.04	0.09	0.19	0.34	0.54	0.73	0.86	0.93	0.97	0.99	0.99	1.00	1.00	1.00
78	25%	0.04	0.08	0.17	0.32	0.51	0.70	0.84	0.92	0.96	0.98	0.99	1.00	1.00	1.00
74	30%	0.03	0.08	0.16	0.29	0.48	0.68	0.83	0.92	0.96	0.98	0.99	1.00	1.00	1.00
70	35%	0.03	0.07	0.14	0.27	0.46	0.65	0.81	0.91	0.96	0.98	0.99	1.00	1.00	1.00
67	40%	0.03	0.06	0.13	0.25	0.43	0.63	0.79	0.90	0.95	0.98	0.99	1.00	1.00	1.00
63	45%	0.03	0.05	0.12	0.23	0.40	0.60	0.77	0.89	0.95	0.98	0.99	1.00	1.00	1.00
60	50%	0.02	0.05	0.11	0.21	0.37	0.58	0.75	0.87	0.94	0.97	0.99	0.99	1.00	1.00
57	55%	0.02	0.04	0.10	0.19	0.35	0.55	0.73	0.86	0.93	0.97	0.99	0.99	1.00	1.00
55	60%	0.02	0.04	0.09	0.18	0.32	0.52	0.71	0.85	0.93	0.97	0.98	0.99	1.00	1.00

Scenario: Wind Speed = 3.5 km/h (1 m/s) AND full contact with grass fuels.															
FFMC	MC	Temperature (ºC)													
		365	375	385	395	405	415	425	435	445	455	465	475	485	495
100	1%	0.01	0.02	0.05	0.11	0.21	0.38	0.58	0.76	0.87	0.94	0.97	0.99	0.99	1.00
96	5 %	0.01	0.02	0.05	0.10	0.20	0.36	0.56	0.74	0.86	0.94	0.97	0.99	0.99	1.00
91	10%	0.01	0.02	0.04	0.09	0.18	0.33	0.53	0.72	0.85	0.93	0.97	0.99	0.99	1.00
86	15%	0.01	0.02	0.04	0.08	0.16	0.31	0.50	0.69	0.84	0.92	0.96	0.98	0.99	1.00
82	20%	0.01	0.02	0.03	0.07	0.15	0.28	0.47	0.67	0.82	0.91	0.96	0.98	0.99	1.00
78	25%	0.01	0.01	0.03	0.07	0.14	0.26	0.45	0.64	0.80	0.90	0.95	0.98	0.99	1.00
74	30%	0.01	0.01	0.03	0.06	0.12	0.24	0.42	0.62	0.79	0.89	0.95	0.98	0.99	1.00
70	35%	0	0.01	0.02	0.05	0.11	0.22	0.39	0.59	0.77	0.88	0.94	0.97	0.99	0.99
67	40%	0	0.01	0.02	0.05	0.10	0.20	0.37	0.57	0.75	0.87	0.94	0.97	0.99	0.99
63	45%	0	0.01	0.02	0.04	0.09	0.19	0.34	0.54	0.72	0.86	0.93	0.97	0.99	0.99
60	50%	0	0.01	0.02	0.04	0.08	0.17	0.32	0.51	0.70	0.84	0.92	0.96	0.98	0.99
57	55%	0	0.01	0.02	0.03	0.07	0.15	0.29	0.48	0.68	0.83	0.91	0.96	0.98	0.99
55	60%	0	0.01	0.01	0.03	0.07	0.14	0.27	0.45	0.65	0.81	0.91	0.96	0.98	0.99

Scenario: Wind Speed = 2 m/s AND contact with the tops of grass fuels.															
FFMC	MC	Temperature (ºC)													
		365	375	385	395	405	415	425	435	445	455	465	475	485	495
100	1%	0.01	0.01	0.03	0.06	0.12	0.24	0.41	0.61	0.78	0.89	0.95	0.98	0.99	1.00
96	5 %	0	0.01	0.02	0.05	0.11	0.22	0.39	0.59	0.77	0.88	0.94	0.97	0.99	0.99
91	10%	0	0.01	0.02	0.05	0.10	0.20	0.37	0.57	0.75	0.87	0.94	0.97	0.99	0.99
86	15%	0	0.01	0.02	0.04	0.09	0.19	0.34	0.54	0.72	0.86	0.93	0.97	0.99	0.99
82	20%	0	0.01	0.02	0.04	0.08	0.17	0.32	0.51	0.70	0.84	0.92	0.96	0.98	0.99
78	25%	0	0.01	0.02	0.03	0.07	0.15	0.29	0.48	0.68	0.83	0.91	0.96	0.98	0.99
74	30%	0	0.01	0.01	0.03	0.07	0.14	0.27	0.45	0.65	0.81	0.91	0.96	0.98	0.99
70	35%	0	0.01	0.01	0.03	0.06	0.13	0.25	0.43	0.63	0.79	0.90	0.95	0.98	0.99
67	40%	0	0.01	0.01	0.03	0.05	0.12	0.23	0.40	0.60	0.77	0.88	0.95	0.98	0.99
63	45%	0	0	0.01	0.02	0.05	0.10	0.21	0.37	0.57	0.75	0.87	0.94	0.97	0.99
60	50%	0	0	0.01	0.02	0.04	0.09	0.19	0.35	0.55	0.73	0.86	0.93	0.97	0.99
57	55%	0	0	0.01	0.02	0.04	0.09	0.17	0.32	0.52	0.71	0.85	0.93	0.97	0.98
55	60%	0	0	0.01	0.02	0.04	0.08	0.16	0.30	0.49	0.69	0.83	0.92	0.96	0.98

Scenario: Wind Speed = 1 m/s AND contact with the tops of grass fuels.															
FFMC	MC	Temperature (ºC)													
		365	375	385	395	405	415	425	435	445	455	465	475	485	495
100	1%	0	0	0	0.01	0.02	0.04	0.10	0.19	0.35	0.55	0.73	0.86	0.93	0.97
96	5 %	0	0	0	0.01	0.02	0.04	0.09	0.18	0.33	0.53	0.72	0.85	0.93	0.97
91	10%	0	0	0	0.01	0.02	0.04	0.08	0.16	0.31	0.50	0.69	0.84	0.92	0.96
86	15%	0	0	0	0.01	0.02	0.03	0.07	0.15	0.28	0.47	0.67	0.82	0.91	0.96
82	20%	0	0	0	0.01	0.01	0.03	0.07	0.14	0.26	0.44	0.64	0.80	0.90	0.95
78	25%	0	0	0	0.01	0.01	0.03	0.06	0.12	0.24	0.42	0.62	0.78	0.89	0.95
74	30%	0	0	0	0	0.01	0.02	0.05	0.11	0.22	0.39	0.59	0.77	0.88	0.94
70	35%	0	0	0	0	0.01	0.02	0.05	0.10	0.20	0.36	0.56	0.74	0.87	0.94
67	40%	0	0	0	0	0.01	0.02	0.04	0.09	0.19	0.34	0.54	0.72	0.86	0.93
63	45%	0	0	0	0	0.01	0.02	0.04	0.08	0.17	0.31	0.51	0.70	0.84	0.92
60	50%	0	0	0	0	0.01	0.02	0.03	0.07	0.15	0.29	0.48	0.68	0.83	0.91
57	55%	0	0	0	0	0.01	0.01	0.03	0.07	0.14	0.27	0.45	0.65	0.81	0.91
55	60%	0	0	0	0	0.01	0.01	0.03	0.06	0.13	0.25	0.43	0.63	0.79	0.90

Appendix 2 (Hot carbon emissions)

Ignition thresholds for grasses from **hot carbon emissions** (hot carbon particles and hot gases exiting a vehicle exhaust). Ignition is based on ambient temperature, relative humidity (RH) and grass moisture content (MC%) or Fine Fuel Moisture Code (FFMC).

Ignition thresholds for management applications (Probability of ignition = 70%)		
Scenario	**FFMC**	**MC (%)**
Ambient temperature between 18.5 and 20.1ºC AND RH between 31 and 54%	69	37
Other environmental conditions - use with caution	83	19

Decision support table of ignition probabilities for grasses from **hot carbon emissions**. Ignition is dependent on ambient temperature and humidity conditions, and Fine Fuel Moisture Code (FFMC) or grass moisture content (MC%).

FFMC	MC (%)	Is the ambient temperature between 18.5 & 20.1ºC and RH between 31 & 54% ?	
		YES	NO
100	1%	0.89	0.76
96	5 %	0.87	0.75
91	10%	0.85	0.73
86	15%	0.83	0.71
82	20%	0.81	0.69
78	25%	0.78	0.67
74	30%	0.75	0.65
70	35%	0.72	0.63
67	40%	0.68	0.61
63	45%	0.64	0.59
60	50%	0.60	0.57
57	55%	0.56	0.54
55	60%	0.52	0.52
52	65%	0.48	0.50
49	70%	0.43	0.48
47	75%	0.39	0.45

Appendix 3 (Metal sparks)

Ignition thresholds for grasses exposed to contact from **metal spark** ignition sources. Ignition is dependent on grass moisture content (MC%) or Fine Fuel Moisture Content (FFMC).

Ignition thresholds for management applications (Probability of ignition = 70%)	
FFMC	MC (%)
77	26

Decision support table of ignition probabilities for grasses from **metal spark** ignition sources (e.g. grinding, railway track cutting). Successful ignition depends on Fine Fuel Moisture Content (FFMC) or grass moisture content (MC%).

FFMC	MC (%)	Probability of ignition
100	1%	0.94
96	5 %	0.92
91	10%	0.89
86	15%	0.84
82	20%	0.78
78	25%	0.71
74	30%	0.63
70	35%	0.54
67	40%	044
63	45%	0.35
60	50%	0.27
57	55%	0.20
55	60%	0.15
52	65%	0.11
49	70%	0.07
47	75%	0.05

Appendix 4 (Open flame)

Ignition thresholds for grasses exposed to contact from **open flame** ignition sources. Ignition is dependent on wind speed and grass moisture content (MC%) or Fine Fuel Moisture Content (FFMC).

Scenario	Ignition thresholds for management applications (Probability of ignition = 70%)	
	FFMC	MC (%)
No wind	78	25
Wind = 1 m/s	59	53

Decision support table of ignition probabilities of grasses from **open flame** ignition sources, depending on Fine Fuel Moisture Code (FFMC) or grass moisture content (MC%) and wind speed.

FFMC	MC (%)	No wind	Wind 1 m/s
100	1%	1.00	1.00
96	5 %	1.00	1.00
91	10%	0.99	1.00
86	15%	0.98	1.00
82	20%	0.91	1.00
78	25%	0.69	1.00
74	30%	0.34	1.00
70	35%	0.10	1.00
67	40%	0.03	0.99
63	45%	0.01	0.86
60	50%	0	0.83
57	55%	0	0.53
55	60%	0	0.20
52	65%	0	0.05
49	70%	0	0.1
47	75%	0	0

Colour table of the probability ranges used in the decision-support tables within these appendices.

Colour	Probability range	Likelihood of ignition
Green	0 to 0.49	Unlikely
Yellow	0.50 to 0.70	Possible
Orange	0.71 to 0.80	Likely
Red	0.81 to 1.00	Highly probable