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The combustibility of turf lawns

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Contents

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Andy Middleton (CanTurf) supplied the turf and provided advice on its maintenance.

Paul de Mar and Hannah Urwin (GHD) assisted with project management and coordination and provided comments on the draft report.

Andrew Sullivan (CSIRO) provided advice on the experimental methodology, equipment and helped with the characterisation of wind conditions and provided constructive comments and suggestions on draft versions of the report.

Executive summary

Bushfires regularly encroach upon communities, threatening lives, properties and infrastructure. The nature of vegetation surrounding these areas, including in gardens and yards, has a large influence on the potential for deleterious impacts.

The combustibility of natural turf ground cover was investigated to provide quantitative evidence of its in-situ utility for resisting ignition around homes and structures. Experiments were conducted in the controlled conditions of the CSIRO Pyrotron with the aim of determining the combustibility of turf (i.e. its ability to ignite and sustain spreading fire).

The combustibility of three common turf varieties, buffalo (*Stenotaphrum secundatum*, Sir Walter), couch (*Cynodon dactylon*) and kikuyu (*Pennisetum clandestinum*) was investigated under three different wind strengths. Turf samples were ignited with a standard flaming ignition source representative of a firebrand, with sustainability defined by the fire spreading independently beyond 0.2 m from the ignition point. The moisture content of the leaf blades was used as the primary explanatory variable.

The results showed that turf lawns must be dead and very dry to ignite and sustain fire spread and that the presence of wind increases the chance of ignition. The ignition thresholds determined for turf fuels are lower than those reported in the literature for forest litter fuels. Kikuyu sustained point ignitions at higher moisture contents than any other variety, probably due to the taller leaf blades in this variety. The range of moisture conditions that enabled sustaining ignitions in kikuyu was still representative of a lawn in a dead and dry condition. Samples of kikuyu that had been cut to very short lengths (~12 mm) were much more difficult to ignite, with sustaining fires only occurring when they were extremely dry (<4% moisture content) in the presence of wind.

Some additional testing was undertaken using actively spreading fire fronts rather than point ignitions to determine how a larger heat flux source may influence the ignitability of lawns. Turf samples were found to sustain fire at higher leaf blade moisture contents when impacted by a line of fire. However, the moisture contents of these sustaining fires were still representative of dead or near-dead lawns.

Well-maintained lawns clear of debris can resist bushfire impacts by not sustaining ignitions during ember attacks and retarding fire spreading from adjacent vegetation. Open areas of low flammability around properties provide a space where defensive firefighting actions can be undertaken which can further reduce the likelihood of damage to assets.

1 Introduction

Bushfires occasionally impact residential areas causing loss of life and damage to homes and valuable infrastructure. Studies of house losses during major wildfire events have found that the combustion of suburban fuels (on both private and public land) is a significant cause of house ignition (e.g. Ellis and Sullivan 2003; Manzello and Foote 2014). These fuels within the immediate surrounds of houses are often ignited by firebrands (flaming material) and embers (glowing combustion) from other locations (Cohen *et al.* 1991; Cohen 1999). Studies on bushfire impacts in urban areas have argued that the management of suburban fuels is a practical means for reducing the risk of house loss (Ramsay *et al.* 1996; Cohen and Butler 1998; Ellis and Sullivan 2004; Gibbons *et al.* 2012). Previous research has investigated the ignition of ground covers such as mulches (Steward *et al.* 2003; Manzello *et al.* 2006; Manzello *et al.* 2008) and leaf litter (Plucinski and Anderson 2008), but has not investigated the ignition of lawns in any detail. Well-maintained lawns that are kept lush and green have the potential to resist bushfire impacts by not sustaining ignitions during ember attacks, in contrast to other ground covers used in landscaping such as leaf litter and mulch that are composed of highly combustible dead biomass material. Open trafficable areas around houses such as lawns also provide a space where defensive firefighting actions can be taken during wildfires that can significantly increase the odds of house survival (Syphard *et al.* 2014).

This report investigates the ability of turf lawns to resist ignition from bushfires and not sustain fire spread. The combustibility of three common turf grasses, buffalo (*Stenotaphrum secundatum*, Sir Walter), couch (*Cynodon dactylon*) and kikuyu (*Pennisetum clandestinum*), were investigated. Here the term combustibility is used to combine the ease of ignition (ignitability) and the ability for a fire to continue burning without a pilot heat source (sustainability).

The main series of experiments undertaken for this study involved the repeated ignition of turf samples using a standard flaming point ignition source. These experiments were designed to simulate the ignition pressure experienced when a bushfire impacts a residential area. The moisture content of the leaf blades was used as the primary explanatory variable, with the effect of wind speed also investigated.

Some additional testing was conducted using established fire fronts spreading from a litter fire adjacent to the turf sample. These tests were undertaken opportunistically to utilise left over turf samples to provide an indication of whether a fire with a higher heat flux spreading from another fuel type would sustain in turf. The quantity of data from this component of the study was limited and insufficient for modelling or detailed analysis, but was presumed to provide some comparison with the point ignition experiments.

All experiments were conducted in the controlled conditions of the CSIRO Pyrotron (Sullivan *et al.* 2013).

2 Point ignition experiments

2.1 Turf storage and preparation

Rolls of the three turf varieties were supplied by CanTurf[1] and were stored on a sunlit concrete slab and maintained with regular heavy watering (Figure 1). Samples of each turf were cut for experiments at different times and slowly dried on aerated bases in a variety of locations (shade, sun, indoors) and for different durations to manipulate the leaf blade moisture content for experimentation (Figure 2). Some samples were further dried in a large laboratory drying oven to attain moisture contents representative of dead fuels on the most extreme fire danger days.

Figure 1 Storage of turf in full sun on a concreate slab prior to cutting and samples preparation.

Figure 2 Cut turf samples being dried on an aerated base prior to experimentation.

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[1] CanTurf, 14 Cessnock Street, Fyshwick, Australian Capital Territory, Australia. Phone: 02 6228 1991, Email: office@canturf.com.au

A portion of the supply of turf was maintained on the concrete slab for three weeks in an effort to attain more growth and a longer blade length, however no significant growth was achieved in this time. All buffalo and couch samples had similar blade lengths during testing. Some samples of the tallest grass, kikuyu, were cut to have a short blade height (~10 mm) in order to investigate the effect of blade height on ignitability (Figure 3).

Figure 3 Example of short cut kikuyu turf. The mean blade height of this sample was 10.3 mm.

2.2 Variables

The majority of previous studies investigating the ignition of bushfire fuels have considered fuel moisture as the main variable (e.g. Plucinski and Anderson 2008; Ganteaume *et al.* 2009; Dimitrakopoulos *et al.* 2010; Ellis 2011; Schiks and Wotton 2014) because it has a major effect on fuel combustibility, is easily altered and can be accurately measured. Ignitions were made with the leaf blades (here generically called fuel) at a range of moisture states ranging from well-watered and thriving state to one that is dead and dry and exposed to high ambient air temperatures and low humidities.

Noting that live turf samples (including unwatered samples stressed from outdoor exposure in summer conditions) could not be ignited, most experimental fires were conducted using samples of dead and dying turf. This was done to allow the point at which an ignition is sustained to be determined precisely with the results of earlier experiments informing the moisture conditions targeted in later experiments. The lowest leaf blade moisture contents were achieved by placing dead turf samples in a drying oven set to 105°C for up to 40 minutes.

Samples of the leaf blades for moisture determination were taken 10 minutes prior to ignition. Leaf blades were cut with scissors and placed in metal tins so that the moisture content could be determined using the oven-dry gravimetric method with the oven set to 105°C and samples dried for least 24 hours as recommended for bushfire fuels (Matthews 2010). Leaf blade moisture contents are thus expressed as mass of water as a percentage of oven-dried weight (ODW) of a sample. If the mass of water lost is greater than the dry mass of the fuel, then the moisture content will be more than 100%.

The presence of wind has also been shown to have an influence on fuel bed ignitability in previous research (Plucinski and Anderson 2008; Plucinski *et al.* 2010; Ellis 2015). For this reason, point ignitions were tested in three different wind conditions representing calm, moderate and strong wind conditions. These conditions were achieved using different fan settings of the Pyrotron (0, 300 and 700 revolutions per minute). Small air movements were occasionally experienced during the zero speed setting as a result of winds outside the Pyrotron affecting the pressure field within the working section. Wind speeds were measured at fuel height using a Windsonic 2D sonic anemometer over five minutes for each setting with mean wind speeds of 0.13 (±0.008), 0.50 (±0.005) and 1.33 (±0.003) m/s recorded for the calm, moderate and strong wind speed settings, respectively.

These measured wind speeds represent winds of much greater strengths at typical measurement heights (2 and 10 m) as a result of typical boundary layer drag effects. The exact relationship between the wind at the ground level and these heights in a typical lawn setting would vary depending on the amount and nature of surrounding obstacles (e.g. garden plants, buildings, fences etc).

Other potentially influential meteorological variables (e.g. temperature and humidity) were controlled by timing ignition experiments to a narrow range of ambient conditions (19 - 36°C air temperature and 10 - 20% relative humidity). Ignitions were targeted to hot and dry conditions so that they would be representative of those associated with destructive bushfires, considered to be a worst case scenario.

The blade height of all turf samples was measured with a metal ruler. The precision of this measurement was limited as it was difficult to consistently determine the location of the base of the leaf blades, particularly for the varieties with bare stolons (runners) and roots present (buffalo and kikuyu).

The fuel load (mass of dry fuel per unit area) was measured in some samples by removing, drying and weighing all leaf blades in a 0.01 m^2 sample area (Figure 4).

Figure 4 Leaf blade moisture content and fuel load being sampled immediately after delivery. Images show from left to right: buffalo, couch and kikuyu.

2.3 Ignition source

A standard flaming firebrand was used for all point ignition experiments. This ignition source represents the most energetic firebrand that is likely to impact on urban areas. The most prevalent type of firebrand is the glowing (non-flaming but still combusting) firebrand but which has far less energy than the flaming type and thus less likely to ignite most fuels in isolation. The standard flaming ignition source consisted of a ball of cotton wool with 1 ml of 90% ethanol injected into it and placed on top of turf samples (Figure 5) immediately prior to experiment commencement. This ignition source has been successfully used in previous ignition experiments (Plucinski and Anderson 2008; Plucinski *et al.* 2010; Gould and Sullivan In Press) and found to be highly consistent and reliable. Other ignition sources, such as matches have been found to have inconsistent properties (Blackmarr 1972; Steward *et al.* 2003) producing unreliable results.

Figure 5 The cotton wool ball as flaming pilot ignition source sitting on a sample of kikuyu turf before, during and after testing [Fire number 175].

2.4 Analysis and modelling

Sustainable ignitions were defined as those that spread 0.2 m or greater from the ignition point. This definition was found to be appropriate during preliminary testing as it allowed the fire within the turf layer to demonstrate sustainability and is similar to definitions that have been used in other fuel types (Plucinski and Anderson 2008; Plucinski *et al.* 2010).

The results of point ignition experiments were compared across a range of moisture contents representing lawns comprised of dead leaf blades that are extremely dry (<5%), very dry (5-10%), and dry (10-20%) and those that are dying (>20%)[2]. These categories represent lawns that have not been watered for a significant time (dependant on prevailing conditions) and are exposed to weather conditions that represent those typical of hot days during a drought (generally associated with elevated grassland fire danger conditions).

The leaf blade moisture contents of sustaining and non-sustaining point ignition tests were compared using the Wilcoxon rank sum test (Wilcoxon 1945) used to estimate the strength of differences when there was sufficient data. This test was used as the datasets were non-parametrically distributed. Boxplots were used to provide a visual interpretation of these comparisons.

The data from point ignition experiments were also used to develop univariate models of ignition probability using logistic regression. Models were developed for each combination of grass type (buffalo, couch and kikuyu) and wind condition (calm, moderate, strong). The goodness of fit of the models was measured by Nagelkerke's pseudo R^2 statistic or likelihood ratio index (Nagelkerke 1991). The area under the Receiver Operating Characteristic (ROC) curve was used to determine the discriminative ability of the model over a range of cut-off points (for details see Hosmer and Lemeshow (2000)). The leaf blade moisture content at which 50% of ignitions were successful,

[2] samples tested in this category were typically less than 30% moisture content

M_{50}, (Plucinski and Anderson 2008) was estimated to allow comparisons between each series. All analysis and modelling was undertaken within the R statistical software framework (R Core Team 2019).

3 Line fire spread sustainability tests

The line fire spread sustainability tests involved turf samples being impacted by a line of fire burning in forest litter fuels on their upwind side. The forest litter fire burned in bed of 50 grams of radiata pine (*Pinus radiata*) needles spread across a 750 mm wide and 100 mm long area and arranged to have a depth of 30-40 mm (estimated bulk density 17-23 kg/m^3). The litter had been dried in an oven at 40 degrees for 1-2 hours immediately prior to experimentation so that it had a moisture content of 6.29 (±0.16) % ODW. The litter bed was ignited by a line of 15 ml of ethanol contained in a shallow 'v'-shaped trough 750 mm long located immediately upwind of the turf sample (Figure 6). All of these tests were undertaken with a moderate wind speed (0.5 m/s at the fuel level). 14 line fire spread sustainability tests were undertaken, with three of these used to compare kikuyu at two different heights (Figure 6b). Spread sustainability was again defined by fire spreading consistently beyond 0.2 m from the ignition source.

Figure 6 The experimental setup used for line fire spread sustainability tests showing the side view prior to pilot ignition (couch) and the plan view immediately following ignition (kikuyu, cut and uncut).

4 Results

The physical structure of the turf varieties varied considerably with buffalo samples having the highest fuel loads and bulk density (Table 1). There may, however, be some inaccuracy in the measurements for this variety at it was very difficult to discern the plant roots from the aerial structure and the samples supplied contained little soil. This turf variety also had the lowest moisture content when delivered. Kikuyu had the tallest blade height and a moisture content that was much higher than the other turf varieties on delivery.

Table 1 General characteristics for each turf type

Turf variety	Average fuel load (standard error) (kg/m^2)	Mean bulk density (standard error) (kg/m^3)	Measured blade height (standard error) (mm)	Fuel moisture content on delivery (%)
Buffalo	1.03 (±0.176)	53.5 (±12.9)	19.7 (±8.2)	51.5
Couch	0.47 (±0.157)	44.8 (±19.8)	16.6 (±5.0)	96.0
Kikuyu	0.45 (±0.059)	31.3 (±17.7)	32.2 (±14.3)	195.8

4.1 Point ignition experiments

The range of testing conditions experienced during the point ignition experiments are presented in Table 2. Full details of the conditions experienced in each experiment are presented in the Appendix. The majority of experiments were conducted in dry conditions (overall median leaf blade moisture content = 9.1% ODW), with warm (median temperature 30°C) and dry (median relative humidity 21.7%) ambient air.

Table 2 The range of conditions experienced during the point ignition experiments

Turf variety	Wind speed setting	Number of ignition attempts (number sustaining)	Leaf blade moisture content range (% ODW)	Temperature range (°C)	Relative humidity range (%)	Estimated blade height (mm), mean (standard error)
Buffalo	Calm	26 (1)	3-27.5	19-35.5	10.5-19.5	24.2 (±0.9)
Buffalo	Moderate	31 (3)	3-27.5	19-36	10.5-19.5	21.4 (±0.6)
Buffalo	Strong	15 (2)	3-27.5	19.5-35.5	10-18.5	22.4 (±1)
Couch	Calm	24 (2)	4.4-30.3	18.5-36	12-19.5	17.6 (±0.4)
Couch	Moderate	25 (5)	4.4-30.3	18.5-36	11-19.5	16.8 (±0.3)
Couch	Strong	17 (3)	4.4-30.3	18.5-36	11-19.5	16.7 (±0.4)
Kikuyu	Calm	15 (7)	4-43.2	21-36	12.5-20	38.4 (±1.3)
Kikuyu	Moderate	13 (2)	10.3-43.2	23.5-32	13.5-18.5	40.8 (±1)
Kikuyu	Strong	13 (4)	7.1-43.2	21-32	12.5-18	39.3 (±1)
Kikuyu (short)	Calm	14 (0)	3.7-11.9	21-35.5	12.5-19	12.4 (±0.8)
Kikuyu (short)	Moderate	17 (1)	3.7-11.9	21-35.5	12.5-19	12.9 (±0.9)
Kikuyu (short)	Strong	11 (1)	3.7-11.4	21-35.5	12.5-19	11.5 (±1.1)

Table 3 Results by leaf blade moisture content class showing the percent sustaining point ignition in each group (ignitions sustained out of the number of attempts)

		Leaf blade moisture content class			
Turf variety	Wind speed setting	Extremely dry (<5% ODW)	Very dry (5-10% ODW)	Dry (10-20% ODW)	Dying (>20% ODW)
Buffalo	Calm	14.3% (1/7)	0% (0/8)	0% (0/10)	0% (0/1)
Buffalo	Moderate	23.1% (3/13)	0% (0/7)	0% (0/10)	0% (0/1)
Buffalo	Strong	0% (0/4)	0% (0/3)	28.6% (2/7)	0% (0/1)
Couch	Calm	33.3% (1/3)	5.9% (1/17)	0% (0/1)	0% (0/3)
Couch	Moderate	100% (3/3)	15.4% (2/13)	0% (0/6)	0% (0/3)
Couch	Strong	50% (2/4)	11.1% (1/9)	0% (0/1)	0% (0/3)
Kikuyu	Calm	100% (1/1)	100% (1/1)	45.5% (5/11)	0% (0/2)
Kikuyu	Moderate	-	-	22.2% (2/9)	0% (0/4)
Kikuyu	Strong	-	100% (1/1)	33.3% (3/9)	0% (0/3)
Kikuyu (short)	Calm	0% (0/3)	0% (0/4)	0% (0/7)	-
Kikuyu (short)	Moderate	50% (1/2)	0% (0/5)	0% (0/10)	-
Kikuyu (short)	Strong	50% (1/2)	0% (0/5)	0% (0/4)	-

4.1.1 Buffalo

72 ignition attempts were made in buffalo turf samples. These were undertaken at moisture contents below what would be expected for a healthy lawn. The majority of testing was concentrated on very dry conditions typical of a dead lawn exposed to hot and dry conditions, as would be expected on a day with very high bushfire danger.

Only one of 26 ignition attempts undertaken in calm conditions sustained combustion. This was at an extremely dry moisture content (3.4% ODW) (Table 3). Six other ignition attempts were made at extremely dry (<5% ODW) moisture contents but did not sustain, giving an overall ignition probability of 14% in extremely dry buffalo calm conditions. It was necessary to partially oven-dry the sample to reach this extremely dry moisture content. It was not possible to run the Wilcoxon rank sum test for this series as there was only one sustained ignition. The boxplot shows the sustained ignition was at the lower end of the range of leaf blade moisture contents tested (Figure 7).

Three of 31 ignition attempts undertaken in buffalo turf with moderate winds were sustained. These were amongst 13 ignition attempts made at extremely dry (<5% ODW) moisture contents, giving an ignition probability of 23% in these conditions. Although the sustained ignitions were at the lower end of the leaf blade moisture contents tested, they were not significantly different to those that did not sustain (Figure 7).

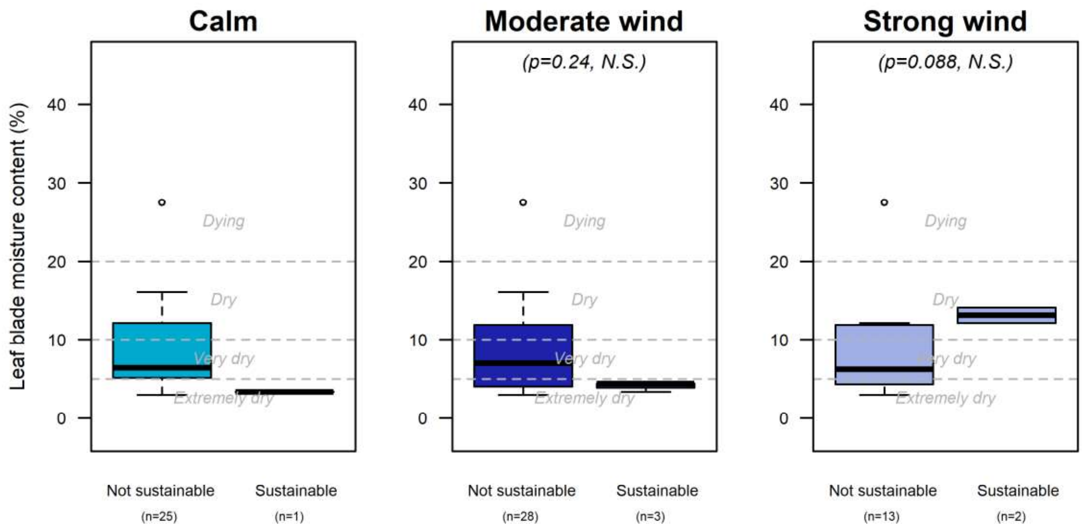

Figure 7 Boxplots comparing the leaf blade moisture content during non-sustained and sustained point ignition tests in buffalo turf under the different wind conditions. Black lines show the plot median, coloured boxes show the range between the upper and lower quartiles. Whiskers show the range other than outliers (circles) that are more than 1.5 times the upper quartile, or less than 1.5 times the lower quartile. P-values are the calculated probability of the result being just from chance and indicate the significance of any differences between these periods as determined using the Wilcoxon rank sum test.

Two of 15 ignition attempts undertaken in buffalo turf with strong winds sustained combustion (see Figure 8 for example). These sustaining ignitions were at moisture contents higher (12 and 14% ODW) than many ignition attempts that did not sustain, and probably indicate the variability in ignition in these conditions. It is also possible that the moisture content within the turf sample was stratified with profiles that had dry tips and moister bases producing a higher overall moisture content measure but resulting in fires able to spread across the drier tops due to the high wind speed. The results from this series were not suitable for modelling.

Figure 8 Sustaining ignition in buffalo grass turf with a strong wind speed (ignition number 167). Unburnt fuel is visible underneath the burnt tips (right)

4.1.2 Couch

66 ignition attempts were made in couch turf samples, with ten of these sustaining combustion. These were also undertaken at moisture contents below what would be expected to be the

minimum for a living turf, with the majority concentrated at very low moisture contents, typical of dead lawns on very hot and dry days.

Only two of 24 ignition attempts undertaken in calm conditions sustained combustion (Table 3). The first of these was at a moisture content of 4.5% ODW and was one of three ignition attempts made in this extremely dry turf condition. The second successful ignition was made with a moisture content of 6.5% ODW and was one of seven attempts made in the very dry moisture range. The leaf blade moisture contents of the sustaining ignitions tended to be lower than those that did not sustain combustion, however the differences between these groups was not statistically significant (Figure 9).

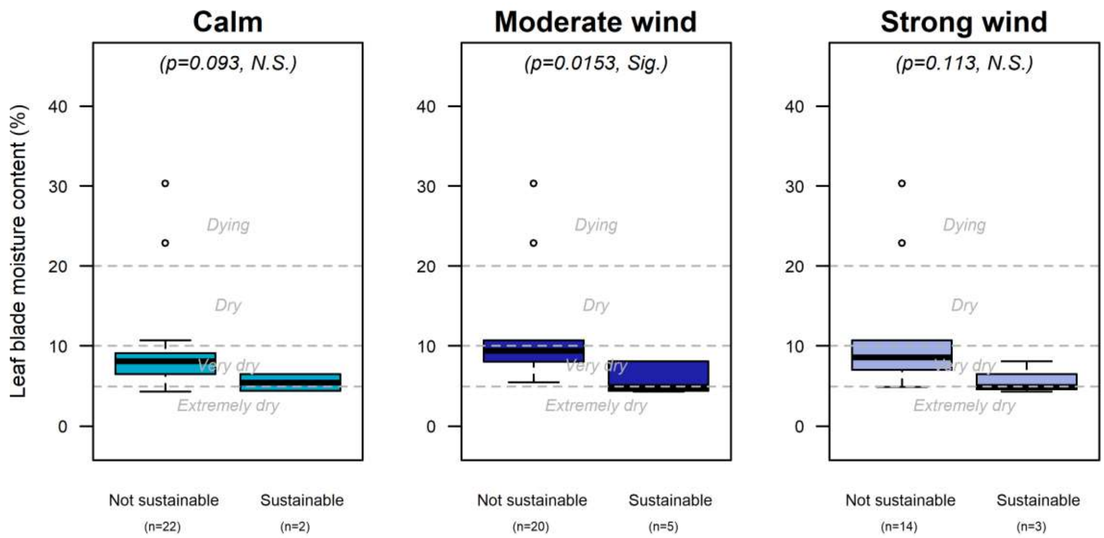

Figure 9 Boxplots comparing the leaf blade moisture content during non-sustaining and sustaining point ignition tests in couch turf under the different wind conditions. Black lines show the plot median, coloured boxes show the range between the upper and lower quartiles. Whiskers show the range other than outliers (circles) that are more than 1.5 times the upper quartile, or less than 1.5 times the lower quartile. P-values are the calculated probability of the result being just from chance and indicate the significance of any differences between these periods as determined using the Wilcoxon rank sum test.

Five of the 25 ignition attempts undertaken in couch turf with moderate winds sustained combustion. This included all three undertaken at extremely dry moisture contents and two of thirteen attempts made in the very dry moisture range. The leaf blade moisture contents of the sustaining ignitions were significantly lower than those for ignitions that did not sustain combustion (Figure 9).

Three of 17 ignition attempts undertaken in couch turf with strong winds sustained combustion. These included two of the four undertaken at extremely dry moisture contents and one of the nine attempts made in the very dry moisture range. The leaf blade moisture contents of the sustaining ignitions tended to be lower than those that did not sustain combustion, however the differences were not statistically significant (Figure 9).

4.1.3 Kikuyu

41 ignition attempts were made in kikuyu turf samples that were in an uncut state. 13 of these sustained combustion. All ignition attempts made at moisture contents below 11.2% ODW were sustainable and those at higher moisture contents did not sustain in all wind conditions. This resulted in very similar results, with statistically significant differences in the leaf blade moisture contents of sustaining and non-sustaining ignitions (Figure 10).

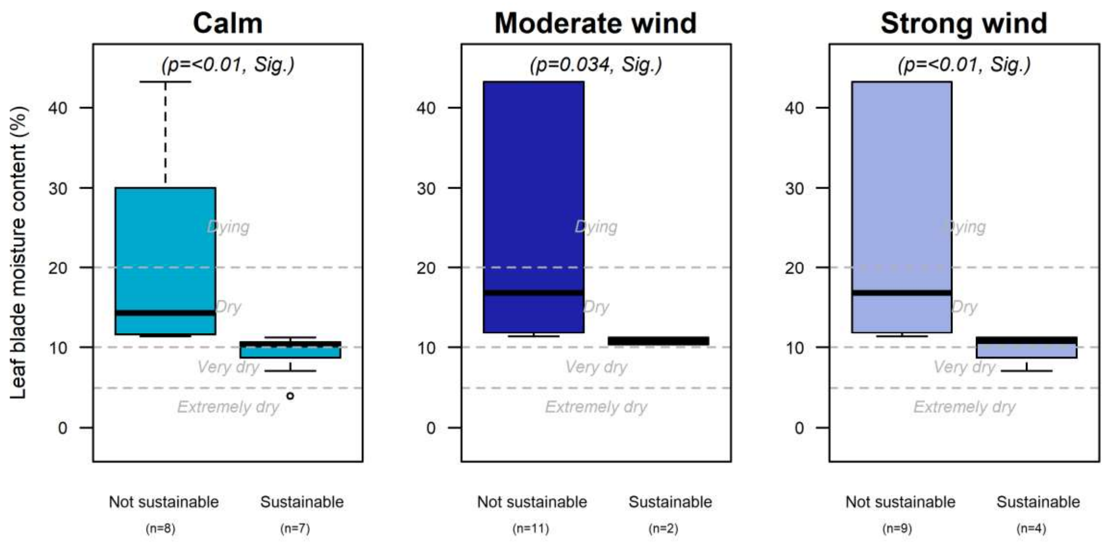

Figure 10 Boxplots comparing the leaf blade moisture content during non-sustaining and sustaining point ignition tests in kikuyu turf under the different wind conditions. Black lines show the plot median, coloured boxes show the range between the upper and lower quartiles. Whiskers show the range other than outliers (circles) that are more than 1.5 times the upper quartile, or less than 1.5 times the lower quartile. P-values are the calculated probability of the result being just from chance and indicate the significance of any differences between these periods as determined using the Wilcoxon rank sum test.

4.1.4 Short cut kikuyu

A further 42 ignitions were made in kikuyu turf that had been cut short, with a mean height of 11.6 mm. These exhibited very different results to those in the uncut kikuyu samples, with only two sustainable ignitions. None of the 14 ignition attempts made in calm conditions with short cut kikuyu sustained combustion. Only one of the 17 ignition attempts made in moderate winds and one of the 11 attempts made in strong winds were sustainable, with both conducted with leaf blade moisture contents of 3.7% ODW, which was the lowest of the moisture contents tested (Figure 11). These data sets were not suitable for applying the Wilcoxon rank sum test as they had one or no sustainable ignitions.

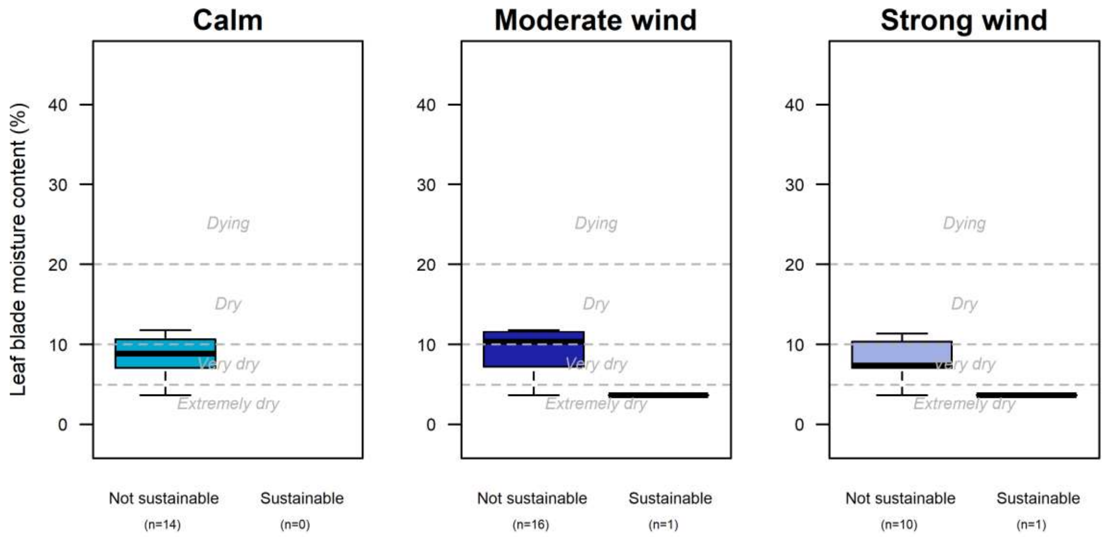

Figure 11 Boxplots comparing the leaf blade moisture content during non-sustaining and sustaining point ignition tests in short cut kikuyu turf under the different wind conditions. Black lines show the plot median, coloured boxes show the range between the upper and lower quartiles. Whiskers show the range other than outliers (circles) that are more than 1.5 times the upper quartile, or less than 1.5 times the lower quartile.

4.1.5 Univariate logistic regression models

Univariate logistic regression models were fit to all data sets except those for buffalo turf with strong winds and short cut kikuyu in calm conditions (Figure 12, Table 4). The models had variable fits ranging from moderate in buffalo to perfect in the uncut kikuyu, owing to the separation of sustaining and non-sustaining results within the distribution of the datasets. Model discrimination, as indicated by the area under the ROC, was mostly high, with perfect discrimination recorded for the uncut kikuyu series. The lowest M_{50}'s were estimated for buffalo turf and indicate that this variety has an extremely low probability of sustaining ignitions. The models and M_{50}'s were nearly identical for all wind speed settings in kikuyu where the M_{50}'s were the highest for all data sets, with values of 11.3% ODW.

Table 4 Logistic regression coefficients, model fits (Nagelkerke's pseudo R^2 statistic and area under the Receiver Operating Characteristic (ROC) curve) and M_{50} of univariate logistic regression models for point ignition sustainability in buffalo, couch, kikuyu and short cut kikuyu turf based on leaf blade moisture content in different wind conditions.

Turf variety	Wind speed setting	Model intercept (a)	Model coefficient for leaf blade moisture content (b)	Nagelkerke's pseudo R^2	Area under ROC	M_{50} (%) ODW
Buffalo	Calm	3.496	-1.524	0.386	0.960	2.295
Buffalo	Moderate	0.205	-0.454	0.212	0.744	0.451
Couch	Calm	3.670	-0.902	0.348	0.886	4.070
Couch	Moderate	5.503	-0.901	0.521	0.890	6.106
Couch	Strong	2.424	-0.563	0.300	0.821	4.303
Kikuyu	Calm	2512.5	-222.7	1.000	1.000	11.281
Kikuyu	Moderate	2458.6	-217.9	1.000	1.000	11.282
Kikuyu	Strong	2535.6	-224.7	1.000	1.000	11.283
Kikuyu (short)	Moderate	21.718	-5.884	0.686	0.969	3.691
Kikuyu (short)	Strong	21.222	-5.750	0.658	0.950	3.691

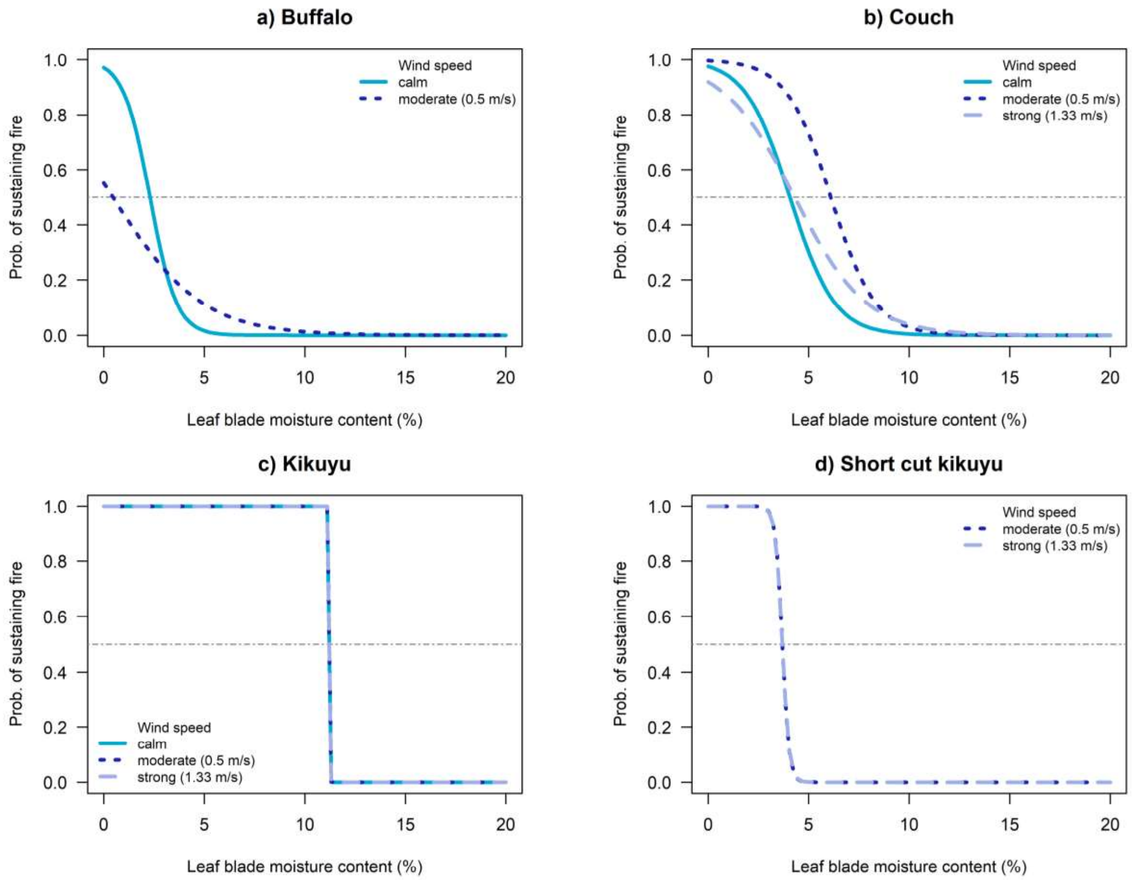

Figure 12 Univariate logistic regression plots for point ignition sustained combustion in buffalo, couch, kikuyu and short cut kikuyu turf based on leaf blade moisture content in different wind conditions.

4.2 Line fire spread sustainability tests

The results of the line fire spread sustainability tests showed that fires spreading into turf areas can sustain at greater moisture contents than those ignited as points (Table 5). All of the fires that did sustain when impacted by surface fires burning in pine needle beds were in turf samples that were within the dead range (<20%), with uncut kikuyu sustaining fire spread when the leaf blades had a moisture content of 16.8% ODW.

Table 5 Summary of results from spread sustainability tests

Id. No.	Turf variety	Mean blade height (mm)	Temp (°C)	Relative Humidity (%)	Moisture content (%) ODW	Outcome and comparison to predicted outcome for a point ignition
15	Buffalo	25.67	24	28	5.27	Sustained when a point ignition had only a small (p=0.1) chance of sustaining.
1	Buffalo	23.67	25.5	40	8.64	Sustained when a point ignition had only a very small (p=0.02) chance of sustaining.
13	Buffalo	19.67	24	25	9.13	Did not spread sustainably across the entire fuel bed, as expected for a point ignition.
7	Buffalo	3.07	31.5	16	16.08	Sustained when a point ignition had an extremely small (p=0.001) chance of sustaining.
16	Buffalo	41.67	24	25	55.25	Did not sustain, as expected for a point ignition.
18	Couch	17.67	35.5	16	8.22	Sustained when a point ignition had only a small chance (p=0.13) of sustaining.
6	Couch	17	30	16	9.67	Sustained when a point ignition had only a very small (p=0.04) chance of sustaining.
12	Couch	16.33	24.5	23	10.68	Sustained when a point ignition had only a very small (p=0.02) chance of sustaining.
2	Couch	22	25.5	40	41.47	Did not sustain, as expected for a point ignition.
14	Couch	22.33	24	25	190	Did not sustain, as expected for a point ignition.
11	Kikuyu	34.67	24	22	11.36	Sustained when a point ignition would not be expected to sustain.
3	Kikuyu	29.67	30	16	13.58	Sustained when a point ignition would not be expected to sustain.
8	Kikuyu	44.67	32	17	16.84	Sustained when a point ignition would not be expected to sustain.
17	Kikuyu	48.33	24.5	54	239	Did not sustain, as expected for a point ignition.
10	Kikuyu (short)	12	24	22	11.36	Did not sustain, as expected for a point ignition.
4	Kikuyu (short)	11	30	16	13.58	Did not sustain, as expected for a point ignition.
9	Kikuyu (short)	10	32	17	16.84	Did not sustain, as expected for a point ignition.

5 Discussion

The results of the experiments presented here show that lawns must be dead and very dry to sustain fire spread. Only ignitions in turf samples that were dead and dry with leaf blade moisture contents less than 20% ODW were observed to allow sustained fire spread. Kikuyu samples were found to facilitate sustainable fire spread initiated at a point by a flaming firebrand at higher moisture contents than in couch and buffalo, probably because of its longer blade lengths. Kikuyu that was cut to very short (~12 mm) lengths were much more difficult to ignite and only sustained fire spread at extremely low (<4% ODW) blade moisture contents and only when there was wind present.

Turf samples were found to sustain fire at higher leaf blade moisture contents when impacted by a line of fire from another fuel type (Table 5), although the moisture contents of these sustaining fires were still representative of dead or near dead lawns. Fire spread was not sustained in any test undertaken using green living turf samples. More of this testing is required at slightly higher moisture contents (20-30%) to determine the upper moisture limit that dead lawns can sustain spread from line ignition sources.

Considerable effort was required to attain the lowest leaf blade moisture contents tested, with some samples subjected to periods of drying in an oven set to 105°C for 40 minutes and the majority of testing undertaken on days with high air temperature and low relative humidity (Table 2). Leaf blade moisture contents in this range can only be attained during hot and dry periods. The moisture content of dead cellulosic fuels, including fully cured standing grass and lawns, can be modelled using the ambient temperature and relative humidity (Viney 1991; Matthews 2014). An application of the most appropriate models for dead grass (Cruz *et al.* 2016) shows that extremely dry moisture contents can be achieved when the ambient air is very hot and dry (Figure 13).

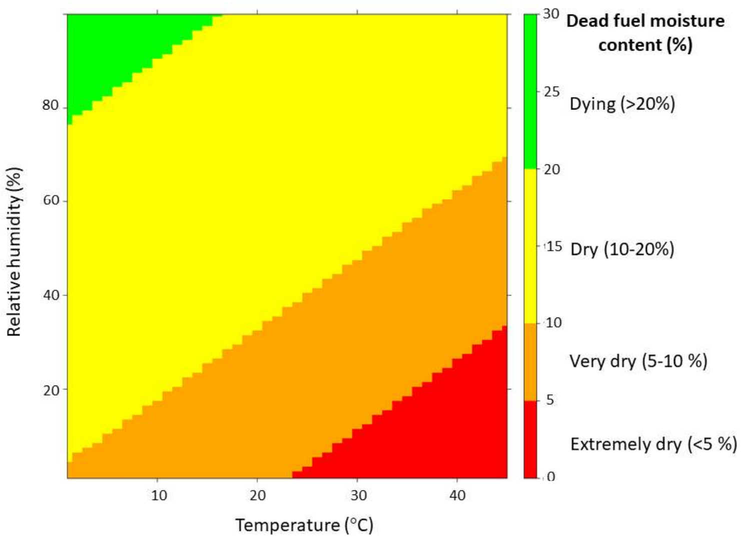

Figure 13 The influence of ambient relative humidity and temperature on the moisture content of dead grass fuels based on Sullivan's (2010) equation for McArthur's (1966) tables.

The flaming pilot ignitions used to ignite points in this study represent a higher energy firebrand and would have a much greater chance of causing a sustaining ignition than glowing firebrands (Ellis 2015) which comprise the majority of firebrands impacting urban areas. The leaf blade moisture contents at which 50% of ignitions were successful (M_{50}) is much lower for dead turf leaf blades (0.5-11.3% ODW, Table 4) than for common litter fuels such as from eucalypt (*Eucalyptus dives*, 22.7% ODW) and pine (*Pinus radiata*, 29.9% ODW) trees (Plucinski and Anderson 2008). This implies that dead lawns would be able to resist ignition in a broader range of conditions than forest litter fuels.

It is important to note that lawns that are not kept clear of combustible debris, such as dead lawn clippings and leaf litter, may be able to sustain fire spread via the litter, particularly in windy conditions (Figure 14). Lawns that have been maintained in a live state without accumulation of litter or dead clippings can readily resist fire spread, as demonstrated by the examples in Figure 15. The use of well-maintained and watered lawns around homes and infrastructure within bushfire prone areas can provide protection from spreading fires whilst allowing access for firefighters and their vehicles.

Figure 14 Litter burning on top of a sample of buffalo turf that did not sustain point ignitions (leaf blade moisture content 5.5% ODW)

Figure 15 Example of a well maintained kikuyu lawn that did not burn after being impacted by the head of a fast moving wildfire on 31 January 2020 in Pentland hills Victoria (air temperature 38°C, relative humidity 22%, wind speed 46 km/h, curing in pasture 95%, Grassland Fire Danger Index 68 (Severe)).

Lawns that have been mown with a catcher have a low biomass. Those measured here had fuel loads that were at the low end of those typical of other fuel types, including native and improved pasture grasses which for fuel loads have been measured between 1.7 and 10.5 t/ha (Cruz *et al.* 2018). It is well appreciated that fire spreads more slowly and has lower flame heights in shorter, lighter fuels than taller heavy fuels (Cheney *et al.* 1993, 1998; Cheney and Sullivan 2008; Cruz *et al.* 2018). The very low biomass of lawns means that even if fires do spread across them, they will have a very low fireline intensity (Byram 1959) and therefore be relatively easy to control and extinguish. The proportion of turf fuel consumed in spreading flame fronts is quite low, as evidenced by the fuel residue following experiments (Figure 16 and Figure 17). The line fire spread sustainability tests appeared to consume less fuel than the point ignition tests (compare Figure 17 with Figure 16), which is probably as a result of these fires spreading faster and having less influence from the pilot ignition source. The profile of the flames during spread sustainability tests, including the shallow flame depth, can be seen in Figure 18.

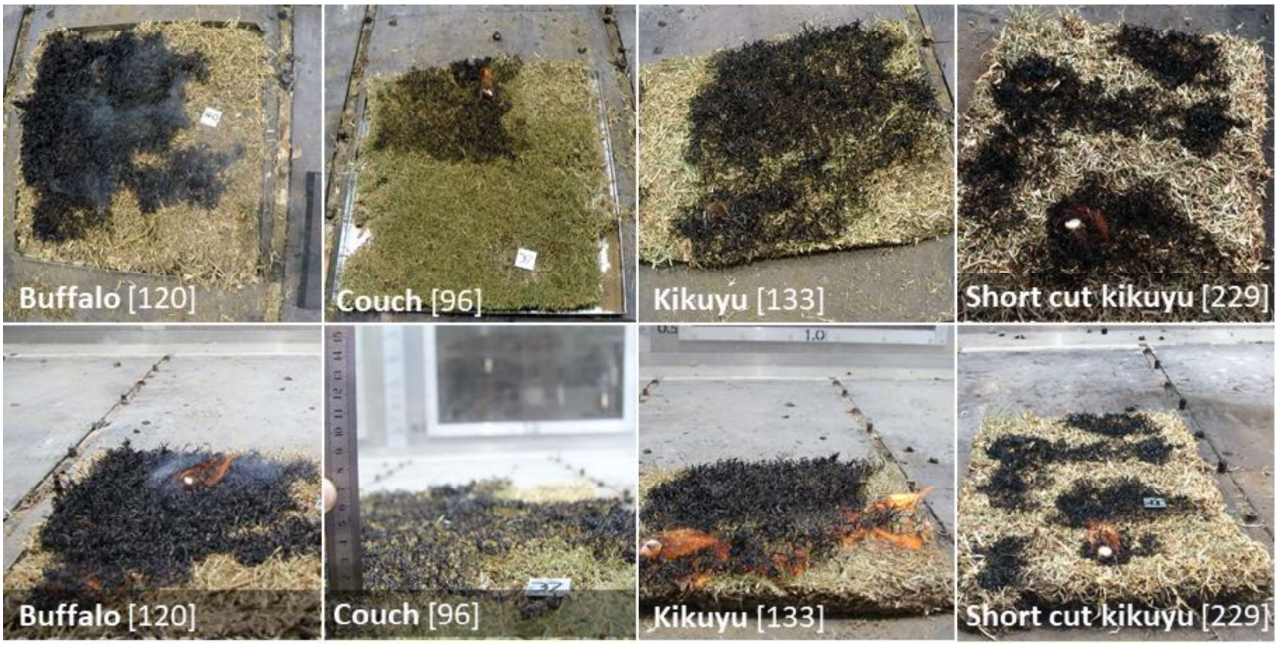

Figure 16 Post fire images showing residual charred fuels following point ignition tests as viewed from above (top row) and the side (bottom row). The reference numbers for each fire relate to the details provided in the Appendix.

Figure 17 Post fire images showing residual charred fuels following spread sustainability tests for the different turf varieties. The numbers refer to the fire reference, see Table 5.

Figure 18 Example of spreading fire burning across the tops of the turf layer. Spread sustainability test 18 (Table 5) burning in couch, as viewed from the side (left) and above (right).

6 Conclusions

The results of the experiments presented in this report shows that well maintained (watered and mown) lawns are not readily combustible under any conditions associated with wildfires unless they are completely dead and have very low moisture contents. Lawns that are dead and very dry may support a spreading fire and may also burn with greater success when other combustible fuel, such as loose dead clippings and overstorey leaf litter, has accumulated on them.

The practice of maintaining lawns in a healthy and clean state will help to provide a non-flammable buffer area around homes and infrastructure in bushfire prone areas.

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Appendix A Experimental data from point ignition experiments

Table A.1 Raw data from the point ignition experiments

Exp. Id.	Turf variety	Wind speed setting	Leaf blade moisture content (%)	Temp (°C)	Relative humidity (%)	Mean blade height (mm)	Ignition sustained (0 = fail, 1=success)
1	Couch	Calm	10.69	18.5	43	16	0
2	Couch	Moderate	10.69	18.5	35	16	0
4	Couch	Strong	10.69	18.5	35	16	0
5	Buffalo	Calm	27.46	19	29	24.3	0
6	Buffalo	Moderate	27.46	19	29	24.3	0
7	Buffalo	Strong	27.46	19.5	23	24.3	0
8	Buffalo	Calm	5.54	25	27	22	0
9	Buffalo	Moderate	5.54	25	27	22	0
11	Buffalo	Strong	5.54	25	27	22	0
12	Couch	Calm	5.53	25	24	13.3	0
14	Couch	Moderate	5.53	25	24	13.3	0
15	Couch	Strong	5.53	25	24	13.3	0
18	Couch	Calm	9.62	25	27	19.7	0
19	Couch	Moderate	9.62	26	23	19.7	0
20	Couch	Strong	9.62	27	20	19.7	0
22	Buffalo	Calm	5.12	29.5	17	17.3	0
23	Buffalo	Moderate	5.12	30	16	17.3	0
24	Buffalo	Strong	5.12	30	16	17.3	0
26	Buffalo	Calm	2.96	31	19	19.3	0
27	Couch	Calm	9.01	31	19	15.7	0
28	Buffalo	Moderate	2.96	31	17	19.3	0
29	Buffalo	Moderate	2.96	31.5	14	19.3	0
30	Buffalo	Moderate	2.96	31.5	14	19.3	0
31	Couch	Moderate	7.02	31.5	14	15.7	0
32	Couch	Moderate	7.02	31.5	14	15.7	0
33	Couch	Moderate	7.02	31.5	14	15.7	0

Table A.1 (continued) Raw data from the point ignition experiments

Exp. Id.	Turf variety	Wind speed setting	Leaf blade moisture content (%)	Temp (°C)	Relative humidity (%)	Mean blade height (mm)	Ignition sustained (0 = fail, 1=success)
34	Couch	Strong	7.02	31.5	14	15.7	0
35	Buffalo	Strong	2.96	31.5	14	19.3	0
36	Couch	Strong	7.02	31.5	14	15.7	0
37	Couch	Strong	7.02	31.5	14	15.7	0
38	Buffalo	Strong	2.96	31.5	14	15.7	0
39	Buffalo	Moderate	2.96	31.5	12	15.7	0
40	Buffalo	Moderate	2.96	31.5	12	15.7	0
41	Buffalo	Calm	2.96	31.5	12	15.7	0
42	Buffalo	Calm	11.89	35	17	20.3	0
43	Buffalo	Moderate	11.89	35	17	20.3	0
44	Buffalo	Moderate	6.99	35.5	14	20	0
45	Buffalo	Moderate	6.99	36	12	20	0
46	Buffalo	Moderate	6.99	35.5	13	20	0
47	Buffalo	Strong	6.22	35.5	13	20	0
48	Buffalo	Strong	11.89	35.5	13	20.3	0
49	Buffalo	Strong	11.89	35.5	14	20.3	0
50	Buffalo	Moderate	11.89	35.5	14	20.3	0
51	Buffalo	Moderate	11.89	35.5	14	20.3	0
52	Buffalo	Calm	11.89	35.5	14	20.3	0
53	Buffalo	Calm	6.99	35.5	13	20	0
54	Buffalo	Moderate	6.99	35.5	13	20	0
55	Buffalo	Moderate	6.99	35.5	13	20	0
56	Couch	Calm	30.30	36	17	15.3	0
57	Couch	Calm	30.30	36	17	15.3	0
58	Couch	Moderate	30.30	36	12	15.3	0
59	Couch	Moderate	30.30	36	12	15.3	0
60	Couch	Strong	30.30	36	10	15.3	0
61	Couch	Strong	30.30	36	10	15.3	0
62	Kikuyu	Calm	3.99	36	13	39	1
63	Couch	Calm	8.57	36	13	21.3	0

Table A.1 (continued) Raw data from the point ignition experiments

Exp. Id.	Turf variety	Wind speed setting	Leaf blade moisture content (%)	Temp (°C)	Relative humidity (%)	Mean blade height (mm)	Ignition sustained (0 = fail, 1=success)
64	Couch	Moderate	8.57	36	13	21.3	0
65	Kikuyu	Calm	11.20	31	33	36.7	1
66	Kikuyu	Moderate	11.20	31.5	22	36.7	1
67	Kikuyu	Strong	11.20	31.5	20	36.7	1
68	Kikuyu	Strong	11.20	31	22	36.7	1
69	Kikuyu	Calm	11.85	26	34	40.3	0
70	Kikuyu	Calm	11.85	26	34	16.3	0
71	Kikuyu	Calm	11.85	26.5	32	40.3	0
72	Kikuyu	Moderate	11.85	27	28	16.3	0
73	Kikuyu	Moderate	11.85	26.5	32	40.3	0
74	Kikuyu	Moderate	11.85	27	25	40.3	0
75	Kikuyu	Moderate	11.85	27	28	16.3	0
76	Kikuyu	Strong	11.85	27	25	40.3	0
77	Kikuyu	Strong	11.85	27.5	21	40.3	0
78	Kikuyu	Moderate	11.85	27	28	16.3	0
79	Kikuyu	Moderate	11.85	27	28	16.3	0
80	Buffalo	Calm	11.87	28	27	26.3	0
81	Buffalo	Calm	11.87	28	27	26.3	0
82	Buffalo	Moderate	11.87	28	27	26.3	0
83	Buffalo	Moderate	11.87	28	27	26.3	0
84	Buffalo	Moderate	11.87	28	27	26.3	0
85	Buffalo	Strong	11.87	28	27	26.3	0
86	Buffalo	Strong	11.87	28.5	22	26.3	0
87	Buffalo	Moderate	3.77	28.5	25	20	0
88	Buffalo	Calm	3.77	28.5	25	20	0
89	Buffalo	Calm	3.77	28.5	25	20	0
90	Buffalo	Moderate	3.77	29	26	20	0
91	Buffalo	Calm	4.32	29	28	21.3	0
92	Buffalo	Moderate	4.32	29	28	21.3	0
93	Buffalo	Moderate	4.32	30	22	21.3	0

Table A.1 (continued) Raw data from the point ignition experiments

Exp. Id.	Turf variety	Wind speed setting	Leaf blade moisture content (%)	Temp (°C)	Relative humidity (%)	Mean blade height (mm)	Ignition sustained (0 = fail, 1=success)
94	Buffalo	Strong	4.32	30	22	21.3	0
95	Buffalo	Strong	4.32	30	22	21.3	0
96	Couch	Calm	4.45	29.5	29	16.7	1
97	Couch	Moderate	4.45	29.5	29	16.7	1
98	Couch	Calm	4.36	30	32	16	0
99	Couch	Moderate	4.36	30	32	16	1
100	Couch	Strong	4.36	30	32	16	1
101	Kikuyu	Moderate	43.19	30.5	25	41.3	0
102	Kikuyu	Moderate	43.19	30.5	25	41.3	0
103	Kikuyu	Strong	43.19	30.5	25	41.3	0
104	Kikuyu	Strong	43.19	31	24	41.3	0
105	Kikuyu	Calm	43.19	31	24	41.3	0
106	Kikuyu	Calm	43.19	31	24	41.3	0
107	Kikuyu	Moderate	43.19	30.5	28	41.3	0
108	Kikuyu	Moderate	43.19	30.5	28	41.3	0
109	Kikuyu	Strong	43.19	31	24	41.3	0
110	Couch	Calm	4.94	30.5	33	18	0
111	Couch	Moderate	4.94	30.5	33	18	1
112	Couch	Strong	4.94	30.5	33	18	1
113	Couch	Strong	4.94	31	26	18	0
114	Couch	Strong	4.94	31	26	18	0
115	Buffalo	Calm	4.39	30.5	30	18.3	0
116	Buffalo	Moderate	4.39	30.5	30	18.3	1
117	Buffalo	Moderate	4.39	30.5	30	18.3	0
118	Buffalo	Moderate	4.39	30.5	30	18.3	1
119	Buffalo	Calm	3.38	30.3	33	24	1
120	Buffalo	Moderate	3.38	30.3	33	24	1
121	Couch	Calm	8.11	28	22	18.3	0
122	Couch	Calm	8.11	28	22	18.3	0
123	Couch	Moderate	8.11	28	22	18.3	1

Table A.1 (continued) Raw data from the point ignition experiments

Exp. Id.	Turf variety	Wind speed setting	Leaf blade moisture content (%)	Temp (°C)	Relative humidity (%)	Mean blade height (mm)	Ignition sustained (0 = fail, 1=success)
124	Couch	Calm	8.11	28	22	18.3	0
125	Couch	Calm	8.11	28.5	20	18.3	0
126	Couch	Moderate	8.11	28.5	20	18.3	1
127	Couch	Strong	8.11	28.5	20	18.3	1
128	Kikuyu	Calm	10.36	29	21	38.3	1
129	Kikuyu	Calm	10.36	29	21	5	0
130	Kikuyu	Moderate	10.36	29	21	5	0
131	Kikuyu	Moderate	10.36	29.5	15	5	0
132	Kikuyu	Strong	10.36	29.5	15	5	0
133	Kikuyu	Strong	10.36	29	21	38.3	1
134	Kikuyu	Strong	10.36	29.5	15	5	0
135	Couch	Calm	22.88	29.5	19	18.3	0
136	Couch	Moderate	22.88	29.5	19	18.3	0
137	Couch	Strong	22.88	29.5	17	18.3	0
138	Couch	Calm	6.50	30.5	19	20	0
139	Couch	Calm	6.50	30.5	19	20	0
140	Couch	Calm	6.50	30.5	19	20	1
141	Couch	Calm	6.50	30.5	19	20	0
142	Buffalo	Calm	6.43	30.5	16	28	0
143	Buffalo	Calm	6.43	30.5	16	28	0
144	Buffalo	Calm	6.43	30.5	16	28	0
145	Buffalo	Calm	6.43	30.5	16	28	0
146	Buffalo	Calm	6.43	30.5	16	28	0
147	Kikuyu	Calm	10.33	30.5	16	44.7	1
148	Kikuyu	Calm	10.33	30.5	16	15.3	0
149	Kikuyu	Calm	10.33	30.5	16	15.3	0
150	Kikuyu	Moderate	10.33	30.5	16	15.3	0
151	Kikuyu	Moderate	10.33	30.5	16	44.7	1
152	Kikuyu	Moderate	10.33	30.5	14	15.3	0
153	Kikuyu	Moderate	10.33	30.5	14	15.3	0

Table A.1 (continued) Raw data from the point ignition experiments

Exp. Id.	Turf variety	Wind speed setting	Leaf blade moisture content (%)	Temp (°C)	Relative humidity (%)	Mean blade height (mm)	Ignition sustained (0 = fail, 1=success)
154	Kikuyu	Strong	10.33	30.5	14	15.3	0
155	Kikuyu	Calm	10.63	29.5	19	29.7	1
156	Kikuyu	Calm	10.63	29.5	19	11	0
157	Kikuyu	Calm	10.63	29.5	19	11	0
158	Kikuyu	Calm	10.63	29.5	19	29.7	1
162	Buffalo	Moderate	16.08	31.5	14	30.7	0
163	Buffalo	Calm	16.08	31.5	14	30.7	0
164	Buffalo	Calm	16.08	31.5	14	30.7	0
165	Buffalo	Calm	16.08	31.5	14	30.7	0
166	Buffalo	Calm	16.08	31.5	14	30.7	0
167	Buffalo	Strong	14.10	31.5	14	30.7	1
168	Buffalo	Moderate	12.13	32	13	25.7	0
169	Buffalo	Moderate	12.13	32	13	25.7	0
170	Buffalo	Moderate	12.13	32	13	25.7	0
171	Buffalo	Calm	12.13	32	13	25.7	0
172	Buffalo	Calm	12.13	32	13	25.7	0
173	Buffalo	Strong	12.13	32	13	25.7	1
174	Buffalo	Strong	12.13	32	13	25.7	0
175	Kikuyu	Moderate	16.84	32	9	44.7	0
176	Kikuyu	Strong	16.84	32	9	44.7	0
177	Kikuyu	Strong	16.84	32	9	44.7	0
178	Kikuyu	Moderate	16.84	32	9	44.7	0
179	Kikuyu	Moderate	16.84	32	9	44.7	0
180	Kikuyu	Calm	16.84	32	9	44.7	0
181	Kikuyu	Calm	16.84	32	9	44.7	0
182	Kikuyu	Calm	7.11	21	32	11	0
183	Kikuyu	Calm	7.11	21	32	35.7	1
184	Kikuyu	Calm	7.11	21	32	11	0
185	Kikuyu	Moderate	7.11	21	32	11	0
186	Kikuyu	Moderate	7.11	21	32	11	0

Table A.1 (continued) Raw data from the point ignition experiments

Exp. Id.	Turf variety	Wind speed setting	Leaf blade moisture content (%)	Temp (°C)	Relative humidity (%)	Mean blade height (mm)	Ignition sustained (0 = fail, 1=success)
187	Kikuyu	Moderate	7.11	21	32	11	0
188	Kikuyu	Strong	7.11	21	32	11	0
189	Kikuyu	Strong	7.11	21	32	35.7	1
190	Kikuyu	Strong	7.11	21	32	11	0
191	Couch	Calm	8.07	23.5	27	17	0
192	Couch	Calm	8.07	23.5	27	17	0
193	Couch	Moderate	8.07	23.5	27	17	0
194	Couch	Moderate	8.07	23.5	27	17	0
195	Couch	Moderate	8.07	23.5	24	17	0
196	Couch	Strong	8.07	23.5	24	17	0
197	Kikuyu	Calm	11.36	23.5	27	12.7	0
198	Kikuyu	Calm	11.36	23.5	27	34.7	0
199	Kikuyu	Calm	11.36	23.5	27	34.7	0
200	Kikuyu	Moderate	11.36	23.5	27	34.7	0
201	Kikuyu	Moderate	11.36	23.5	27	34.7	0
202	Kikuyu	Moderate	11.36	23.5	27	12.7	0
203	Kikuyu	Strong	11.36	24	22	12.7	0
204	Kikuyu	Strong	11.36	24	22	34.7	0
205	Kikuyu	Strong	11.36	24	22	34.7	0
206	Couch	Moderate	10.68	24	22	16.3	0
207	Couch	Moderate	10.68	24	22	16.3	0
208	Couch	Moderate	10.68	24	22	16.3	0
209	Couch	Moderate	10.68	24	22	16.3	0
210	Couch	Moderate	10.68	24	22	16.3	0
211	Couch	Calm	9.13	24	28	16.7	0
212	Couch	Calm	9.13	24	28	16.7	0
213	Couch	Calm	9.13	24	28	16.7	0
214	Couch	Moderate	9.13	24	28	16.7	0
215	Couch	Moderate	9.13	24	28	16.7	0
216	Couch	Strong	9.13	24	28	16.7	0

Table A.1 (continued) Raw data from the point ignition experiments

Exp. Id.	Turf variety	Wind speed setting	Leaf blade moisture content (%)	Temp (°C)	Relative humidity (%)	Mean blade height (mm)	Ignition sustained (0 = fail, 1=success)
217	Couch	Strong	9.13	24	28	16.7	0
218	Kikuyu	Calm	7.37	35.5	16	10.3	0
219	Kikuyu	Calm	7.37	35.5	16	16	0
220	Kikuyu	Moderate	7.37	35.5	16	10.3	0
221	Kikuyu	Moderate	7.37	35.5	16	16	0
222	Kikuyu	Strong	7.37	35.5	16	10.3	0
223	Kikuyu	Strong	7.37	35.5	16	16	0
224	Kikuyu	Strong	7.37	35.5	16	16	0
225	Kikuyu	Calm	3.69	29	33	12.7	0
226	Kikuyu	Moderate	3.69	29	31	12.7	0
227	Kikuyu	Moderate	3.69	29.5	26	12.7	1
228	Kikuyu	Strong	3.69	29.5	26	12.7	0
229	Kikuyu	Strong	3.69	30	25	12.7	1
230	Kikuyu	Calm	3.69	30	25	12.7	0
231	Kikuyu	Calm	3.69	30	25	12.7	0

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