Hort Innovation

Final Report

Conveying the benefits of living turf – a bushfire retardant

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Conveying the benefits of living turf – a bushfire retardant TU17008

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Content

Summary

GHD and CSIRO were commissioned by Hort Innovation to conduct new research into the fire protection benefits of living turf as a component of landscaping and to provide the turf industry with information to develop and market sustainable products for use in reducing bushfire risk in bushfire-prone areas. This project includes a literature review and a scientific evidence-based assessment of the fire protection benefits of living turf, along with fact sheets summarizing these results. In addition, the literature review of this project considers the susceptibility of artificial turf to combustion and the testing methods used to rate synthetic turf products, which have rarely been considered in a bushfire context. This project contributes to the **Turf Industry Strategic Investment Plan** – Outcome 1 – **Strategy 4**, i.e. Undertake review of existing literature to collate benefits and identify information gaps and **Strategy 5** i.e. Conduct research to address information gaps.

Three common Australian turf varieties were studied in depth throughout this project; buffalo, kikuyu and couch. However, many of the results also apply more broadly to any turf with similar properties.

Specifically, through the course of this project three resources have been developed:

1. A literature review of synthetic and living turfs and their flammability, combustion materials and bushfire protection implications
2. A scientific report detailing the results of ignition experiments on three living turf types at various fuel moisture contents and wind speeds
3. Fact sheets for each of the three turf types to communication the fire protection benefits of living turf.

Keywords

Turf; bushfire; combustibility; flammable; ignition; moisture content; asset protection zone; defendable space; landscaping; buffalo; kikuyu; couch.

Introduction

The severe bushfire season experienced in Australia during the 2019/20 summer resulted in over 46 million acres of damage to the Australian landscape. The impact of the fires were estimated to cost $3.9 billion to the economy, with insured claims estimated to be approximately $1.9 billion. Almost 3,000 homes, and thousands of businesses and other buildings were destroyed (CDP 2020). This fire season has once again brought the importance of bushfire planning and preparation to the forefront of public discourse, for which the design and maintenance of buffers or asset protection zone around buildings is a critical component. The role of turf as a suitable component of asset protection zones is widely recognised by fire agencies, but there is very little information available to the public that documents the bushfire protection properties conferred by turf and the scientific properties that underpin them. In addition, while synthetic turf is increasing in popularity for use in gardens and outdoor spaces, little consideration has been given to its suitability for landscaping in the context of bushfire planning. These two knowledge gaps begin to be answered by this project.

GHD was engaged by Hort Innovation to undertake a study on the benefits of living turf; a natural fire retardant, to extend information in this area and fill a research gap for turf producers. The research performed through the course of this project, including scientific testing of Australian turf samples, addresses the lack of evidence-based information surrounding the fire-resistant properties of living grasses. The literature review component of the project draws on existing information of the living and synthetic turf industries in Australia, the principles of landscaping for bushfire and technical knowledge of firefighting practices. The combustion properties and testing methods used for synthetic turf were also examined, to consider whether these testing methods are appropriate in a bushfire context.

These resources can give turf industry participants confidence, and scientific evidence, that turf can play an important part of protecting property in bushfire prone areas where it is maintained correctly, and can assist firefighters in their response by providing safe areas from which to defend properties. An example of this is shown in Figure 1 below where a kikuyu lawn has slowed the spread of a bushfire which has been controlled before causing damage to property.

Figure 1 Turf as a component of firewise landscaping

Methodology

This project consists of three components:

1. A literature review of synthetic and living turf properties in relation to bushfire risk management
2. A scientific report detailing the results of ignition experiments to assess the flammability of three turf types (buffalo, couch and kikuyu) under varying moisture contents
3. Fact sheets summarising the results of the literature review and combustion experiments for each turf type

Literature review

GHD has undertaken a synthetic grass flammability attributes literature review seeking to identify:

- A typology of different synthetic turf types (materials/composition) available in the Australian market
- Melting points and ignition temperatures
- Flammability
- Key information from Material Safety Data Sheets (including if available combustion products)
- Testing standards used to assess the flammability of synthetic turf
- Types of damage caused to the product when subject to ignition, embers, radiant heat exposure etc.

GHD has also undertaken a literature review of garden and landscaping advisory material produces by Australian fire and emergency services (and relevant material from other countries) to identify:

- Turf species on the Australian market; their attributes and maintenance requirements
- The flammability of living turf
- The extent to which living turf is highlighted as a component of firewise garden/landscape design
- The extent to which there are opportunities to improve the specifying living turf as a fire retardant feature in garden/landscape design.

Combustibility experiment

CSIRO undertook many attempted ignitions of buffalo, couch and kikuyu at varying fuel moisture content to understand the combustibility of these turf types. Combustibility describes the ability of a material to both ignite and sustain fire spread. These experiments were performed in the CSIRO Pyrotron in Canberra, which further allowed testing under three wind speed conditions (low, moderate and high). Kikuyu samples were also tested at shorter and longer lengths to observe any difference in fire spread cause by leaf blade length. Turf samples were dried progressively on a concrete surface in the sun, and oven-dried to attain extremely low moisture content levels. Cotton balls injected with ethanol were used as a standard point ignition source for consistent results as shown in Figure 2 below. Any ignitions which were able to sustain a fire for more than 20 cm from the point source were deemed to be sustained. Some samples were tested using a line of fire from a leaf litter source to observe the effect of a hotter fuel source.

Figure 2 Point ignition experiment sequence

The results of the ignition experiments are presented as graphs which identify the likelihood of ignition at different fuel moisture contents for each turf type.

Factsheets

Factsheets have been developed using a combination of pertinent information from both the literature review and flammability experiments. These fact sheets are designed to communicate the key points from this research to turf industry participants to demonstrate the strong bushfire protection potential of correctly using living turf as a landscaping component around properties in bushfire prone areas.

Outputs

In order to provide turf industry stakeholders with new scientific evidence to develop and market firewise turf products and use, this project delivers:

- A documented literature review identifying relevant combustion products and testing standards of synthetic turf products, and the uses and benefits of living turf as documented by fire agencies and in other relevant literature
- A scientific report presenting the results of live turf ignition experiments, presenting the evidence that turf must be essentially dead and extremely dry to sustain fire
- Scientifically validated fact sheets suitable for promoting the fire protection benefits of living turf identified during the project

The three deliverables of this project communicate the benefits of living turf and address information gaps that have been previously underutilised by the turf industry in marketing and product performance, which has relevant application to landscaping considerations in bushfire prone areas.

Outcomes

The end-of project outcomes for this research include scientific knowledge and analytical outputs which enable the live turf industry to effectively communicate the fire protection benefits of living turf to relevant customer markets including landscape architects, DIY landscaper/gardeners, recreational park/facility and sporting field managers, fire safety industry, fire and emergency services, town planners and others. Information gaps present in the turf industry were identified and addressed through reviewing existing literature on the bushfire protection benefits of living turf, and novel scientific research to demonstrate the very low flammability of living turf which makes it ideal for use in asset protection zones. Table 1 outlines the intermediate (longer term) outcomes of the individual outputs delivered by the project.

Table 1: Intermediate outcomes of project deliverables.

Output	Outcomes
Scientific literature review	The scientific literature review provides a useful basis for improving the awareness of living turf benefits, appropriate maintenance to maximise its capacity to reduce fire spread, and identifying further information gaps in the industry. This review will also improve the scientific knowledge of the combustion products of common synthetic turf materials and highlights the gap in current testing standards for these products which are not equivalent to a bushfire context.
Turf ignition experiment	The living turf ignition experiments at various fuel moisture contents provide a scientifically validated basis for the promotion of the bushfire protection benefits of living turfs. This information will improve the scientific understanding of the fire protection benefits of living turf, particularly its resilience to ember attack and flame impingement. These experiments also demonstrated the reduction in combustibility by maintaining lawn in a short condition where it is not able to be kept alive or has already died.
Fact sheets	Three fact sheets have been developed to describe the bushfire protection benefits conferred by living turf for each of buffalo, couch and kikuyu turf. Fact sheets provide a useful means of communicating the fire-retardant benefits of living turf to relevant turf market sectors. This information extends the scientific understanding of the ignition probability for lawns facing ember attack in bushfire weather conditions and summarises the key results from the scientific report in an easy to read format for each turf type for the benefit of industry levy payers. These fact sheets may be used as a resource for the turf industry to develop marketing materials.

Monitoring and evaluation

The Key Evaluation Questions (KEQs) for this project have been successfully addressed as documented in Table 2 and developed in the Monitoring and Evaluation (M&E) plan at the commencement of the project.

Table 2: Achievement of Key Evaluation Questions

KEQ	Response
To what extent has the project increased industry knowledge of the combustibility and combustion products of the synthetic turf products which compete with live turf products?	The literature review provides information regarding chemical and physical properties of synthetic turf and standards that are currently used to assess its fire retardant capability. This includes features such as melting point and ignition point gathered from a wide variety of sources given the variation in these features between products.
To what extent has the scientific knowledge basis underpinning the fire retardant benefits of living turf been extended?	Experiments performed by CSIRO provide robust scientific evidence that living turf is resistant to ignition and therefore may be used to mitigate bushfire risk as a part of landscaping for bushfire protection. These have been undertaken using common Australian turf varieties that are used in gardens across the country.
To what extent has the project provided outputs suitable for improving market awareness of the benefits of living turf for bushfire protection applications in town planning, landscape architecture and public bushfire safety management?	All three outputs (literature review, experiment report and factsheet) may be used to improve the market awareness of the benefits of living turf in bushfire protection to supress fire spread and provide a defendable space surrounding property. The literature review and fact sheets includes photographic evidence demonstrating successful examples of turf providing property protection from recent bushfires in Victoria.
To what extent has the project met the needs of turf industry levy payers?	All three outputs of the project contribute to the Turf Industry Strategic Investment Plan – Outcome 1 – Strategy 4, i.e. Undertake review of existing literature to collate benefits and identify information gaps and Strategy 5 i.e. Conduct research to address information gaps. In particular, the literature review identifies previous information gaps in evidence-based knowledge of the combustibility of turf which the ignition experiments directly address.
How well have turf industry levy payers been engaged in the project?	This project has provided numerous touch points with turf industry participants. Turf samples used in the experiments were provided by CanTurf who are part of the turf industry based near Canberra. Turf Australia had the opportunity to review and provide feedback on draft versions of the literature review and fact sheets. Additionally, content was provided for two magazine articles which were produced during the course of the project to inform turf industry participants of the progress and anticipated results.
To what extent were the project activities and findings appropriate to	The project delivers resources of varying formats, providing in-depth scientific and analytic outputs. An easy-to-read summary (fact

KEQ	Response
the target audience/s of the project?	sheets) of the results of both scientific report and literature review are also made available to benefit industry levy payers. This means that turf levy payers are able to use the resource (and corresponding level of detail) that most suits their needs.
What efforts did the project make to improve efficiency?	All turf samples were provided by a local turf levy payer who was willing and able to supply samples to the CSIRO pyrotron in Canberra in a timely manner.

Recommendations

This research provides new information for turf industry participants to read, digest and use to develop marketing materials, and otherwise disseminate the information to promote the use of turf as a firewise component of landscaping.

In particular, a focus on the appropriate maintenance that allows turf to resist ignition and spread could be of use to bushfire-prone communities. For example, ignition experiments performed in the course of this research have shown that turf should be kept in a living state (although can be water-stressed), free of combustible materials, and where it is not possible to attain a live state should be cut short to reduce its combustibility. Existing materials that describe landscaping for bushfire protection in Australia are often focused on a certain state or territory, do not have a strong emphasis on turf and do not describe appropriate maintenance regimes or requirements in detail. The turf industry could consider developing a landscaping for bushfire protection guide that focuses on turf as a material that slows fire spread and supports suppression activities. This could cover southern Australia and include turf types and maintenance appropriate to numerous jurisdictions where turf can be an important part of bushfire protection planning.

Refereed scientific publications

The output of this project includes a scientific report which has been peer-reviewed. This report has not been published elsewhere, as this report has been commissioned by GHD for the purposes of this project.

Plucinski, M.P., 2020. The combustibility of turf lawns. CSIRO Land and Water Client Report No. EP201008, Canberra, Australia.

References

Centre for Disaster Philanthropy (CDP), 2020. 2019-2020 Australian bushfires. Accessed 12/03/2020 at https://disasterphilanthropy.org/disaster/2019-australian-wildfires/

All sources for contributing reports are listed in the References section of the relevant Appendix.

Intellectual property, commercialisation and confidentiality

No project IP, project outputs, commercialisation or confidentiality issues to report.

Acknowledgements

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Andy Middleton from CanTurf, for providing the three turf types that were used for the scientific experiments.

Matt Plucinski from CSIRO, for the contribution of photos and providing feedback on the fact sheets.

Hort Innovation and Turf Australia provided feedback on draft versions of the outputs of this project.

Appendices

Appendix 1 – Literature review undertaken by GHD for this project:

Living turf fire benefits study – Literature review

Appendix 2 – Scientific report undertaken by CSIRO for this project:

The combustibility of turf lawns

Appendix 3 – Series of fact sheets conveying the results of this project, developed by GHD:

Fact sheet 1 – *Bushfire protection benefits of buffalo turf*

Fact sheet 2 – *Bushfire protection benefits of couch turf*

Fact sheet 3 – *Bushfire protection benefits of kikuyu turf*

Horticulture Innovation Australia Limited

Living turf fire benefits study - Literature review

April 2020

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1. Introduction

1.1 Purpose

This living turf fire benefits project includes a desktop study and a scientific evidence-based assessment of the fire protection benefit of living grass, with some comparison to synthetic grass. The purpose of this report is to articulate the benefits of living grass in firewise landscape design, and to provide the turf industry with information to develop and market sustainable products for use in reducing bushfire risk in bushfire-prone areas. This project contributes to the **Turf Industry Strategic Investment Plan** – Outcome 1 – **Strategy 4**, *i.e. Undertake review of existing literature to collate benefits and identify information gaps* and **Strategy 5***, i.e. Conduct research to address information gaps.*

1.2 Background

In bushfire-prone areas, the nature of vegetation surrounding houses and buildings has a very strong influence on the degree of bushfire damage/loss risk to which a building is exposed. The presence of flammable vegetation and combustible materials in close proximity to a house or building is a key factor which increases house/building ignition risk, whereas risk is reduced by vegetation and materials which are not conducive to being ignited by airborne embers or when exposed to high radiant heat levels. For these reasons planning regulations in most Australian States and Territories require new dwellings/extensions and other building types in bushfire-prone areas to be subject to *Bushfire Attack Level* (BAL) assessment (quantifying radiant heat exposure levels at the building being assessed). Based on such assessments, buildings are then required to be separated from bushfire-prone vegetation by a distance appropriate to their design and construction, and for the intervening space (variously referred to as Asset Protection Zones or Defendable Space) to be established and maintained in a condition which minimises the potential for fires to start and spread within such zones.

To this end, fire and emergency service agencies in the different states and territories have developed advisory materials providing guidance on firewise landscaping design and plant selection around houses, and providing standards for maintaining outdoor areas including vegetation around houses and buildings in a firewise condition. Well maintained lawns have the potential to resist ember attack by not sustaining ignitions during ember attacks, in contrast to some other ground covers used in landscaping. One of the more detailed publications currently available is *Landscaping for Bushfire* (CFA Victoria, 2011[1]) developed in response to Recommendation 44 of the Victorian Bushfires Royal Commission. The *Landscaping for Bushfire* guide promotes the use of gravel paths, non-flammable mulch, and mown grass in areas separating homes from bushfire-prone vegetation, and cautions against incorporating flammable materials and objects in such areas, particularly immovable ones. Live turf and lawns maintained in a short, green condition are promoted, and no mention is made of artificial turf or lawn products.

Synthetic turf, as a substitute to living turf, is increasingly being used in landscaping, particularly in backyards, sports fields and playgrounds. Synthetic turf is typically made of a mixture of polypropylene (PP), polyethylene (PE) or nylon fibres, some products also incorporating ‘rubber crumb’ often recycled from tyre rubber, and with base material variously comprised of materials including rubber and latex. Depending on the materials mix used, different synthetic turf products have different propensity for ignition by embers and radiant heat and different potential for sustaining fire spread across the laid synthetic turf product. Such materials when undergoing

[1] For Table of Contents and link to full online document, see https://www.cfa.vic.gov.au/plan-prepare/landscaping

combustion may generate health risks due to the release of toxic gases like dioxins, furans and other noxious emissions produced when they burn (Verma & Vinoda 2016).

Some synthetic grass manufacturers/suppliers subject their products to fire testing, very often using test methods applicable for carpet and indoor flooring products, and some provide on-line You-Tube clips of their products being flame tested with hand-held gas guns. Such tests typically are static tests, with no accounting for the effects of wind (or high fuel temperature), which is a major influence on fire spread in outdoor environments, but not relevant for testing of indoor flooring materials.

Given the lack of evidence-based bushfire-relevant information on the fire-resistant nature of living grass compared to synthetic grass, and the gap in guidance materials relating to choosing between living or synthetic grass products in bushfire-prone landscape design, this project has the potential to provide important evidence and information for the turf industry to develop and market sustainable bushfire-wise products for use in reducing bushfire risk in bushfire-prone areas.

1.3 Scope and limitations

This report has been prepared by GHD for Horticulture Innovation Australia Limited and may only be used and relied on by Horticulture Innovation Australia Limited for the purpose agreed between GHD and the Horticulture Innovation Australia Limited as set out in section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than Horticulture Innovation Australia Limited arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer to section 1.4 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

1.4 Assumptions

In preparing this report, GHD has made the following assumptions:

- Turf species tested are limited to buffalo, kikuyu and couch on the assumption these are the main commercial turf species on the market in Australia – no inference is made as to whether the fire protection benefits attributable to these species also extend to other species;
- The peak bushfire season in southern Australia corresponds mostly to the summer months (December, January, February), however GHD notes that in sub-tropical areas the bushfire season is principally in spring (September, October, November), and in the tropics is in the late wet season (typically July to September). In all cases, it is assumed these periods are active growth periods for living turf/lawns.

2. Method

GHD undertook a literature review as a component of the project TU17008 *Conveying the benefits of living turf – A bushfire retardant*. This literature review has been divided into two main components, to assess the suitability of synthetic grass and subsequently living grass to be used as part of firewise landscaping.

The synthetic turf literature review has identified synthetic grass flammability attributes including:

- A typology of different synthetic turf types (materials/composition) available in the Australian market
- Melting points and ignition temperatures
- Flammability
- Key information from Material Safety Data Sheets (including combustion products if available)
- Types of damage caused to the product when subject to ignition, embers, radiant heat exposure etc.

The synthetic turf literature review is presented in section 3.

GHD has also undertaken a literature review of garden and landscaping advisory material produced by Australian fire and emergency services (and relevant material from other countries) to identify:

- Turf species on the Australian market; their attributes and maintenance requirements
- The flammability of living turf
- The extent to which living turf is highlighted as a component of firewise garden/landscape design
- The extent to which there are opportunities to improve the specifying of living turf as a fire retardant feature in garden/landscape design.

The living turf bushfire protection benefits review is presented in section 4.

3. Synthetic turf review

3.1 Overview of artificial turf development and composition

Synthetic turf, initially termed Chemgrass, was developed and first installed in 1964 at Moses Brown School in Providence, Rhode Island, USA. This was followed by a larger installation at Houston Astrodome, from which it derived its colloquial label ‘Astroturf’ (Turf Australia n.d.).

Over the past 50 years synthetic turf has undergone three major generations of product development. The first generation was made of short, 10-12 mm, high-density nylon yarn which, unless used wet, caused severe friction burns on exposed skin in situations where a person fell and slid on the synthetic grass (Turf Australian n.d., Victoria State Government 2017).

Second generation synthetic turf products were principally made of polypropylene and were designed with a longer blade length, 20-35 mm, and comprised a lower density of blades. To give the required support and stability, rounded sand was used as an infill (Turf Australia n.d.).

The third generation of synthetic turf has been in use since the late 1990s, being the generation of synthetic turf products in most common use today. It is made using a softer polyethylene fibre, with a longer blade design than previous versions, of around 40-65 mm (Technical Textiles & Nonwoven Association 2013). To give the rigidity and support required for the turf, rubber or plastic granules are often used as infill. Many third generation synthetic turf products feature synthetic ‘thatch’ between the taller synthetic grass blades, giving a less uniform appearance better imitating the variability of colour found in natural lawn systems. The third generation synthetic turf products have increased both the popularity and use of synthetic turf in Australia, increasingly expanding markets from sporting and commercial applications into residential/landscaping uses (Artificial Turf 2019).

A fourth generation of artificial turf products seeks to dispense with infill components through providing a dense structure (web) of twisted synthetic fibres to provide support to the synthetic grass blades. The web is most frequently made of polypropylene (PP), polyethylene (PE), PE and PP copolymer, polyamide (PA) or nylon (PA6) and may also consist of a mixture of polyethylene, polypropylene or nylon fibres (Kukfisz 2018).

Over recent years, synthetic turf has increasingly been taken up in residential and commercial landscaping settings with clients perceiving that synthetic turf will have lower maintenance requirements than natural turf (Victoria State Government 2017).

As synthetic turf products have become more common, a range of concerns regarding their safety and utility, relative to natural turf, have emerged with comparative studies typically following after product take-up by the market. One of the more studied areas of synthetic turf – natural turf comparative studies is in relation to sporting injury occurrence (Department of Local Government, Sport and Cultural Industries). A wide range of studies covering different sports and injury types have been undertaken with variable results, however many of the studies indicate higher injury rates on synthetic turf surfaces.

Another field of comparative study is in relation to the surface temperatures in outdoor environments (Department of Local Government, Sport and Cultural Industries). Live turf has been found to sustain substantially cooler surface temperatures than synthetic turf surfaces, with some studies showing synthetic surface temperatures up to three times hotter than natural turf. An American study by Williams and Pulley (2009) recorded temperatures as high as 93ºC. In Australian summer conditions, synthetic lawns have been recorded to reach 80°C. Accordingly, it has become necessary for high volume water sprinkler systems to be installed and operated periodically on synthetic turf sporting fields in warm climates, to temporarily cool the surface temperatures and reduce heat-stress health risk (Department of Local Government, Sport and Cultural Industries). Synthetic turf flammability has also been studied in recent years (although not nearly as extensively as the aforementioned fields) with findings summarised in this report.

3.2 Materials and properties

Synthetic turf is created using methods similar to those used in carpet manufacturing. The turf comprises three components including a backing material that serves to hold the plastic blades of the synthetic grass, and infill which maintains the turf structure (Victoria State Government 2017). The backing material is typically a combination of polypropylene, polyethylene or nylon, and will be coated in a latex or other adhesive to hold the materials together. The plastic blades are usually polyethylene (in third generation products) and the infill material varies, depending whether the turf is for commercial or private use; either silica sand, rubber, cord or envirofill is used. The rubber infill (also referred to as 'rubber crumb') is often applied in commercial and/or sporting field use, and is made of old tyres, crushed down to create the supportive particles. Recent studies have raised the potential issue of the toxins released from the rubber crumb (refer Bleyer 2017).

The principal components of installed synthetic turf products (Victoria State Government 2017, TenCate Grass n.d.) are:

- Synthetic grass blades which can be:
  - Polyethylene group polymers
  - Polypropylene group polymers
  - Nylon group polymers
- Infill material which can be:
  - Polypropylene and/or Polyethylene group polymers
  - 'Rubber crumb' (principally vulcanised tyre rubber)
  - Silica sand (non-combustible)
- Backing material
  - Typically polypropylene and/or latex rubber
- Adhesive (typically all-weather solvent-based adhesive containing a blend of polymers, solvents and additives)

With the exception of silica sand infill components used in some products, all components are combustible.

3.3 Susceptibility of artificial turf to fire ignition

As synthetic turf comprises a mixture of combustible plastics, when exposed to an ignition source it is predisposed to melting and ignition. The flammability of plastics varies greatly between the different types of plastic and the additives used.

The combustible polymers in artificial turf have relatively low melting points (see Table 3.1). The most widely used (third generation) artificial turf products are comprised of polyethylene and have a melting point in the range of 110 to 130^{o}C. Further heating volatilises the polyethylene into hydrocarbon vapours, with ignition occurring from its flashpoint of around 330^{o}C (comparable to the flashpoint of the organic polymer cellulose from which dead, dry grass and paper is principally comprised, noting that live green grass is principally comprised of water). Glowing embers, as are commonly blown in front of an advancing bushfire, have a temperature of around 700-800^{o}C, and the flame of a burning leaf has a temperature of around 700^{o}C. Strips of polyethylene can be ignited with the flame of a match which has a temperature of around 700^{o}C.

Ignition testing undertaken by Kukfisz (2018) established that all polyethylene and polypropylene turf products tested ignited when exposed to radiant heat flux of less than 3 kW/m^2, which is considered ‘easily flammable’ (flammability class E_{fl}).

Table 3.1 Synthetic turf combustion properties

Material	Melting point (°C)	Ignition temperature (°C)	Combustion products (toxins)	Usage trends	Other information (risks/ease of damage)
Nylon	Highest melting point 160 – 260[3] 160 – 275[4]	485 – 575[3] 424 – 532[4]	Carbon monoxide and dioxide Smoke (particulates)	Stronger, more expensive[5]	May be more prone to high extractable lead concentrations Attracts water[6]
Polyethylene (PE)	109 – 123[7] 85 – 140[8] 126[9] 107 – 137[4]	349[4] 330 – 410[8]	Carbon monoxide and dioxide Smoke (particulates)	Softness[10] makes it appropriate grass material – looks more natural	UV stable Unable to absorb moisture[10]
Polypropylene (PP)	Higher melting point than PE 165[9] 158 – 168[4]	570[4] >357[11]	Carbon monoxide and dioxide Smoke (particulates)	Prevalent, inexpensive, but less durable Typically a backing (matrix) material	Doesn't maintain colour well Prone to UV breakdown[12]
Rubber	The melting point of crumb rubber is typically not reported.	260 – 316[4]	Carbon monoxide and dioxide Sulfur dioxide Zinc oxides Smoke (particulates)	Small particles provide support to turf blades	The EPA have identified several ingredients in tyres including: benzene, mercury, styrene-butadiene, polycyclic aromatic hydrocarbons, and arsenic, among several other chemicals, heavy metals and carcinogens. Tyre rubber combustion emissions are estimated to be 16 times more mutagenic than residential wood combustion in a fire place.[13]

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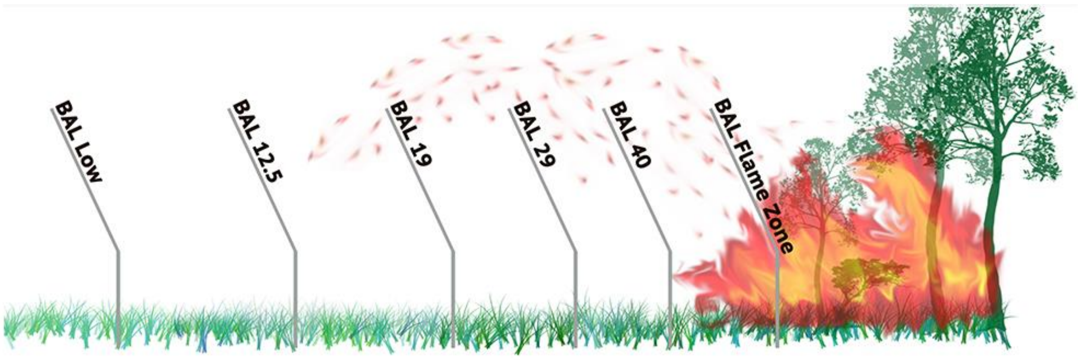
When polypropylene or polyethylene turf is installed in an external landscaping setting around homes in bushfire prone areas, it may be subject to an approaching bushfire. There are three forms of bushfire attack which the artificial turf may be subject to:

- **Ember attack** – low to high volumes of glowing embers blown ahead of the approaching fire by the wind, and continuing to be blown in from nearby areas of burnt, smouldering vegetation after the fire front has passed, potentially for several hours afterwards.
- **Radiant heat** – radiates directly from the flame front of the approaching fire. Assuming the standard design fire for a forest fire as used in AS3959:2018 *Construction of Buildings in Bushfire Prone Areas* (Forest fire on level ground, with a surface fuel load of 25 tonnes per hectare, burning under a Forest Fire Danger Index (FFDI) of 100, with a flame front width of 100 metres) the forest fire flame front will generate a modelled radiant heat flux (RHF) of >3 kW/m^2 at a distance of 110 metres ahead of the fire. At a distance of 50 metres the RHF will have increased to 11.65 kW/m^2, at 20 metres the RHF is over 38 kW/m^2, and at 10 metres away it will be 76 kW/m^2. Note that the radiant heat flux generated in 'reaction to fire testing' of floor coverings has a maximum RHF exposure of around 11 kW/m^2 at the point closest to the radiant heat source.
- **Flame contact** – as the bushfire front approaches the synthetic turf landscaped area, flames from the fire front can directly impact the turf. The modelled flame length for the FFDI 100 design forest fire assumed in AS3959 is 23.7 metres.

The modelled radiant heat flux calculations referred to above are made using the detailed AS3959 Method 2 (normative) for determining the Bushfire Attack Level (BAL).



Source: NSW RFS

Figure 1 Mechanisms of bushfire attack

The Bushfire Attack Level (BAL) values referred to in Figure 1 refer to radiant heat flux (in units of kW/m^2). Embers lofted forward of the fire front (or blown from burning/smouldering areas after passage of the fire front) can land in combustible material and ignite them. Radiant heat decays with increasing distance from the fire, however it can still be sufficient to ignite combustible materials at BALs exceeding 12.5 (and in the case of PE and PP, less than this). The flame front is the third key mechanism of bushfire attack.

Claims that synthetic turf will not sustain fire spread are misleading. It may be true that in a wind-free environment, a synthetic turf product exposed to a point ignition source such as a match or hand-held gas burner may result in melting and localised flaming combustion at the point of ignition, with fire not spreading from the ignition point if the flame source is removed. Such a test cannot be taken to validly simulate conditions in a vigorous bushfire attack scenario. Polyethylene and polypropylene have the potential to sustain fire spread. In the case of polyethylene this has been illustrated in a number of recent catastrophic building fires which involved flammable composite cladding (typically a composite comprised of a polyethylene core, sandwiched between two aluminium sheets). Fires spreading via combustible cladding containing a polyethylene core have quickly spread floor-to-floor or engulfed multi-storey buildings, such as occurred in the 20 storey Grenfell Tower fire in London, UK in 2017, and the Neo200 building in Melbourne in 2019.

3.4 Synthetic turf flammability testing standards

The burning behaviour of synthetic grass is technically difficult to test and evaluate. Presently, there is no common international standard ignition or fire testing for outdoor application of artificial turf.

Some artificial turf manufacturers may have fire or burning testing undertaken, however in the absence of fit-for-purpose outdoor environment burn testing methodologies, typically such testing is undertaken using testing methodologies designed for indoor floor coverings, as may be required for indoor floor coverings such as broadloom carpet, carpet tiles and other internal flooring products. These tests do not heat the test samples to the high temperatures attainable in exposed sunny outdoor settings on hot adverse fire danger days, nor do they apply any wind during the tests, noting that wind is a critical contributing factor which influences bushfire spread and intensity.

For indoor 'reaction to fire' testing for building products, test samples conditioned for testing in accordance with BSEN 13238:2010 are conditioned at a temperature of 23±2ºC and a relative humidity of 50±5%. These test conditions may be relevant for many indoor conditions, however they are not relevant for outdoor installed synthetic turf exposed to direct sun and adverse fire danger conditions. Synthetic turf surface temperatures have been measured at more than three times the test conditioning temperature, and relative humidity below 10% (less than one fifth of the test conditioning relative humidity) has been observed in a number of high-consequence bushfire events. Adverse bushfire weather is commonly associated with hot, dry winds. Bushfire spread modelling incorporated in the *Australian Standard for Construction in Bushfire Prone Areas* (AS3959:2018) applies a wind speed of 45 km/hr. The conditions used for fire testing of indoor floor coverings are not representative of realistic outdoor environmental conditions to which synthetic turf products would be exposed during adverse fire weather conditions.

In Australia, Flammability/Flame Resistance testing for indoor floor coverings is undertaken using two test methods:

a) AS/NZS 2111.18:1997 for determination of fire propagation properties – a small ignition source (Methenamine Pill) is applied to the surface of the floor covering and ignited. No wind is present and the tests are carried out in an atmosphere with a temperature between 10 - 30°C, and 20-65% relative humidity.

b) AS/ISO 9239-1:2003 for determination of burning behaviour (Critical Radiant Flux) using a radiant heat source. The test involves a floor covering product being placed horizontally under the influence of a radiant heat source at one end – the test sample is ignited at the heat source end and the radiant heat flux at which combustion ceases is determined. The radiant heat received by the test sample is about 11kW/m^2 at the end closest to the heat panel, reducing down to 1 kW/m^2 at the end furthest away. The amount of smoke generated is also determined. This test may be relevant for indoor testing scenarios simulating the potential of radiating heaters to cause ignition, but for outdoor radiant heat flux in a bushfire scenario the test is not fit-for-purpose. AS 3959 (*Construction in Bushfire Prone Areas)* considers that at radiant heat flux of 12.5 kW/m^2 or less, building materials have a low likelihood of ignition such that the principle ignition source of concern is ember attack. The radiant heat flux levels of concern in bushfire situations are from 12.5 to 40+ kW/m^2. Again, the testing does not involve any exposure to wind.

The testing which is currently used for synthetic turf occurs in environmental conditions which are very much less extreme than those likely to be experienced during exposure to a bushfire during adverse fire weather. While synthetic turf samples may be able to pass flammability testing designed for indoor flooring materials, great care should be taken not to infer that fire-tested synthetic turf products are safe or fire resistant in a realistic bushfire scenario.

3.5 Smoke and combustion products

Polyethylene – PE (C_2H_4) and polypropylene – PP (CH_3) are both hydrocarbons. Combustion products of hydrocarbons are principally carbon monoxide and carbon dioxide and soot (particulates). Material Safety Data Sheets for PE and PP identify that fires involving these materials may produce irritating gases and dense smoke. Carbon monoxide (CO) toxicity occurs from breathing in CO at excessive levels. Carbon monoxide primarily causes adverse effects by combining with haemoglobin to form carboxyhemoglobin (HbCO) preventing the blood from carrying oxygen.

Accordingly, environments contaminated by smoke from PE or PP are considered toxic environments – firefighters will only enter structures containing smoke from burning PE and PP wearing self-contained breathing apparatus, to rescue occupants who are otherwise likely to die from smoke inhalation and/or carbon monoxide toxicity. The vast majority of bushfire fighters typically operate without self-contained breathing apparatus and are not able or allowed to operate in environments contaminated by dense smoke and irritating gases emanating from synthetic materials.

3.6 Fire damage

Due to the low melting point of synthetic grass surfaces, and their susceptibility to spot ignitions from embers, synthetic turf areas are vulnerable to permanent damage from embers during a nearby bushfire, and from other heat sources including cigarette butts and embers from barbeques or fire places/pits.

Figure 2 Example of melted synthetic turf from point ignition source

4. Living turf review

4.1 Overview of the live turf industry

History

The living turf industry in Australia began with planting imported Kikuyu Grass at the Hawkesbury Agricultural College in the 1920s and 1930s. The region's climate and fertile soils created the perfect environment for quick establishment and rapid growth of the grass. The region soon became a production zone of Kikuyu grass and people were able to cut and transplant the runners (Turf Australia n.d.).The primary use for Kikuyu in the 1930s was for establishing livestock pasture. However, due to the ease in transplanting and establishing the grass, it soon became a common feature in gardens.

The initial transplanting method involved long battens being laid on the turf, using an axe to cut along the edge of the batten. A shovel would then be used to cut under the strip of turf, then the turf would be rolled ready for transportation (Turf Australia n.d). The principals of turf cutting have remained the same over the past 80 years. However, improvements have been made as new technologies have been developed. In the 1960s the 'Ryan' Turfcutter was introduced, which was followed by the Brouwer Turfcutter in the 1980s. The 'sod' planter was invented later in the 1990s, and served to advance the turf industry, and increase the overall efficiency of the process.

Turf species

Over the past 90 years biological improvements have also been made in the turf industry. Additional turf grass species have been introduced and cultivated for specific lawn use. These include Buffalo Grass, Couch, Zoysia, Tall Fescue and Tif Turf, a Hybrid Bermuda grass. The addition of these species means living turf is a viable option for a range of Australian regions and climates. A variation of grass species also means a differing management requirements, some grass species require a higher level of maintenance. Species such as Kikuyu and Couch are fast growing and often invade undesirable areas, and therefore require mowing maintenance. Fescue is slow growing, however requires copious amounts of water particularly in summer, and is prone to fungal and pest diseases (Lawn Solutions Australia n.d.). Currently the most popular grass species is Buffalo Grass, as it can handle full sun to 70% shade, is highly drought tolerant, and has low maintenance costs (The Turf Farm n.d.). Specifically the brand Sir Walter Buffalo Grass is recognised as Australia's most popular turf and is supported by most industry experts as the best buffalo grass.

Turf industry

In 2017-18 the value of cultivated turf production in Australia was almost $250 million (ABS 2019). NSW is the state with the highest gross value for cultivated turf in 2017-18 (at $127 mil) followed by Queensland and Victoria with $47 mil and $41 mil respectively (ABS 2019). Turf Australia, the peak body for the turf industry, reported 176 Australian turf growers in 2017/18 (Turf Australia 2018). The Australian turf market in is dominated by the three species of Buffalo, Couch/Hybrid Couch and Kikuyu, which collectively represent around 90 per cent of total turf production volume in Australia, and 87 per cent of the value of the industry (Turf Australia 2018). Turf producers usually deliver the turf to the customer (67% direct delivery) with a small proportion having a contractor in between (14%) or being picked up directly by the customer (18%) (Turf Australia 2018).

Turfing methods

A variety of lawn species are available through specialised turf companies as well as general house and hardware stores. The easy access to a variety of turf species and the quick installation of the 'instant green carpet' gives landowners confidence in installing turf themselves. Industry experts suggest one of the most important steps in turf installation is the preparation of the soil before laying out the roll, and is key to maintaining healthy turf. In particular, having at least 75-100mm of topsoil helps the grass form a deep root system (Centenary Landscaping n.d.). Consequently in dry periods or drought, the turf is effective at finding water and will remain greener for longer (Centenary Landscaping n.d.).

Whilst rolls of lawn are the most common choice, seeding a lawn is another viable option and can save on cost (Centenary Landscaping n.d.). However due to the time and effort required in establishing a healthy lawn by seed, it is usually not the preferred option.

Living turf can be significantly cheaper than other options for outdoor surfaces such as artificial turf, concrete or pavers (Lawn Solutions Australia n.d.).

4.2 Turf types and biological attributes

Different grass species are likely to have different bushfire mitigation properties due to their particular biological attributes. Three grass types have been selected for this project which are common and popular turf species in Australia: Buffalo, Couch and Kikuyu. These species are described in further detail in the following sections and summarised in Table 4.1 below.

4.2.1 Buffalo grass

Buffalo grass is the common name for the popular turf species *Stenotaphrum secundatum* 'Sir Walter' which arrived in Australia in the 1840s. The reported origin of the species is the Indian Ocean region, which lends the plant to growing well in tropical, subtropical and warm temperate climates (OGTR 2018).

Buffalo grass is a perennial species which grows via branching stolons. When mowed or grazed this biology results in a dense thatch structure which excludes weeds. Buffalo grass grows best with partial or full shade. The stoloniferous growth means that although it is liable to spread, it is less invasive than other species that also spread via underground rhizomes (OGTR 2018).

Buffalo grass is distributed throughout the Australian turf industry, but is particularly common in Queensland and New South Wales. The turf is propagated by planting stolon cuttings or runners. Typically, when rolls are harvested a strip of grass is left behind which allows the Buffalo grass to revegetate the area.

The grass growth slows in autumn and in winter Buffalo grass becomes dormant in temperate environments. In tropical environments it will grow all year (OGTR 2018). This means that in summer, Buffalo grass is typically green which reduces bushfire risk and makes it a good choice for a lawn species in bushfire prone areas (CFA 2011).

4.2.2 Kikuyu

Kikuyu (*Pennisetum clandestinum*) is a grass species used for turf in Australia which was originally brought to the country from Kenya as a pasture species (Atlas Turf 2019). Kikuyu is a perennial grass with the key growth period in spring, summer and autumn. It is a drought tolerant species which is highly competitive and forms a dense mat which supresses weeds (DPI).

It can be highly invasive and therefore is likely to spread from wherever it is planted, due to the presence of both branching stolons and underground stems called rhizomes (Pastures Australia

2007). Kikuyu is the main turf species grown in South Australia, but is also grown in most turf regions other than Queensland and the Northern Territory (Turf Australia 2018).

4.2.3 Couch

Couch grass is widespread across Australia, and it is unclear whether it is indigenous to Australia or was an early coloniser. Couch is a perennial grass with stolons and rhizomes that forms into a mat (DJPR 2019). It can produce toxins that inhibit the growth of other species (known as allelopathy) and is not particularly shade tolerant (Western Australian Herbarium 1998).

The growth of Couch slows in cooler seasons (Western Australian Herbarium 1998). It is a resilient species that is able to tolerate changes in moisture including moderate flooding, and some salinity (AWI & CRC Salinity 2006).

Queensland and the Northern Territory are by far the largest Couch producers in Australia. Couch is the most commonly grown turf species in Australia (Turf Australia 2018).

4.2.4 Maintenance

Appropriate maintenance of these turf types includes regular mowing and watering. All of these grass species should be irrigated over summer to maintain moisture content which reduces bushfire risk (CFA 2011).

Mowing should use sharp blades, not cut more than a third of the blade height and leave 4 cm or more to reduce stress to the plant (Turf Australia 2016). Grass turf should be maintained in a state less than 100 mm in length to provide bushfire protection to property (NSW RFS 2019).

Good management such as allowing proper establishment, and watering at particular times of day (e.g. before 10 a.m.) can minimise water use (Turf Australia 2016). Buffalo, Couch and Kikuyu are all warm season species and as such require on average 20 per cent less water than cool season species such as Fescue (Turf Australia 2016). Watering for longer but less frequently encourages plants to develop deeper roots which also increases their resilience to drought (CFA 2011).

The ideal watering regime varies across different parts of Australia. A turf lawn that is well-established or has partial shade is likely to require less water. During summer, lawns in full sun of Couch, Buffalo or Kikuyu would require watering from 1 (East coast) to 3 times (Adelaide/Perth) per week (Turf Australia 2016).

It is worth noting that with a warm climate prone to drought, regions of Australia may be subject to water restrictions which can impact a householder’s ability to water outdoor spaces. However, water restrictions are unlikely to impact water use in such a way that green turf cannot be maintained. Restrictions often promote watering of grasses at a time when the water may be more beneficially used by the grass (rather than evaporating) such as before 10 a.m. For example, in Victoria, Stage 3 water restrictions allow watering of residential lawns between 6 a.m. and 8 a.m. on alternate days (DELWP 2019) which is easily enough to allow maintenance of a green lawn. Even if watering is completely prohibited, greywater and rainwater may be collected and used to water lawns and gardens, which are common practice in periods of extreme drought.

In addition, many Australian turf species are able to recover rapidly from periods of complete drought (3-4 weeks) and associated dormancy when they are watered by rain or irrigated (Lawn Solutions n.d.).

Table 4.1 Summary of three main turf Species in Australia

Turf attribute	Buffalo	Couch	Kikuyu
Scientific name	*Stenotaphrum secundatum*	*Cynodon dactylon*	*Pennisetum clandestinum* (syn. *Cenchrus clandestinus*)
Image *(Source: Turf Australia)*			
Production	All regions, mainly NSW and QLD/NT	All states, mainly QLD /NT	Most states (very little in QLD/NT), mainly NSW/ACT
Growth form	Branching stolons	Branching stolons and rhizomes	Branching stolons and rhizomes
Position	High tolerance to shade	Full sun	Full sun (tolerates some shade)
Lifespan	Perennial	Perennial	Perennial
Growth season	Summer and autumn (warm temperate) All year (tropical)	Spring/summer	Spring/summer
Benefits	Drought tolerant Tight cover excludes weeds Less invasive than Couch and Kikuyu Suitable for stabilising sandy soils Can withstand high wear	Drought tolerant Low maintenance Can withstand very high wear	Drought tolerant Supresses weed growth Stabilises soils Fast growing Can withstand high wear
Maintenance	Low maintenance requirements Low water demand	Requires frequent mowing Low water demand	Requires frequent mowing (every 5 to 7 days in peak growth) Low water demand

4.3 Live turf physical properties for fire resistance

Live turf, kept in a short green condition, is highly resistant to ignition by bushfire. This is due to the high moisture content in the live green leaf blades. The leaf blades will not ignite until the moisture contained within the blades has been driven-off by the heat source. Embers typically have insufficient heat energy to do this, and radiant heat exposure sufficient to reduce moisture levels to a combustible state take prolonged exposure to high levels of radiant heat.

The peak growth period of Buffalo, Couch and Kikuyu in summer means that they are likely to be actively growing and therefore more able to retain their green, moisture-rich nature during the highest period of bushfire risk (OTGR 2018).

4.4 Live turf benefits in a bushfire context

The Australian Standard 3959 -2018 *Construction of Buildings in Bushfire-prone areas* considers maintained turf to be a low threat vegetation (low likelihood of supporting bushfire spread). This standard cites grasslands managed in a minimal fuel condition including maintained lawns, golf courses, maintained public reserves, parklands and sporting fields as examples of low threat vegetation (Clause 2.2.3.2). Accordingly, live turf is a key component (and mitigation strategy) for the implementation of asset protection zones, and providing defendable space.

The following specific guidance is provided in relation to garden/landscape design scenarios for a Victorian context.

TURF

The lawn areas are planted with *Stenotaphrum secundatum* 'Sir Walter' (Sir Walter Buffalo Grass), a soft-leaf, hard-wearing turf species. It can be managed to a low height and will be irrigated over summer. This maintenance helps create a defendable space.

LAWN

The lawn species is *Pennisetum clandestinum* (Kikuyu Grass). It is tough, hard wearing and able to be managed at a low height. These lawns will be irrigated over summer to assist in maintaining a green, defendable space.

Figure 3 Excerpts from Landscaping for bushfire protection (CFA 2011)

4.4.1 Asset protection zones

Asset Protection Zones (APZs) are designed provide a low fuel buffer zone between a bushfire and a potentially fire-vulnerable asset. The NSW RFS (2005) identifies that APZs provide an area of reduced bush fire fuel that allows suppression of fire, and also provide an area from which backburning (for property protection) may be conducted. The APZ provides "an area which allows emergency services access and provides a relatively safe area for fire fighters and home owners to defend their property" (source: Standards for Asset Protection Zones; NSW Rural Fire Service; 2005).

APZ dimensions vary depending upon the surrounding type of vegetation, slope, regional fire weather factors, and the design/construction standard of the structure. Any APZ is to be maintained regularly during the locally declared bushfire season, by reducing fuel loads and minimising potential radiant heat levels (New South Wales Rural Fire Service 2019). Planting and maintaining live turf around a structure is encouraged on the basis it will not support surface fire spread to the adjacent dwelling/building, and will not be ignited by embers.

4.4.2 Defendable space

Conceptually a “defendable space” (terminology used in Victoria) is the equivalent of an Asset Protection Zone. The Victorian Country Fire Authority define Defendable Space as:

> *Defendable space is an area of land around a building where vegetation (fuel) is modified and managed to reduce the effects of flame contact and radiant heat associated with a bushfire. It usually comprises an inner zone and outer zone. Defendable space is one of the most effective ways of reducing the impact of bushfire on a building.*

Two key requirements of a defendable space are:

- A 10 metre zone immediately around a building within which CFA recommends to “avoid flammable objects near vulnerable parts of the building”; and
- An “Inner Zone” being “an area immediately around the house. It provides separation from fuel sources, radiant heat, eliminates direct flame contact and reduces ember attack. Vegetation needs significant and intense management. Fuel is managed to a minimum in this zone” (source: “Landscaping for Bushfire”; Country Fire Authority; 2011).

Maintained lawns are one of a number of ‘low fuel’ types the CFA encourages home owners and occupiers to maintain within a Defendable Space – others specifically identified are ponds, pools and tennis courts. Maintained lawn areas around houses provide defendable space for fire and emergency services to operate and defend homes.

Figure 4 below shows an example of how a defendable space operates in practice, in this case for Rural Fire Service crews provided by well-maintained turf lawns from the Tathra bushfires in 2018, with a high intensity bushfire approaching. Such locations, where maintained lawn and non-combustible surfaces (such as roads, driveways, footpaths and paved areas) not compromised by areas of flammable vegetation, are sought by emergency crews as locations from which to defend life and property. Such areas provide relatively safe areas around fire appliances where firefighters can remain safe while they respond to bushfire attack in the form of falling embers and tolerable levels of radiant heat.

Figure 4 Defendable space in use at the Tathra bushfire 2018 (source: news.com.au 2018)

4.4.3 Evidence of fire protection benefit

It is common in post-bushfire impacted areas to observe green lawns remaining largely undamaged by fire surrounding either unburnt houses, or burnt houses where airborne ember attack has directly impacted the house but the surrounding lawn remains unburnt.

Live turf is known operationally to both mitigate fire spread, and to provide defendable space to allow safe defence of properties. Lawns and walkways create firebreaks which interrupt the path of surface fire spread. Well-maintained lawns have low flammability and risk of ignition, and have been shown to remain intact even in the context of extreme bushfires which have occurred in Australia.

The following figures demonstrate the low chance of ignition of managed turf even under severe Australian bushfire conditions and ember attack.

Figure 5 Yarloop damage following Waroona bushfire (source: ABC News 2016)

The Waroona bushfire which burnt through Yarloop in Western Australia in 2016 destroyed 181 houses. Figure 5 above shows the green lawns around destroyed houses which reduced fire spread. Airborne ember attack direct to vulnerable housing, and house-to-house ignition, and ignition of garden trees/shrubs were the leading causes of fire loss and damage.

Figure 6 Tathra (NSW) following bushfires in 2018 (source: Clubs NSW 2019)

In 2018, Tathra (NSW) was subjected to a high intensity bushfire which approached from the west through forest, but as shown in Figure 6 above, has not spread across maintained lawns. Rather, airborne embers landing in pockets of fire-prone vegetation have resulted in the burning of some isolated garden beds, while maintained lawns remain largely intact.

4.5 Live turf as a component of firewise landscape design

Landscaping to reduce the impact of fire is known as 'firewise design'. Firewise design considers an asset at the centre of an area which should be situated so that it is increasingly protected from fire as you get closer to the asset. Firewise design is a well-established concept in American literature, where extreme wildfires are experienced in many states. The 'entire home ignition zone' is the zone surrounding a property or assert and can be up to a 60 metre radius (NFPA 2014). This zone is broken into a number of smaller zones. In general, the zones closest to the structure should comprise low to the ground vegetation, and be well irrigated to maximise their moisture content, while minimising fuels.

The Victorian Country Fire Authority's Landscaping for bushfire (CFA 2011) is one of the few resources in Australia which describes good landscaping practices to mitigate bushfire risk to property, including the choice of appropriate plant species based on their flammability.

There are four main principles of landscaping for bushfire, or firewise design, described as follows (CFA 2011):

1. **Create defendable space** – grass should be no more than 10 cm tall. Lawn space is identified as an area of low fuel to provide defendable space.
2. **Remove flammable objects from around the house** – the inner zone of defence around a house should have grass maintained to 5 cm height. Plants and materials that are flammable should be avoided within a 10 metre radius from the building.
3. **Break up the fuel continuity** – breaking up areas of flammable vegetation reduces the likelihood of fire spreading. Mown grass is identified as a barrier that can be used between groups of plants to create a break in fuels.
4. **Carefully select, locate and maintain trees** – maintaining trees reduces the chance of fire spread, the type of tree, location and pruning regime all influence the risk. Trees should be maintained so that they do not overhang roofs or have continuous canopies, but may be used as a windbreak.

The flammability of a plant relates to whether it will ignite, continue to burn, and how much fuel there is to burn through (CFA 2011). The CFA's Plant Selection Key rates grasses as Moderately Firewise (from Not Firewise, At-risk Firewise, Moderately Firewise to Firewise). This means that this type of vegetation may be used in the garden but must be maintained to ensure their less flammable condition is maintained. In the case of grasses this includes regular watering, mowing, and adequate disposal of cutting debris. If turf does turn brown from drought, it is best to cut it short, and dispose of litter immediately (CFA 2011; NFPA 2014).

Live grasses have oven dry weight ranging from 30% to 260% (CFA 2014). Scientific research into grass fires in field conditions (Cheney & Sullivan 2011) has identified that in dead grass fuels, in light winds, at fuel moisture contents above 20% (of oven dry weight), fires will not spread. In well maintained live lawns, and even drought-stressed live lawns, fuel moisture content is typically many times higher than the 20% fuel moisture threshold for fire spread in dead grass – as demonstrated in Figure 5 and Figure 6, areas of live lawn do not support fire spread.

4.6 Opportunities for the turf industry

Currently there are very few Australian resources that recognise the benefits of living turf to mitigate bushfire risk to property, by providing a defendable space, and an area of low flammability which reduces the risk of radiant heat and direct flame contact. These typically do not have much focus on turf, are confined to particular states or territories, and are largely silent on the maintenance strategies to maintain turf in a state that provides bushfire protection benefits.

Typically, fact sheets promoting the live turf industry compare aspects such as cost, maintenance, longevity, surface temperature and environmental impacts. However it is uncommon to find resources with information on the bushfire risk mitigation benefits conferred by turf which is maintained in a short, green condition.

This literature review, along with the accompanying scientific report and fact sheets to this report aim to begin to fill this gap, to provide turf producers with information which can be used for marketing purposes to demonstrate the value of living turf in firewise landscaping, or landscaping for bushfire.

Refer to the following resources for further reading:

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The combustibility of turf lawns

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Contents

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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.

[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)

Turf variety	Wind speed setting	Leaf blade moisture content class			
		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).

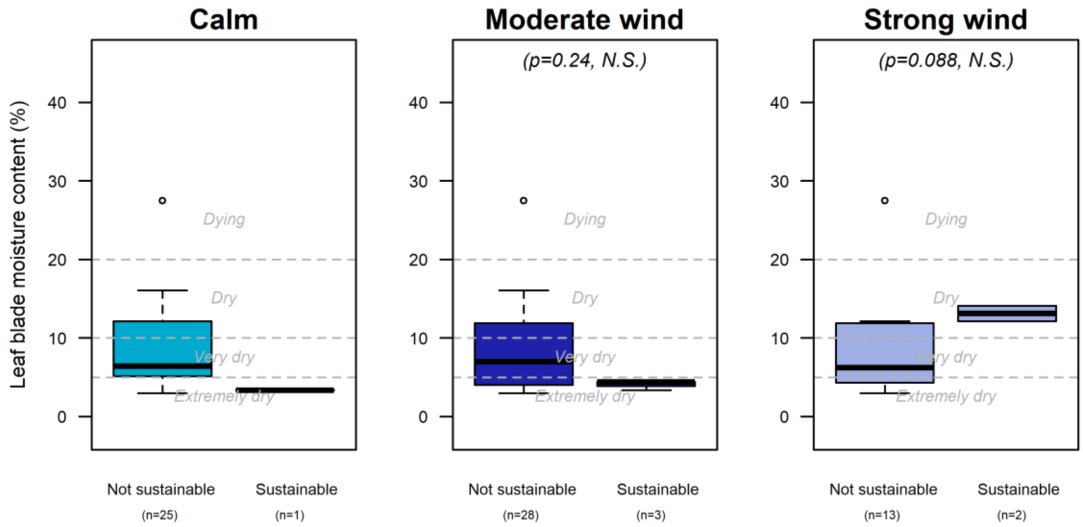

Figure 7 Boxplots comparing the leaf blade moisture content during non-sustained and sustained point ignition tests in buffalo turf under the different wind conditions. Black lines show the plot median, coloured boxes show the range between the upper and lower quartiles. Whiskers show the range other 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).

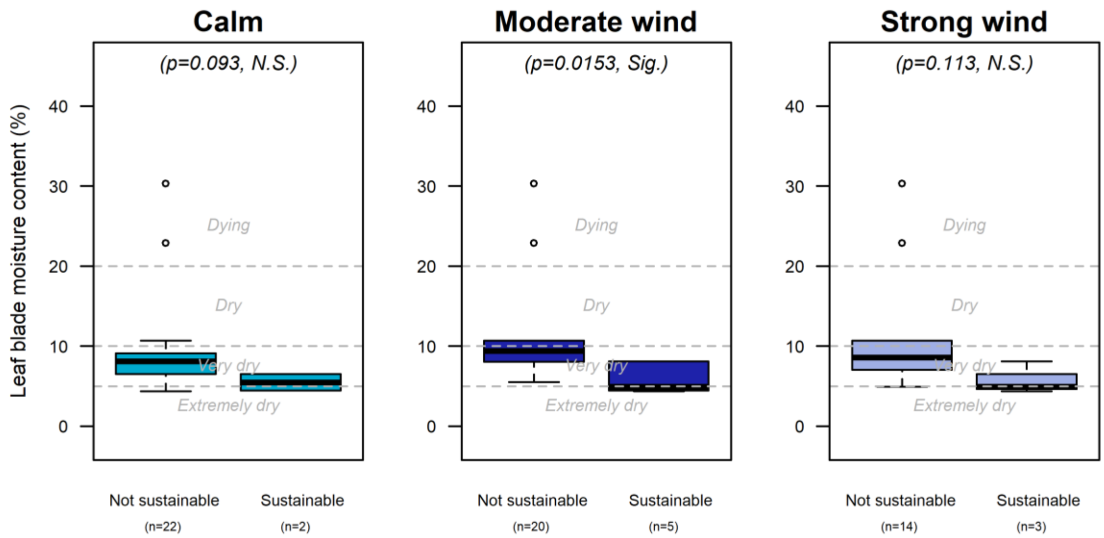

Figure 9 Boxplots comparing the leaf blade moisture content during non-sustaining and sustaining point ignition tests in couch turf under the different wind conditions. Black lines show the plot median, coloured boxes show the range between the upper and lower quartiles. Whiskers show the range other 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).

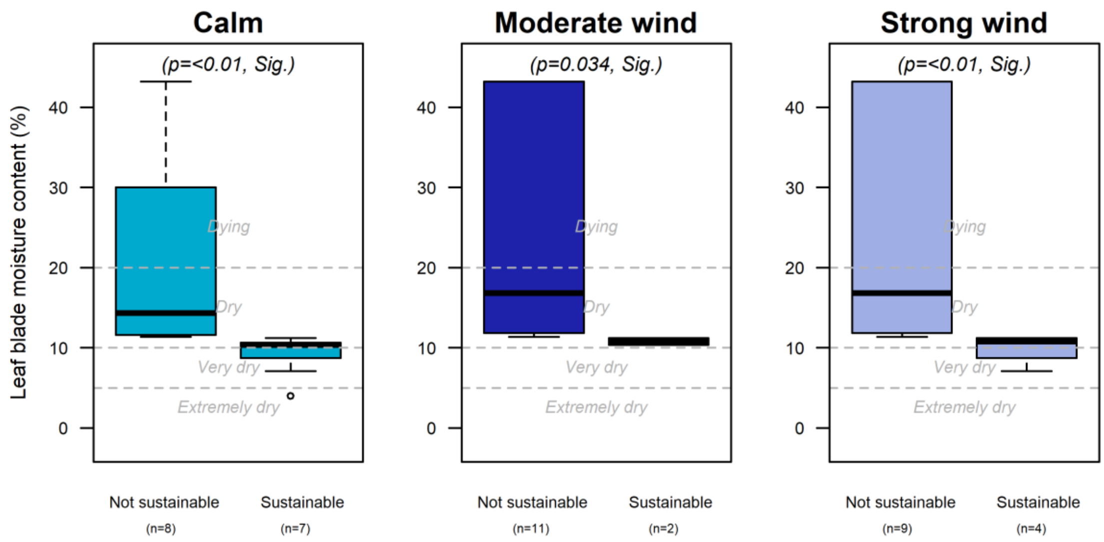

Figure 10 Boxplots comparing the leaf blade moisture content during non-sustaining and sustaining point ignition tests in kikuyu turf under the different wind conditions. Black lines show the plot median, coloured boxes show the range between the upper and lower quartiles. Whiskers show the range other 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.

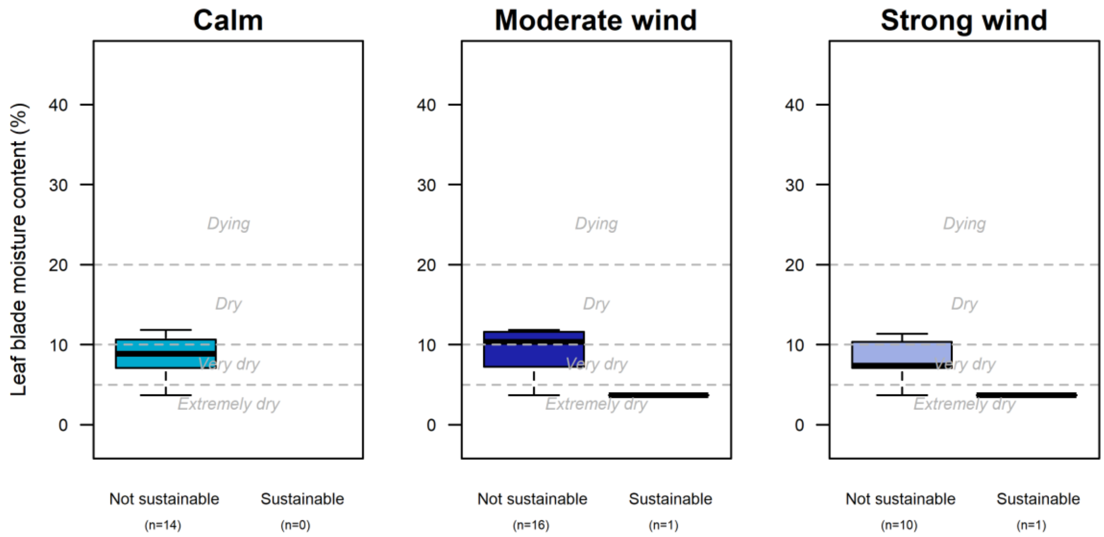

Figure 11 Boxplots comparing the leaf blade moisture content during non-sustaining and sustaining point ignition tests in short cut kikuyu turf under the different wind conditions. Black lines show the plot median, coloured boxes show the range between the upper and lower quartiles. Whiskers show the 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

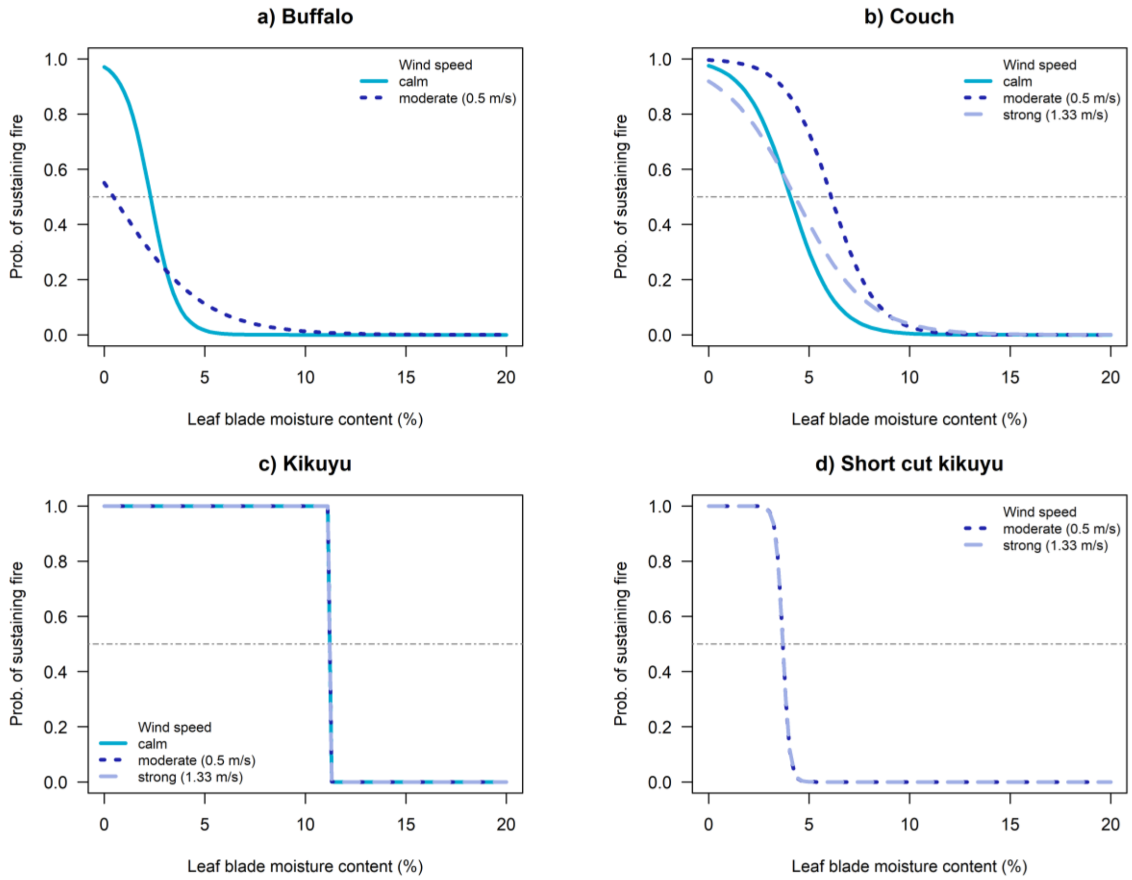

Figure 12 Univariate logistic regression plots for point ignition sustained combustion in buffalo, couch, kikuyu and short cut kikuyu turf based on leaf blade moisture content in different wind conditions.

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).

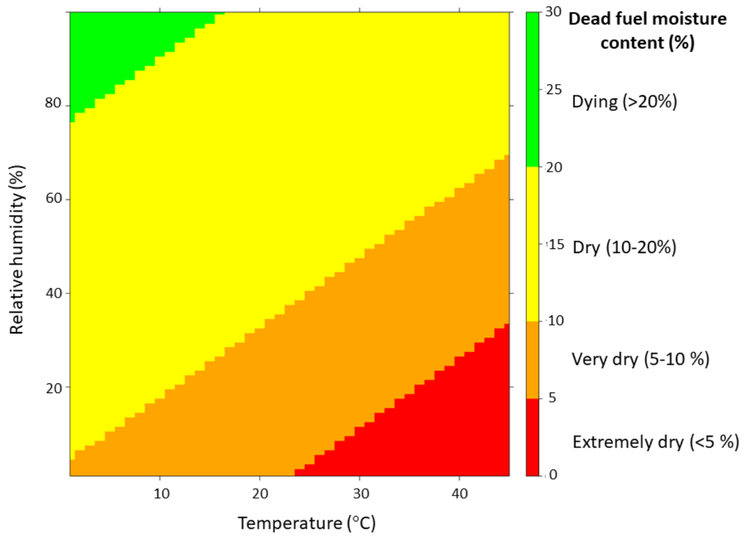

Figure 13 The influence of ambient relative humidity and temperature on the moisture content of dead grass fuels based on Sullivan's (2010) equation for McArthur's (1966) tables.

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.

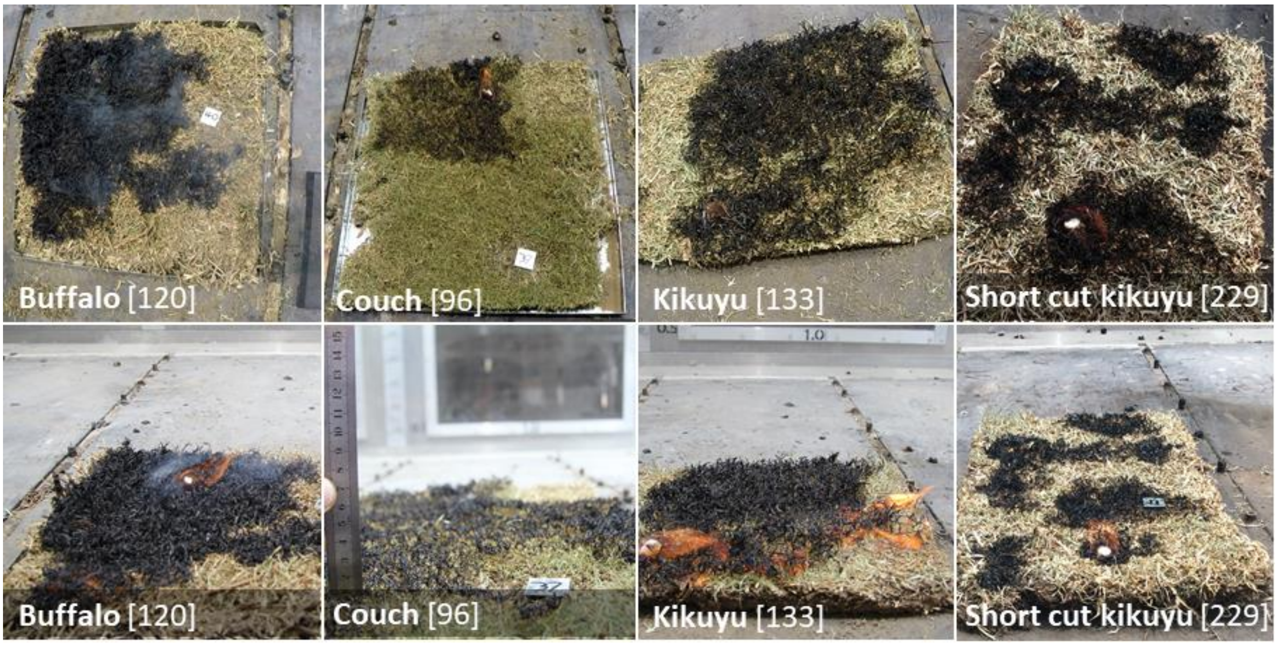

Figure 16 Post fire images showing residual charred fuels following point ignition tests as viewed from above (top row) and the side (bottom row). The reference numbers for each fire relate to the details provided in the Appendix.

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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Bushfire protection benefits of buffalo turf

Background

Hort Innovation commissioned GHD in collaboration with the CSIRO to undertake a study into the bushfire protection benefits of three common Australian turf varieties. This was performed through a literature review and scientific experiments. The turf types studied were kikuyu, couch and buffalo grass, but the results apply more broadly to other turf types with similar characteristics.

Proven benefits of living turf for bushfire protection

It is common to observe that where bushfires have spread into a community, green turf provides demonstrated benefits from impeding the spread of surface fire from bushfire-prone vegetation to fire-vulnerable assets. Live turf does not sustain surface fire spread as shown in the images above taken by CSIRO in 2020 following a fire in Pentland Hills, Victoria. This kikuyu lawn example has provided significant protection benefits for property, when curing in adjacent pasture was 95% and the Grassland Fire Danger Index was Severe. Even where turf is dead and very dry, the low biomass of mown turf means that to the extent any fire spread is sustained, fire can only burn at very low intensity and is readily controlled and extinguished.

Turf as a component of landscaping for bushfire protection

Living turf has long been recognised by fire agencies as a desirable component of landscaping to prevent or reduce damage from bushfire. Turf has the further benefit of providing a defendable space from which firefighters can seek to protect properties. In the Australian Standard 3959 *Construction of buildings in bushfire-prone areas*, managed turf is not considered a bushfire hazard. Land areas across which the principal vegetation cover is live turf, such as sports fields, maintained lawns, golf courses and other managed grasslands are termed low threat vegetation. The Victorian CFA's *Landscaping for Bushfire* guide also describes the benefits of turf and its maintenance requirements to reduce bushfire risk. Buffalo grass grows in summer which means it is able to be maintained in a green, healthy state over the peak bushfire season in Australia. Therefore turf is a very suitable groundcover for use in Asset Protection Zones.

Experimental design of this project

CSIRO conducted experiments in the CSIRO Pyrotron in Canberra attempting to ignite buffalo turf using simulated embers at a variety of leaf moisture contents and using three different wind speeds.

Experimental conditions were designed in order to represent typical bushfire conditions of hot days and low relative humidity. The ignition source was a lit cotton ball injected with ethanol. Ignitions which spread more than 20 cm were deemed 'sustained ignitions'. The extremely dry samples could only be attained through a process of oven-drying.

Buffalo maintenance

- ✓ ***Water turf*** to keep in a green, live state
- ✓ Keep the turf ***short – up to 100 mm*** height
- ✓ Keep the turf ***cleared of leaf litter*** and other flammable materials
- ✓ ***Install the turf correctly*** to promote a well-formed root system, this will make the turf more likely to retain moisture in dry periods

This project has been funded by Hort Innovation using the Turf Industry levy fund. Thanks to CanTurf for providing the turf samples for the Pyrotron experiments.



No live turf samples in a green, or partially green state (suffering severe moisture deficit stress) were able to be lit. Therefore, experiments focused on dead or dying turf, in a very dry state, to establish how dry turf needs to be to sustain fire spread.

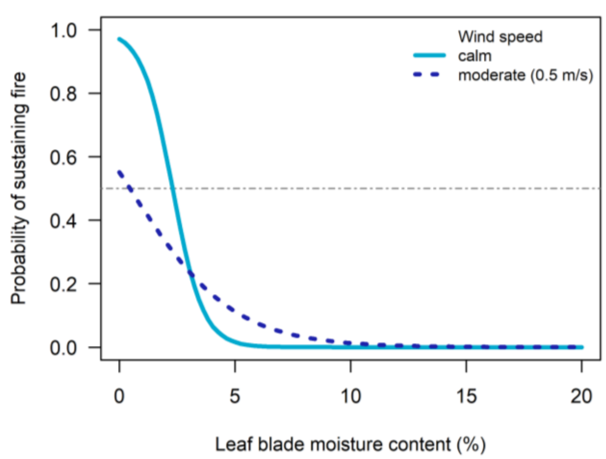
Results of the buffalo ignition tests

The following table shows the number of sustained ignitions under the three wind speed and four leaf blade moisture content scenarios (ODW refers to oven-dried weight). A total of six out of 72 ignition attempts were sustained, four of which were at extremely dry moisture content (<5% ODW), attained through partial oven-drying.

Buffalo turf (dead) sample results

Wind speed setting	Extremely dry (<5% ODW)	Very dry (5-10% ODW)	Dry (10-20% ODW)	Dying (>20% ODW)
Calm	14.3% (1 out of 7)	0% (0 out of 8)	0% (0 out of 10)	0% (0 out of 1)
Moderate	23.1% (3 out of 13)	0% (0 out of 7)	0% (0 out of 10)	0% (0 out of 1)
Strong	0% (0 out of 4)	0%(0 out of 3)	28.6% (2 out of 7)	0% (0 out of 1)

The figure below shows the modelled probability for point ignitions in buffalo grass based on leaf blade moisture content in different wind conditions.



Probability of point ignition in buffalo

Key points

- Live grasses have oven-dried weight ranging from 30% to 260% (CFA *Grassland Curing Guide* 2014). The average moisture content across the turf types tested was greater than 100% upon delivery.
- These experiments showed that buffalo grass did not catch fire above 20% ODW. In well-maintained live lawns, and even drought-stressed live lawns, fuel moisture content is typically many times higher than 20% ODW.
- Buffalo grass has an extremely low probability of sustaining ignitions.

Further reading:
GHD (2020) *Living turf fire benefits study, literature review*
Plucinski MP (2020) *The combustibility of turf lawns*. CSIRO Land and Water Client Report No. EP201008, Canberra, Australia.
CFA (2011) *Landscaping for Bushfire, Garden Design and Plant Selection*

Bushfire protection benefits of couch turf

Background

Hort Innovation commissioned GHD in collaboration with the CSIRO to undertake a study into the bushfire protection benefits of three common Australian turf varieties. This was performed through a literature review and scientific experiments. The turf types studied were kikuyu, couch and buffalo grass, but the results apply more broadly to other turf types with similar characteristics.

Proven benefits of living turf for bushfire protection

It is common to observe that where bushfires have spread into a community, green turf provides demonstrated benefits from impeding the spread of surface fire from bushfire-prone vegetation to fire-vulnerable assets. Live turf does not sustain surface fire spread as shown in the images above taken by CSIRO in 2020 following a fire in Pentland Hills, Victoria. This kikuyu lawn example has provided significant protection benefits for property, when curing in adjacent pasture was 95% and the Grassland Fire Danger Index was Severe. Even where turf is dead and very dry, the low biomass of mown turf means that to the extent any fire spread is sustained, fire can only burn at very low intensity and is readily controlled and extinguished.

Turf as a component of landscaping for bushfire protection

Living turf has long been recognised by fire agencies as a desirable component of landscaping to prevent or reduce damage from bushfire. Turf has the further benefit of providing a defendable space from which firefighters can seek to protect properties. In the Australian Standard 3959 *Construction of buildings in bushfire-prone areas*, managed turf is not considered a bushfire hazard. Land areas across which the principal vegetation cover is live turf, such as sports fields, maintained lawns, golf courses and other managed grasslands, are termed low threat vegetation. The Victorian CFA's *Landscaping for Bushfire* guide also describes the benefits of turf and its maintenance requirements to reduce bushfire risk. Couch grass grows in summer which means it is able to be maintained in a green, healthy state over the peak bushfire season in Australia. Therefore turf is a very suitable groundcover for use in Asset Protection Zones.

Experimental design of this project

CSIRO conducted experiments in the CSIRO Pyrotron in Canberra attempting to ignite couch turf using simulated embers at a variety of leaf moisture contents and using three different wind speeds.

Experimental conditions were designed in order to replicate typical bushfire conditions of hot days and low relative humidity. The ignition source was a lit cotton ball injected with ethanol. Ignitions which spread more than 20 cm were deemed 'sustained ignitions'. The extremely dry samples could only be attained through a process of oven-drying.

Couch maintenance

- ✓ ***Water turf*** to keep in a green, live state
- ✓ Keep the turf ***short – up to 100 mm*** height
- ✓ Keep the turf ***cleared of leaf litter*** and other flammable materials
- ✓ ***Install the turf correctly*** to promote a well-formed root system, this will make the turf more likely to retain moisture in dry periods

This project has been funded by Hort Innovation using the Turf Industry levy fund. Thanks to CanTurf for providing the turf samples for the Pyrotron experiments.

No live turf samples in a green, or partially green state (suffering severe moisture deficit stress) were able to be lit. Therefore, experiments focused on dead or dying turf, in a very dry state, to establish how dry turf needs to be to sustain fire spread.

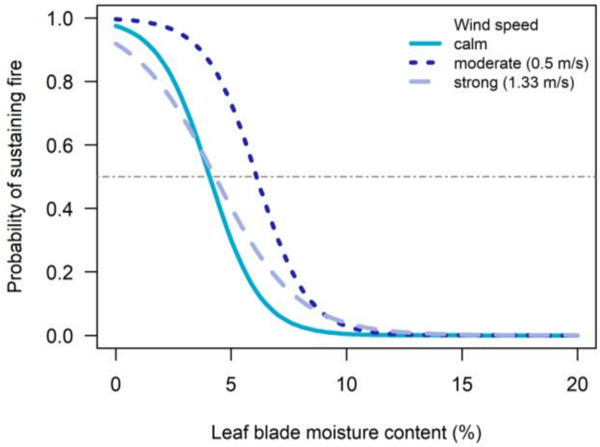
Results of the couch ignition tests

The following table shows the number of sustained ignitions under the three wind speed and four leaf blade moisture content scenarios (ODW refers to oven-dried weight). A total of ten out of 66 ignition attempts were sustained, all of which were at extremely dry or very moisture content (<10% ODW), attained through partial oven-drying.

Couch turf (dead) sample results

Wind speed setting	Extremely dry (<5% ODW)	Very dry (5-10% ODW)	Dry (10-20% ODW)	Dying (>20% ODW)
Calm	33.3% (1 out of 3)	5.9% (1 out of 17)	0% (0 out of 1)	0% (0 out of 3)
Moderate	100% (3 out of 3)	15.4% (2 out of 13)	0% (0 out of 6)	0% (0 out of 3)
Strong	50% (2 out of 4)	11.1% (1 out of 9)	0% (0 out of 1)	0% (0 out of 3)

The figure below shows the modelled probability for point ignitions in couch based on leaf blade moisture content in different wind conditions.



Probability of point ignition in couch

Key points

- Live grasses have oven-dried weight ranging from 30% to 260% (CFA *Grassland Curing Guide* 2014). The average moisture content across the turf types tested was greater than 100% upon delivery.
- These experiments showed that couch grass did not catch fire above 10% ODW. In well-maintained live lawns, and even drought-stressed live lawns, fuel moisture content is typically many times higher than 10% ODW.
- Couch grass has a very low probability of sustaining ignitions.

Further reading:
GHD (2020) *Living turf fire benefits study, literature review*
Plucinski MP (2020) *The combustibility of turf lawns*. CSIRO Land and Water Client Report No. EP201008, Canberra, Australia.
CFA (2011) *Landscaping for Bushfire, Garden Design and Plant Selection*

Bushfire protection benefits of kikuyu turf

Background

Hort Innovation commissioned GHD in collaboration with the CSIRO to undertake a study into the bushfire protection benefits of three common Australian turf varieties. This was performed through a literature review and scientific experiments. The turf types studied were kikuyu, couch and buffalo grass, but the results apply more broadly to other turf types with similar characteristics.

Proven benefits of living turf for bushfire protection

It is common to observe that where bushfires have spread into a community, green turf provides demonstrated benefits from impeding the spread of surface fire from bushfire-prone vegetation to fire-vulnerable assets. Live turf does not sustain surface fire spread as shown in the images above taken by CSIRO in 2020 following a fire in Pentland Hills, Victoria. This kikuyu lawn example has provided significant protection benefits for property, when curing in adjacent pasture was 95% and the Grassland Fire Danger Index was Severe. Even where turf is dead and very dry, the low biomass of mown turf means that to the extent any fire spread is sustained, fire can only burn at very low intensity and is readily controlled and extinguished.

Turf as a component of landscaping for bushfire protection

Living turf has long been recognised by fire agencies as a desirable component of landscaping to prevent or reduce damage from bushfire. Turf has the further benefit of providing a defendable space from which firefighters can seek to protect properties. In the Australian Standard 3959 *Construction of buildings in bushfire-prone areas*, managed turf is not considered a bushfire hazard. Land areas across which the principal vegetation cover is live turf, such as sports fields, maintained lawns, golf courses and other managed grasslands, are termed low threat vegetation. The Victorian CFA's *Landscaping for Bushfire* guide also describes the benefits of turf and its maintenance requirements to reduce bushfire risk. Kikuyu grass grows in summer which means it is able to be maintained in a green, healthy state over the peak bushfire season in Australia. Therefore turf is a very suitable groundcover for use in Asset Protection Zones.

Experimental design of this project

CSIRO conducted experiments in the CSIRO Pyrotron in Canberra attempting to ignite kikuyu turf using simulated embers at a variety of leaf moisture contents, two lengths and using three different wind speeds.

Experimental conditions were designed in order to replicate typical bushfire conditions of hot days and low relative humidity. The ignition source was a lit cotton ball injected with ethanol. Ignitions which spread more than 20 cm were deemed 'sustained ignitions'. The extremely dry samples could only be attained through a process of oven-drying.

Kikuyu maintenance

- ✓ ***Water turf*** to keep in a green, live state
- ✓ Keep the turf ***short – up to 100 mm*** height
- ✓ Keep the turf ***cleared of leaf litter*** and other flammable materials
- ✓ ***Install the turf correctly*** to promote a well-formed root system, this will make the turf more likely to retain moisture in dry periods

This project has been funded by Hort Innovation using the Turf Industry levy fund. Thanks to CanTurf for providing the turf samples for the Pyrotron experiments.

No live turf samples in a green, or partially green state (suffering severe moisture deficit stress) were able to be lit. Therefore, experiments focused on dead or dying turf, in a very dry state, to establish how dry turf needs to be to sustain fire spread.

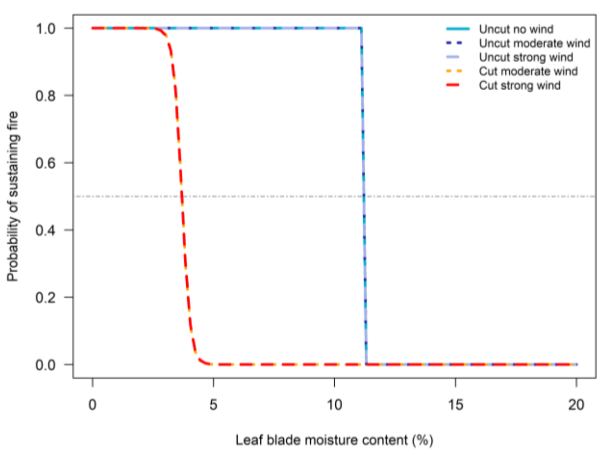
Results of the kikuyu ignition tests

The following table shows the number of sustained ignitions under the three wind speed, two lengths and four leaf blade moisture content scenarios (ODW refers to oven-dried weight). 13 out of the 41 uncut kikuyu ignitions sustained, compared to two sustaining ignitions out of 42 attempts in the short cut kikuyu.

Kikuyu turf (dead) results for uncut (approx. 40 mm) and short cut (approx. 12 mm) samples

Length	Wind speed setting	Extremely dry (<5% ODW)	Very dry (5-10% ODW)	Dry (10-20% ODW)	Dying (>20% ODW)
Uncut	Calm	100% (1 out of 1)	100% (1 out of 1)	45.5% (5 out of 11)	0% (0 out of 2)
Uncut	Moderate	-	-	22.2% (2 out of 9)	0% (0 out of 4)
Uncut	Strong	-	100% (1 out of 1)	33.3% (3 out of 9)	0% (0 out of 3)
Short	Calm	0% (0 out of 3)	0% (0 out of 4)	0% (0 out of 7)	-
Short	Moderate	50% (1 out of 2)	0% (0 out of 5)	0% (0 out of 10)	-
Short	Strong	50% (1 out of 2)	0% (0 out of 5)	0% (0 out of 4)	-

The figure below shows the modelled probability of point ignitions in uncut kikuyu based on leaf blade moisture content in different wind conditions.



Probability of point ignition in kikuyu

Key points

- Live grasses have oven-dried weight ranging from 30% to 260% (CFA *Grassland Curing Guide* 2014). The average moisture content across the turf types tested was greater than 100% upon delivery.
- These experiments showed that kikuyu grass did not catch fire above 20% ODW. In well-maintained live lawns, and even drought-stressed live lawns, fuel moisture content is typically many times higher than 20% ODW.
- Dead grass is less likely to sustain fire spread at shorter lengths, as seen in the kikuyu results.

Further reading:
GHD (2020) *Living turf fire benefits study, literature review*
Plucinski MP (2020) *The combustibility of turf lawns*. CSIRO Land and Water Client Report No. EP201008, Canberra, Australia.
CFA (2011) *Landscaping for Bushfire, Garden Design and Plant Selection*