RISKS FROM CLIMATE CHANGE

FACING THE AUSTRALIAN MUSHROOM INDUSTRY

Hort Innovation Strategic levy investment
MUSHROOM FUND

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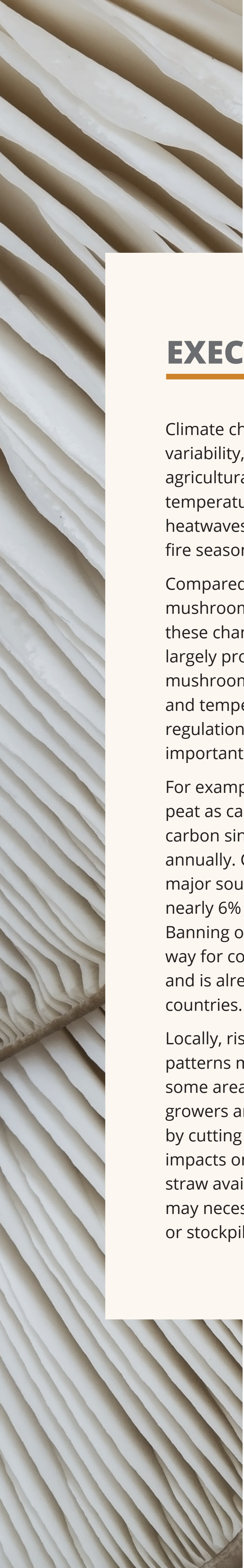

EXECUTIVE SUMMARY

Climate change, and increased climate variability, represent a major risk to Australian agricultural industries. Predicted higher temperatures, more intense and longer heatwaves, drier conditions and an extended fire season are already occurring.

Compared to other horticultural industries, the mushroom industry is relatively secure from these changes. Climate controlled environments largely protect both compost production and mushroom growing from the vagaries of rainfall and temperature. However, changes to inputs, regulation and the external environment are still important sources of risk.

For example, all mushrooms are grown using peat as casing material. Peatlands are a major carbon sink, sequestering 0.5 gigatons of CO_2 annually. Conversely, draining peatlands is a major source of greenhouse gases, equating to nearly 6% of global anthropogenic emissions. Banning or restricting peat mining is an easy way for countries to meet emission targets and is already occurring in some European countries.

Locally, rising temperatures and changed rainfall patterns may increase production of wheat in some areas but decrease it in others. Wheat growers are adapting to changed conditions by cutting higher and retaining stubble. This impacts on the cost, quality and availability of straw available for compost production, and may necessitate longer transport distances and/or stockpiling.

The other major ingredient in compost is manure. Poultry producers use straw, rice hulls and other materials for bedding. Limited availability of these products means that they are changing to products such as wood waste and nut hulls, and recycling bedding multiple times. This alters the nitrogen content of the manure, forcing adjustment of the C:N ratio in raw materials used for compost.

Along with compost and casing, mushroom production requires large amounts of water. Most producers use town water supplies, which are relatively secure. In many areas rainfall is likely to decrease resulting in more frequent dry spells, particularly for Perth, Mildura and Adelaide. These areas are most likely to be impacted if there are restrictions on water use.

The effects of climate change on pests and diseases are still unclear. Warm conditions may increase populations of insects and mites, as well as diseases on straw. However, hot and dry conditions could have the opposite effect.

Energy is a major cost for both compost producers and mushroom farms. Future changes in government policy will clearly affect pricing. Under current policies, ongoing uncertainty is forecast to result in price increases of up to 20%. In contrast, implementation of a clean energy target scheme could significantly reduce prices, as investment in renewables forces prices down. Interruptions to supply due to fires, heatwaves or other natural disasters are also a source of risk.

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INTRODUCTION

There is growing awareness that not only is climate change a reality, but Australia will be particularly strongly impacted. This is not new information. For example, for several years the Australian Institute of Company Directors (AICD) has named climate change as the most important risk potentially affecting their businesses. Even before the Garnaut report in 2008, there were warnings that climate change would have severe adverse effects on Australian agriculture and on the natural environment. For example, Garnaut predicted that irrigated agriculture in the Murray Darling basin would decline by 6% or 20% if CO_2 was held to 450ppm or 550ppm respectively. Conversely, the report predicted that dryland wheat production could slightly increase, although wheat quality (e.g. protein quality) would decline. Prophetically, it also stated that: "*Recent projections of fire weather suggest that fire seasons will start earlier, end slightly later and generally be more intense. This effect...should be directly observable by 2020.*"

The weather and events of 2019-2020 have brought those predictions of our future climate into sharp reality. According to the Bureau of Meteorology, 2019 was Australia's warmest year on record, with temperatures 1.52°C above the long-term average. Maximum temperatures were 2.09°C above average, with significant heatwaves experienced in January and December[a]. Only a few years ago it would have been unthinkable that Sydney would experience temperatures close to 50°C, yet on Saturday 4 January Penrith was the hottest place on the planet, recording 48.9°C.

It was also Australia's driest year on record, with average rainfall down 40%. As a result, much of Australia was severely affected by drought, conditions being worst in New South Wales and southern Queensland. In contrast, cyclones in the north meant rainfall was above average for parts of the Queensland tropics.

The combination of drought and high temperatures meant the forest fire danger index was the highest since national records began in the 1950s. The bushfires of the 2019-2020 summer left few parts of the country unscathed. More than 186,000 square kilometers were burned, destroying houses and businesses, killing an estimated one billion animals and pushing many species to the brink of extinction. Smoke blanketed the eastern cities, with impacts felt around the globe[b].

The mushroom industry may seem protected from climate change, at least compared to fruit and vegetable producers. Mushrooms are already produced in controlled environments and the industry is an efficient user of resources. Mushroom farms are certainly less affected by the vagaries of rainfall and temperature than those growing in less protected environments.

However, mushroom production depends on a wide range of inputs and is inevitably affected by the surrounding environment. Climate variability and change therefore still present significant risks. Managing these risks is a triple bottom-line issue, with environmental, economic and social implications.

Growers and compost producers were surveyed regarding the effects of recent extreme temperatures on farm operations, as well as the potential impacts of climate change on inputs such as peat, compost materials, water and energy. Participants represent more than 70% of mushroom production and included all the major mushroom production facilities as well as smaller farms producing less than a tonne a week.

Finding alternatives to wheat straw and peat were high priorities, as was increasing water efficiency.

[a] http://www.bom.gov.au/climate/current/annual/aus/

[b] https://en.wikipedia.org/wiki/2019–20_Australian_bushfire_season

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Uncertainty over future energy costs means many are keen to become more independent, generating their own energy on farm. This includes finding ways to utilize spent compost – currently a waste product, but with a range of potential uses. Concerns were expressed about changing government policies, and how best to navigate the tangle of grants, subsidies and other funding opportunities.

The survey also revealed that many Australian mushroom farms are relatively old. Only two farms were established within the last 10 years, while nine were 30 years older or more. Older farms are likely to be relatively low technology. For example, while the trend overseas has been to shelf operations, only five of 20 farms surveyed were using this system. While older farms have undoubtedly been adapted and modernized over the years it is harder to adapt ageing infrastructure to a hotter environment.

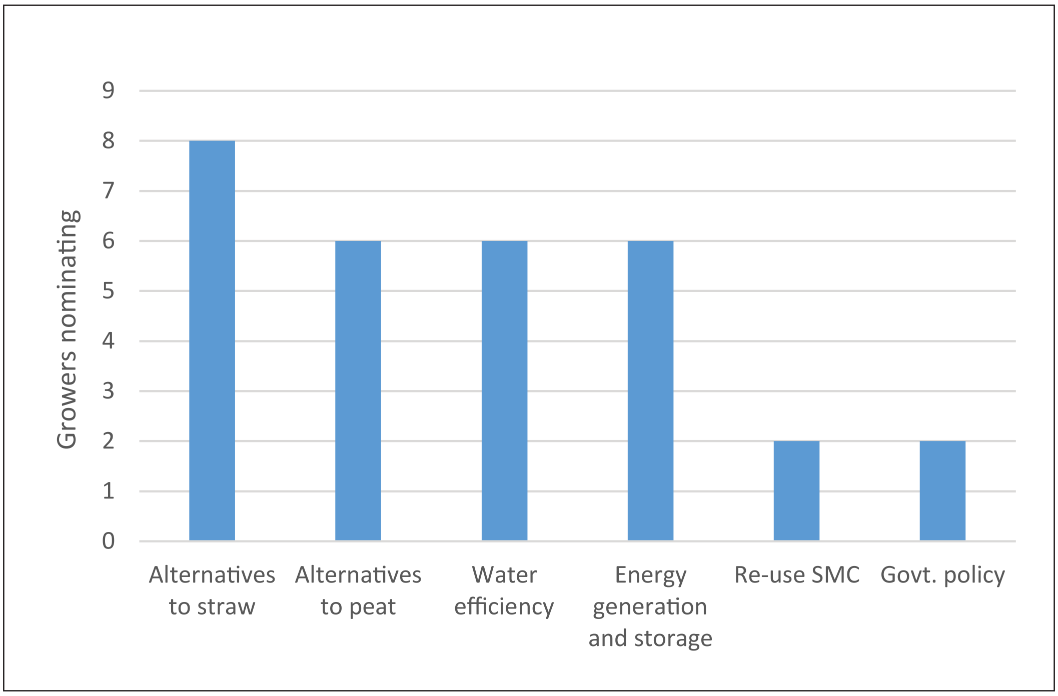


Figure 1. Priorities for adapting to climate change; results of a survey of mushroom growers and composters

This document details the major sources of risk to Australian mushroom production from climate change and variability. Most projections are limited to 2050, as the rapid changes now occurring make it difficult to predict over a longer period. The possible climate change effects on inputs such as straw, manure and casing materials are discussed, along with energy costs, availability of water, changes in pests and diseases and the impacts of more frequent heatwaves.

01. AVAILABILITY OF PEAT FOR CASING

Likelihood – HIGH risk of increased cost and reduced availability of peat, LOW risk that peat becomes completely unavailable.

Impact – The cost of peat is a relatively small component of total production costs. However, reduced availability could potentially have significant impacts on production.

Management options – There are a number of products which may be used to supplement current supplies of peat, including green waste, spent mushroom compost and recovered and recycled casing.

Industry vulnerability – There is currently no viable alternative to fully replace peat.

Summary

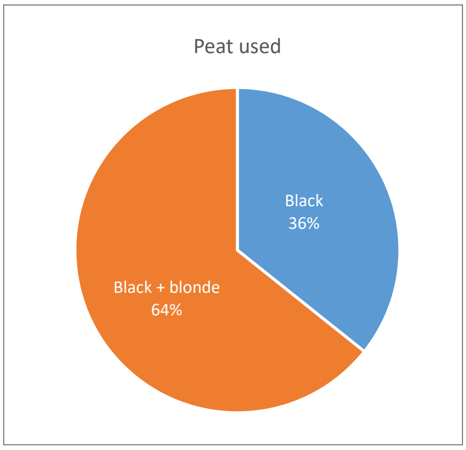
Peatlands are a major carbon sink, sequestering 0.5 gigatons of CO_2 annually. Conversely, draining peatlands is a major source of greenhouse gases, equating to nearly 6% of global anthropogenic emissions. Banning or restricting peat mining is therefore an easy way for countries to meet emissions targets, and this is already occurring in some European countries. While some consider peat supplies secure, it seems highly likely that prices will increase and future supplies will be limited.

Current practice

The industry currently sources peat from Germany, Ireland, the Netherlands, Canada and the Baltic states. Most farms use a 90:10 or 80:20 blend of hard, black peat to blonde (Canadian) peat, although at least three use 100% German black peat.

While one respondent stated that the supply of peat from Germany and the Netherlands was guaranteed for the next 50 years, a number of other farms were concerned about ongoing cost and supply. Alternatives that have been trialed include coconut coir, brown coal products, spent barley from breweries, composted green waste and spent diatomaceous earth.

Six farms indicated they were interested in finding alternatives to peat compared to seven that were not, with the remainder undecided. Four farms nominated finding alternatives to peat as a key component of a climate change action plan for the industry.



While peat is a relatively minor cost in mushroom production, there is clear concern regarding the sustainability of ongoing use of peat, and potential future interruptions to supply. This was therefore considered to be an important industry vulnerability.

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Potential effects of climate change

PEATLANDS AND CO_2

Peatlands are the largest natural terrestrial carbon store. Known peatlands are estimated to cover 3-4% of the world's land area, containing at least 612 giga-tonnes of carbon[1]. Peatlands continue to sequester significant amounts of CO_2. For example, a recent study by Lunt[2] estimated that peat bogs sequester 9-12 tonnes CO_2/ha annually. In total, peatlands sequester up to 0.5 gigatons of CO_2 each year, representing 1-5% of global anthropogenic greenhouse gas emissions[3].

Conversely, 10% of global emissions from the agriculture, forestry and land use sectors are caused by the draining of peatlands. This equates to almost 6% of global anthropogenic CO_2 emissions[4]. This happens because allowing oxygen into the previously anaerobic environment of the peatlands leads to rapid decomposition, emitting large amounts of both CO_2 and nitrous oxide (N_2O).

Moreover, drained peatlands are extremely susceptible to fire, especially when combined with increasingly hot, dry conditions. Such fires can smoulder underground for weeks. For example, in 2018 the Saddleworth moor peatlands outside Manchester ignited into an intense, wide-ranging fire as a result of drainage of the moors combined with an un-seasonally hot summer[5]. Similarly, the 2019-2020 underground peat fire near Port Macquarie took 210 days to extinguish, and then only with the combination of 260mm of rain combined with pumping 65 megalitres of reclaimed water onto the wetlands[6].

Limits on peat extraction

According to the International Union for the Conservation of Nature (IUCN), "the protection and restoration of peatlands is vital in the transition towards a low carbon economy". They further propose a moratorium on peat exploitation, and for peatlands to be included alongside forests in agreements relating to climate change (e.g. carbon credits/debits), geodiversity and biodiversity.

It is likely the European Union will introduce regulations to limit or ban the draining and extraction of peat to reduce European greenhouse gas emissions. There is strong pressure to restore previously exploited peatlands, as well as prevent further drainage and mining of these areas, as a strategy to combat climate change. According to Achim Steiner, previously the executive director of the UN Environment Program, protecting and restoring peatland is "low hanging fruit", being one of the most cost-effective options for mitigating climate change[7];

- Ireland has already closed 17 peat bogs and plans to close the remaining 45 bogs by 2025[8].
- The EU "Peat Life Restore" project aims to restore peatlands in Germany, Estonia, Latvia, Lithuania and Poland to meet the objective of reducing greenhouse gas emissions 40% by 2030 compared to 1990 levels.

Peat used for casing is therefore likely to become both more difficult to access and more expensive.

Figure 3. Peat mining and drying in the Shetlands.
Photo by C. Smith.

[1] Yu, Z et al. 2011. Peatlands and their role in the global carbon cycle. Eos, Trans. Amer. Geophysical Union 92:97.
[2] Lunt, PH, Fyfe R, 2019. Role of recent climate change on carbon sequestration in peatland systems.
[3] Friedlingstein PRM et al. 2014. Persistent growth of CO_2 emissions and implications for reaching global targets. Nature Geosci. 7:709-715.
[4] International Union for Conservation of Nature, www.iucn.org/resources/issues-briefs/peatlands-and-climate-change
[5] Plester, J. 2018. Weatherwatch: Wildfires highlight importance of UK's peatlands. 3 July 2018 www.theguardian.com/news/2018/jul/02
[6] Bungard, M. 2020. Fire near port Macquarie extinguished after 210 days. www.smh.com.au/environment/weather
[7] www.newscientist.com/article/dn13034-peatland-destruction-is-releasing-vast-amounts-of-co2/
[8] www.theguardian.com/world/2018/nov/27/ireland-closes-peat-bogs-climate-change

02. IMPACTS OF TEMPERATURE EXTREMES ON COMPOST PRODUCTION AND MUSHROOM GROWING

Likelihood – HIGH

Impact – HIGH

Management options – Additional cooling systems, composting in climate-controlled environments, refrigeration while moving Phase III compost

Industry vulnerability – Low

Summary

Along with average temperature increases, the number of extreme hot days is forecast to increase. The effects are not the same everywhere; whereas the number of days over 40^{oC} is forecast to double by 2030 in places such as Richmond (NSW) and Perth, Sydney, Cairns and Hobart may be less affected.

High temperatures slow compost production and damage mycelia during spawn run. While many production facilities have climate control, Phase III compost is vulnerable to heat during transport.

Mushroom farms have climate control, with many reporting they have already designed excess capacity. However, sequential hot days and high night temperatures are likely to challenge existing systems, especially if combined with high humidity.

Current practice

COMPOST PRODUCTION

Composting produces significant amounts of heat. Both extreme high and extreme low temperatures slow this process. While the latter slows heating, high temperatures reduce the induction of cool air into the pile, thereby limiting availability of oxygen to the microbes within.

Although many compost producers now use indoor facilities with climate control, extreme temperatures increase water use as well as cause issues for staff. The maximum daily temperature mushroom compost producers can cope with ranges from 43°C to above 50°C, depending on the climate control systems installed.

In the last 10 years there has been a move away from using Phase II compost in cropping rooms to filling trays or beds with compost already inoculated with spawn (Phase III). Once the compost is colonized by the Agaricus mycelia, the material can be loaded onto trucks for transfer to mushroom farms. This system has the advantage of making more efficient use of mushroom production facilities. Of the seven compost producers surveyed, three produce Phase III material.

MUSHROOM GROWING

With the possible exception of some exotic mushroom farms, mushrooms are produced in fully climate-controlled environments. While this makes them less vulnerable to extremes of heat and cold than other crops, cooling and heating systems need to have enough capacity to cope with temperature extremes. The maximum daily temperature surveyed farms could cope with ranged from 30°C to 50°C, with a median of 44°C. However, how well farms could cope with extreme temperatures was also affected by the number of successive hot days, RH and overnight minimums. Comments on this issue included:

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"More than 40°C is a problem, especially if it's humid. January is the worst month"

"Overnight temperatures need to get below 32°C in order to recover"

"We lost two crops this summer when the temperature went over 40°C during spawn run"

"40°C for one day is difficult, but if temperatures go over 40°C for 3 days that's total crop failure"

"If it gets up to 45°C the rooms get hard to manage. We need to pick fast to get the crop off, then yield and quality of following crops are reduced"

Potential effects of climate change

PHASE III COMPOST

Temperatures during spawn running ideally range from 24 to 27°C[9]. If temperatures become very high (>30°C) during transport from compost facility to farm, the mycelia can be damaged, reducing productivity. Susceptibility varies between strains. For example, there is evidence some hybrid off white strains can tolerate temperatures up to 35°C for 24 hours without loss of yield, while a hybrid white strain was negatively affected after only 12 hours at 27°C.

Temperatures above 35°C invariably reduce yield, and if these conditions persist for more than 24 hours then yield may be reduced by nearly 60%[10]. The increasing frequency of hot conditions may therefore make it unfeasible to move Phase III compost, or necessitate cooling during transport.

MUSHROOM GROW ROOMS

Prediction of extreme weather events and climate variability is challenging. It is not currently possible to predict with any confidence the precise variability in temperature for Australia's mushroom growing areas. Frustratingly, it is temperature variability, especially high and low temperature spikes, which is vital to understand for short- and longer-term planning.

Table 1 shows how projections of climate trends are most likely to change the annual number of extreme hot days (>40°C). While the number of hot days will increase in all regions, the effects are not the same in all areas. For example, Sydney will change only slightly, whereas 50km west in Richmond (NSW) the number of hot days will more than double by 2030. Similarly, the number of hot days in Perth will also double whereas Hobart and Cairns are unchanged[11].

While cooling requirements for mushroom production are forecast to significantly increase, heating needs are likely to decrease. For example, the estimated average number of days experiencing temperatures below 4°C will decrease from 74 to 58 days in Hobart, 43 to 29 days in Richmond and 38 to 29 days in Mildura.

REGION	PRESENT AVERAGE (1981–2010)	2030 AVERAGE (LOW EMISSIONS) RCP 4.5	2030 AVERAGE (HIGH EMISSIONS) RCP 8.5	2050 AVERAGE (LOW EMISSIONS) RCP 4.5	2050 AVERAGE (HIGH EMISSIONS) RCP 8.5
Brisbane	0	0.1	0.3	0.1	0.2
Cairns	0	0	0	0	0.1
Hobart	0	0	0	0.1	0.1
Sydney	0.5	0.7	0.7	0.8	1.3
Melbourne	0.8	1.3	1.7	2.1	2.6
Richmond	1.4	3.1	2.9	2.6	4.7
Perth	1.5	3.0	3.5	4.1	4.8
Adelaide	2.4	4.3	5.2	4.9	6.3
Mildura	7.8	11.9	12.1	12.8	17.3

Table 1. Average number of days where temperatures exceed 40°C under scenarios where emissions peak by 2040 and then decline (RCP 4.5) or continue to rise unchecked (RCP 8.5). *Source: Climate change in Australia – Projections for NRM regions*[11]

[9] Noble R. et al. 2008. Measuring and improving the rate of spawn-running in compost. Mushroom Sci XVII, 207-220.

[10] Wuest PJ, Hetrick TR, Wilkinson V. 2004. Agaricus bisporus: temperature management for cultures and spawn run.

[11] www.climatechangeinaustralia.gov.au/en/climate-projections/explore-data/threshold-calculator/. Acc. 9-4-2020

03. AVAILABILITY, COST AND QUALITY OF WHEAT STRAW FOR COMPOST

Likelihood – HIGH risk of increased cost and reduced availability of straw, MEDIUM risk of reduced quality of straw.

Impact – The cost of straw is a significant part of the cost of compost production, which in turn is a major input to mushroom farms.

Management options – Straw may be stockpiled in good years for later use. Other carbon sources are available, with corn stover and sugar bagasse the most likely to be suitable. However, transport is likely to increase costs, especially for southern producers, and practice changes are likely to be needed to optimise compost for mushroom production.

Industry vulnerability – The key industry vulnerability is more likely to relate to cost than supply.

Summary

Wheat straw is the primary carbon source for mushroom production. The 2018-2019 drought resulted in big price increases and greatly reduced availability. Many grain growers are adapting to changes in climate by cutting higher and retaining stubble. While this reduces losses from the system, it also reduces availability of straw for compost production. Changes in straw quality may also issues for compost producers.

Increased temperatures and reduced rainfall are likely to decrease wheat production in many regions, particularly south west WA. However, southern production areas may benefit, with improved yield forecast for parts of Victoria and NSW. This may result in additional transport costs, or necessitate stockpiling during good seasons.

Current practice

Most mushroom compost producers source wheat straw locally, when it is available. During the 2018-19 drought, most composters outside Victoria had difficulty sourcing good quality wheat straw. All composters paid more for their straw and transported the straw further; in at least one case, straw was sourced from 500km away. Nearly half (43%) of composters surveyed reported they received straw that was less mature than normal.

"The straw has had to be sourced from further away, which increased transport costs 8%. The transport can easily cost more than the straw itself."

Two composters reported increases in disease affecting compost, which they considered likely to be due to drier and dustier conditions:

"Smoky mould* was a major issue this year in compost from South Australia, most likely caused by dust storms in the straw growing area. We had 60% loss in two rooms affected by this disease."

A number also commented that they thought the straw was lower quality and brittle; this affects cohesion and texture in the end compost. Structural changes in the compost were believed to have affected yield at the same time as prices increased:

"Shorter straw length and lower quality during the drought reduced compost quality. There was initially a 10-15% drop in production. Although we could eliminate this yield loss by adding more supplement, costs were increased."

In total, 57% of composters have considered reusing spent mushroom compost, but none have successfully done so. Risk of disease, transport costs and possible effects on yield have so far prevented the successful reuse of spent mushroom compost. This is particularly an issue where the compost facility is distant from the farm; the economics of returning it to the compost facility have made this unfeasible.

Some composters have experimentally included cotton trash, bagasse from sugar cane and wood shavings

in compost. However, supply and transport costs are also an issue for these sources of carbon. One commented that such materials are difficult to source due to demand for biofuel production. All composters said they would like research into alternative carbon sources.

Potential effects of climate change

DROUGHTS AND PRICE

According to Porter et al[12], global studies predict that crop production will fall by 6% for every degree of warming. Wheat straw is the preferred carbon source for making mushroom compost. However, its supply is becoming uncertain. The recent drought reduced availability, while the demand for hay as stock feed increased greatly. Drought increases the competition from the livestock industry for straw, leading to higher prices and uncertain supply.

Predicted hotter and drier conditions associated with climate change are likely to impact on the availability and quality of dry-land wheaten straw. Irrigated wheat crops could also be impacted by reduced water allocations due to drier conditions. These are negative factors in relation to wheat straw for composting[13].

Drought through 2017 to 2019 significantly reduced grain crops while also increasing demand for straw as animal feed. The result was volatile and inflated prices for wheat straw in Australia. Price shocks were most extreme and prolonged in the strongly drought affected states of Queensland and New South Wales, shown in Australian Fodder Industry Association weekly price data (Figure 3). Western Australia and Tasmania are less influenced by wheat straw markets compared to the eastern states of mainland Australia.

Figure 3 Weekly wheat straw prices in Australia May 2014 to November 2019. Source: Australian Fodder Industry Association, 2020.

[12] Porter JR et al. 2014. Food security and food production systems. In: Climate Change 2014: Impacts, adaptation and vulnerability. Part A: Global and Sectoral aspects. Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University press, Cambridge, UK pp. 485-533.

[13] Jones N. 2013. Raw materials review: wheat straw. The Spawn Run December 2013 pp7-8.

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CLIMATE CHANGE IN WHEAT PRODUCTION AREAS

According to GRDC, the climate in many wheat growing areas is likely to become both hotter and drier.

Recent (2019) case studies were conducted on Goondiwindi in the eastern Darling Downs and Walgett in northern NSW by the climate change institute at ANU[14], [15]. Wheat yield in areas such as Goondiwindi are relatively high but sensitive to changes in temperature and rainfall, while yields in Walgett are generally much lower.

The study found temperatures in Goondiwindi have already increased by 1.1°C since 1950. Although very high temperatures occurred approximately 7 times annually between 1951 and 1980, they now occur up to 44 times annually. While this shift has occurred across all seasons, the biggest change has been during spring. Spring rainfalls also show the most pronounced decline, with increased lengths of dry spells between rain and fewer heavy rain events in general. In Walgett, maximum temperatures have increased by approximately 1.2°C since 1950, while annual rainfall has fallen by 23% and evaporation rates have increased.

The effects of these changes on wheat yields were modelled using the Agricultural Production simulator. A 1.1°C increase in temperature and 5% decline in rainfall could potentially increase the extreme high and low yields for Goondiwindi by around 80kg/ha. However, if temperatures increase by 1.9°C with a similar decline in rainfall, there are likely to be significant reductions in yields, particularly for 'good' seasons. Maximum yield under these conditions is likely to decrease by up to 100kg/ha.

In Walgett, changes in rainfall are relatively small, due to projected increases in summer and autumn rainfall being offset by decreases during winter and autumn. These changes suggest small increases of 80 to 200kg/ha are possible for low yielding years. If temperatures were to increase by 2.1°C and annual rainfall increased by 8%, then further improvements are possible in low yield seasons.

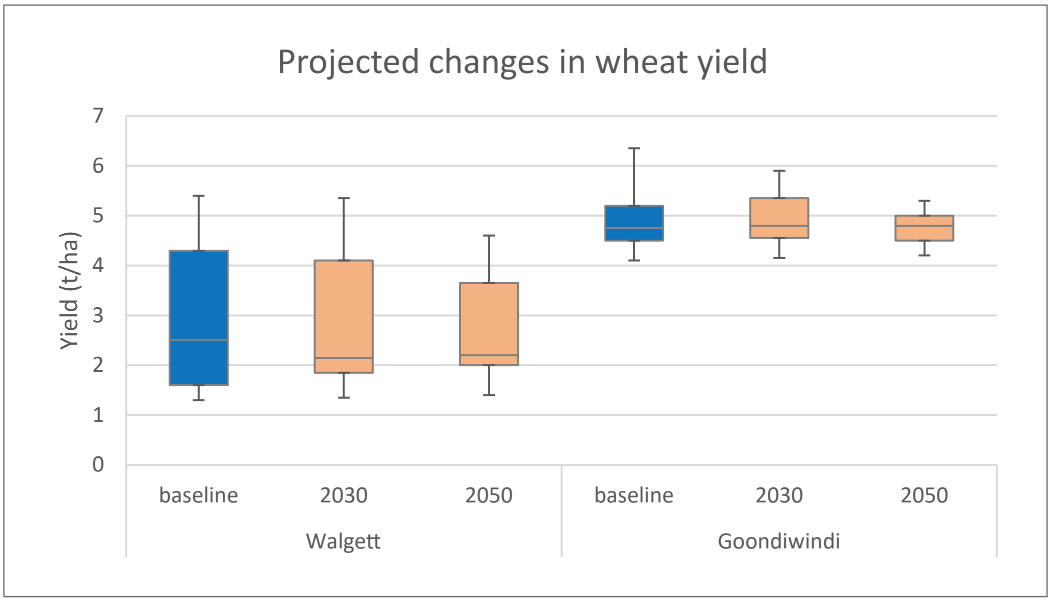


Figure 4. Boxplots of forecast wheat yield (t/ha) in Walgett and Goondiwindi for 1990 to 2018 (baseline) and for 28-year periods centred on 2030 and 2050. The horizontal line indicates average yield, and the top and bottoms of each box represent yields exceeded in ¾ and ¼ of years. Derived from Crimp and Howden, 2019.

14 Crimp S, Mahani M, Howden M. 2019. Predicted climate change impacts on northern NSW farming systems. Accessed online May 2020. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2019/08/predicted-climate-change-impacts-on-northern-nsw-farming-systems

15 Crimp S, Howden M. 2019. Predicted climate change impacts on northern farming systems. Accessed online May 2020. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2019/03/predicted-climate-change-impacts-on-northern-farming-systems

These trends are consistent with a large modelling project reported by Taylor et al. (2018). This project considered likely changes in major wheat production areas across Australia (Figure 6).

Changes in rainfall and runoff in southern Qld and northern NSW are relatively small, while much greater reductions have been forecast for the wheatbelt in Western Australia. Even if there are moderate reductions in CO_2 emissions (Representative Concentration Pathway 4.5), rainfall in these areas is still predicted to decrease by 13% by 2050, with temperatures increasing by an average of 1.7°C. If emissions continue to increase at current rates (RCP

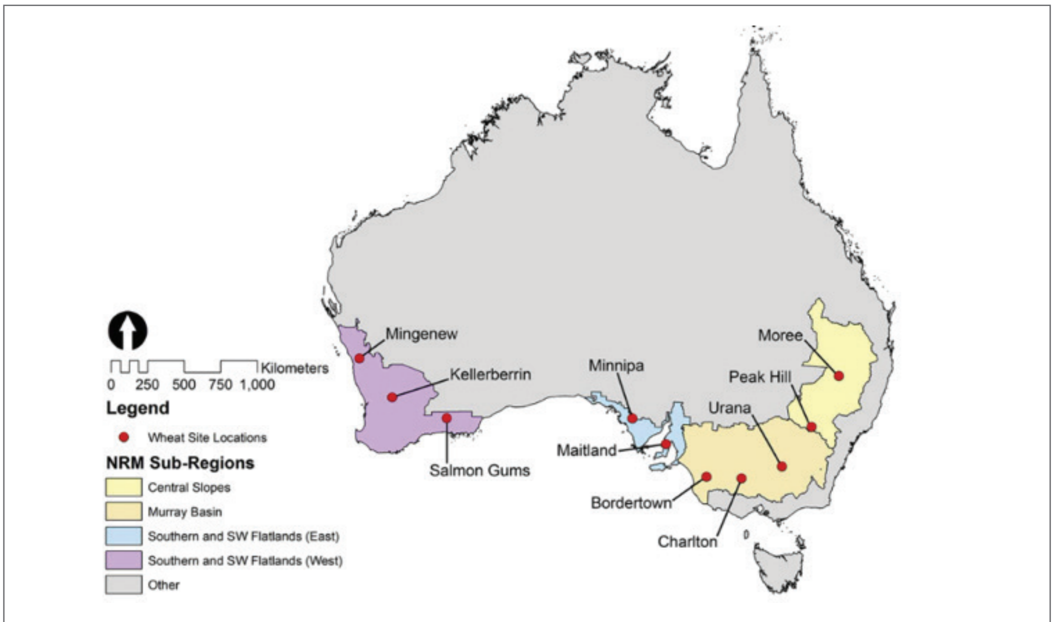


Figure 5. Locations of study sites reported by Taylor et al., 2018.[16]

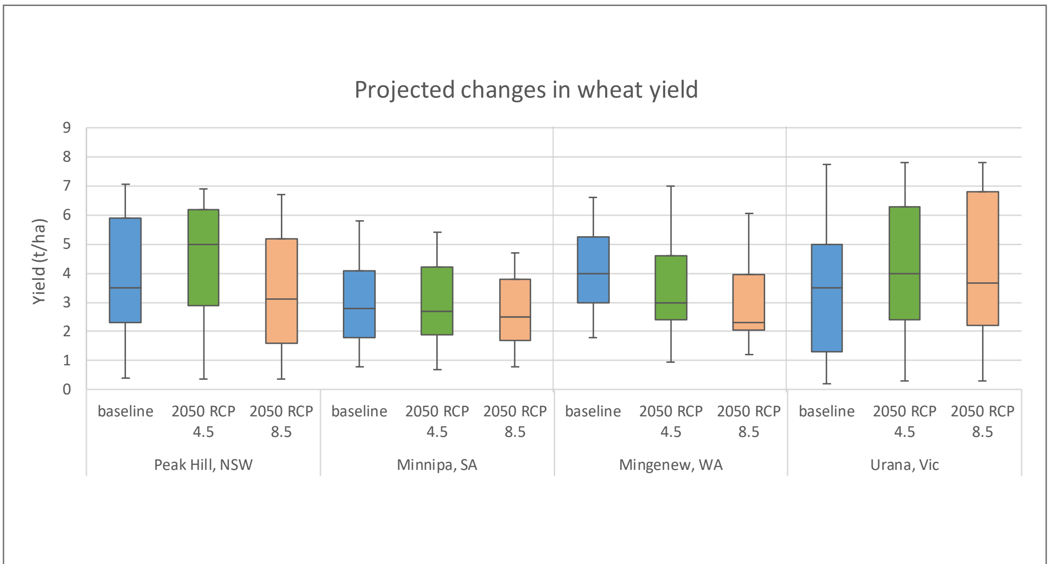


Figure 6. Projected "most likely" changes in wheat yields in different parts of Australia under low (RCP 4.5) and high (RCP 8.5) emission scenarios. Derived from Taylor et al., 2018.[16] The horizontal line indicates average yield, and the top and bottoms of each box represent yields exceeded in ¾ and ¼ of years.

8.5), then rainfall may decrease by more than 27%[16]. The result is that median wheat yields are projected to decline by between 26 and 38%.

This effect may be contrasted with the Murray Basin region, that extends across northern Victoria and southern NSW. While high and low yields in these regions are likely to remain similar, average yields are forecast to increase by 300 to 3,000 t/ha by 2050. These increases occur under both high and low emission scenarios, primarily due to warmer conditions in southern growing areas[13].

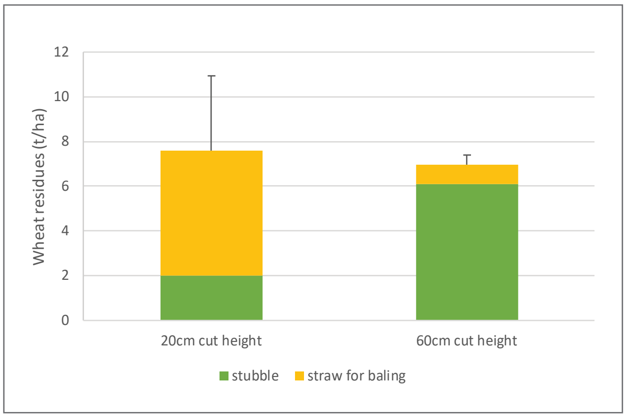


Figure 8. Loose crop residues available for baling when harvesting with 20cm vs 60cm cutting heights.
Data from the Western Australia No-tillage Farmers Association (wantfa.com.au).

Figure 9. Cutting wheat high protects the soil and allows more efficient harvesting, but means less straw is available for baling. Photo by S. Crump, ABC.

Changes in agronomy

The availability, and therefore price, of wheat straw is not only due to crop failures, but also to changed agronomic practices. There is increasing adoption of conservation farming methods as grain growers adapt to a hotter, drier climate. Conservation farming aims to increase or maintain carbon levels in the soil, improve water infiltration, reduce evaporation, insulate the soil from heat and reduce erosion during wind andrain events. As a result, grain crops are frequently cut higher than previously to maximise retention of stubble in the field.

Cutting high (e.g. 60cm instead of 20cm) increases the efficiency of harvesting as the machine can travel faster and fuel/ha is reduced[17]. Leaving long stubble in the field reduces soil moisture evaporation and retains nutrients in the system; it is estimated that baling 2t/ha of straw removes 10-20kg Nitrogen, 5-15kg potassium, 1 kg phosphorus, 3kg sulfur and various trace elements. As a result, yield of subsequent grain crops can be significantly increased by high cutting heights[14].

Retaining stubble and reducing tillage are proposed by GRDC as key adaptations for grain farmers given forecast changes in climate. However, these practices reduce the volume of straw available for baling and, therefore, compost production.

[16] Taylor C et al. 2018. Trends in wheat yields under representative climate futures: Implications for climate adaptation. Agric. Systems. 164:1-10.
[17] GRDC. 2011. Stubble management Fact Sheet. https://grdc.com.au/__data/assets/pdf_file/0026/224198/stubble-management.pdf.pdf

04. WATER AVAILABILITY, COST AND QUALITY FOR COMPOST PRODUCTION AND MUSHROOM GROWING

Likelihood – Moderate

Impact – Moderate

Management options – Increased water recycling combined with water purification systems, more efficient use of water, alternate water sources.

Industry vulnerability – Low

Summary

Both compost and mushroom production use large amounts of water; potentially up to 30L/kg mushrooms. Most mushroom farms use town water supplemented by bores, rainwater and surface water sources. Potential restrictions on water use represent an ongoing risk to production. Forecasts of climate change indicate moderate changes in rainfall in most regions, although extended dry spells may become more frequent in Perth, Mildura and Adelaide.

Current practice

Mushroom production requires large volumes of water, both for compost production and during growing, cleaning and processing at the farm. Estimates of the water required for vary widely between businesses. In the case of compost production, most estimates were between 800 and 2,000 Litres/tonne compost. Mushroom farms use approximately 8 to 20L per kg of mushrooms produced. This suggests that 11 to 30L of water is needed to produce one kg of mushrooms. This is substantially less than the 64L/kg estimated for mushroom production in the US[18].

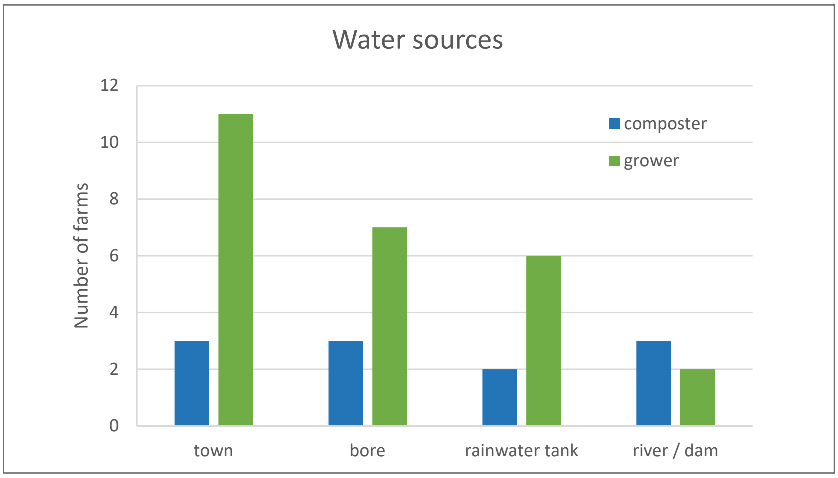
Most mushroom farms, and 3 of 7 surveyed compost producers, have access to town water. Many also use bore water, rainwater tanks or pump from surface water sources such as rivers and dams. Use of surface water is more common among compost producers, as they tend to be located in more rural areas.

Using town water ensures it is of suitable microbial and chemical quality for all purposes on the farm. However, one of the key effects of climate change is likely to be reduced availability of fresh water. While most farms gained exemptions from water restrictions in the most recent drought, this represents an ongoing vulnerability for many producers. Even where bore water is available, high salt content may limit its use. Recycling is also limited by accumulation of salts and other impurities. This may be one reason why only 30% of farms currently recycle water, and few have installed other water efficiency systems.

"Our town water supply is limited by the size of the pipes, and means we have to truck water in occasionally. The farm can't expand further unless we can improve the supply of water."

Most farms irrigate mushrooms by hand, using watering trees or overhead sprinklers. While drip irrigation systems are available, none of the mushroom farms surveyed were using this technology.

[18] Robinson B. et al. 2018. A life cycle assessment of Agaricus bisporus mushroom production in the USA. Int. J. Life Cycle Assess. 24:456-457.



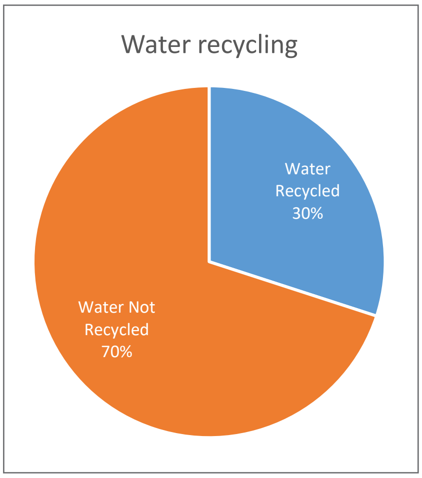


Figure 15. Water sources used by composters and farms, and the percentage of mushroom farms recycling water for non-critical uses (e.g. cleaning).

Potential effects of climate change

Forecasts of climate change generally suggest that annual rainfall will fall for many areas, and that more rainfall will occur in large storm events. However, as with temperature, the effects are not the same in all regions. Some of the most severe reductions in rainfall are forecast for south-west Western Australia, Tasmania and north-west Victoria.

The variability of rainfall makes it difficult to predict. One way of expressing increasing rainfall variability is to consider the number of months where rainfall is less than the historical lowest 10%. That is, rainfall is close to the lowest it has ever been. The "Climate change in Australia" thresholds calculator suggests that dry periods will increase for Perth and Mildura but remain similar to current conditions in Brisbane and Sydney (Table 2).

Even if rainfall stays the same, warmer conditions will increase evapotranspiration from surface water sources. Moreover, increasing populations may create additional pressure on town water sources, at least in major population centres. As many mushroom farms are in peri-urban areas, access to town water remains a source of risk.

REGION	PRESENT AVERAGE (1981–2010)	2030 AVERAGE (LOW EMISSIONS) RCP 4.5	2050 AVERAGE (LOW EMISSIONS) RCP 4.5
Cairns	0.9	1.2	1.1
Brisbane	1.0	1.1	1.0
Richmond	1.0	1.2	1.1
Sydney	1.1	1.1	1.1
Hobart	1.2	1.3	1.4
Melbourne	1.2	1.4	1.4
Adelaide	1.3	1.6	1.5
Perth	1.5	2.0	2.0
Mildura	1.5	1.8	1.6

Table 2. Average number of months where rainfall is less than the historical lowest 10%, under a scenario where emissions peak by 2040 and then decline (RCP 4.5).
Source: Climate change in Australia – Projections for NRM regions[11]

05. ENERGY – COSTS OF POWER AND RELIABILITY OF THE GRID

Likelihood – MODERATE to LOW

Impact – Moderate

Management options – On-farm power generation, energy efficiency technologies

Industry vulnerability – Moderate

Summary

Mushroom farms are big users of electricity. While some are also using solar, LPG and diesel, the majority of power is sourced from the grid. Half of all farms already have solar systems, most have installed LED lights and have backup generators available; other actions to reduce electricity costs are limited.

Future changes in electricity costs rely on government policy. Forecasts suggest that a clean energy target scheme will reduce costs. In contrast, ongoing uncertainty and reluctance to invest in renewable energy sources under the current policies will result in price increases of up to 20%.

Current practice

Electricity for cooling, heating and equipment is clearly one of the biggest costs of operation for both composting facilities and mushroom farms. Energy costs are generally highest in summer due to cooling requirements; several farms report increases of about 50% in electricity costs during summer. Key energy uses on farm include:

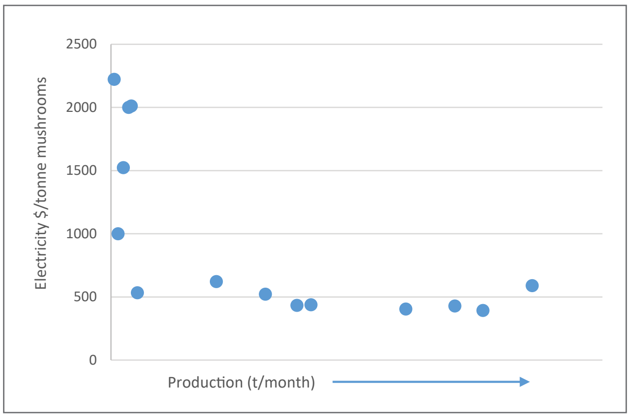


Figure 11.Cost of electricity per tonne mushrooms produced, each point is one farm.

- Cooling/heating of grow rooms
- Heat and steam generation during room cookout
- Cooling/heating of processing and packing areas
- Postharvest cooling and storage of mushrooms
- Equipment such as forklifts, pumps, fans, belts etc.

Estimates of the electricity cost per tonne of mushrooms from the farms surveyed ranged from $393/tonne to $2,011/tonne, with a median of $533/month. Small farms pay significantly more for electricity in terms of $ per tonne of mushrooms grown compared to large farms, even if they have installed solar systems. Only five of the surveyed farms did not have backup generators, three of whom were exotic mushroom producers. One grower commented that;

> *"We had total crop loss from a blackout previously, we couldn't survive that happening again. Now we have a large generator that's big enough to power the farm."*

Half of the farms surveyed already had solar systems installed, with four others planning to install a system in the future. The size of systems varied from 30 to 250 Kwh.

"We installed solar 3 years ago and it supplies 85% of our daytime electricity needs. It's managed by a smart meter and rarely feeds into the grid"

There were also two farms which had previously, or are currently, investigating biogas production using spent mushroom compost. A number of farms use LPG for forklifts, with several also using natural gas, LPG or diesel to power boilers used to cook-out rooms.

In terms of energy efficiency, most farms had installed LED lighting, sometimes linked to movement sensors. One farm noted that they had improved insulation on ducting, while another had installed energy recovery units on the air-conditioning units; these pre-heat or pre/cool incoming air, reducing load on the air-conditioning system.

Despite the extreme conditions of the 2019-20 summer, only one farm reported a significant power interruption.

Potential effects of climate change

In 2017, the federal government commissioned an enquiry into the future security of the National Energy Market[19]. This was to consider the effects of varying government policy on the price and reliability of energy supplies for domestic and business uses.

There is a great deal of uncertainty about future policy in this area, which can change with an election or even simply party leadership, and may be heavily influenced by targets to reduce emissions. Some of the scenarios considered were:

- Business as usual (BAU), with continued uncertainty over abatement policy and investment decisions
- A clean energy target (CET), where emissions targets must be met
- An emissions intensity scheme (EIS), where rewards and penalties are awarded to power generators based on emissions compared to an industry baseline

Perhaps surprisingly, energy costs are highest under the BAU scenario, primarily due to ongoing uncertainty about investment. If uncertainty about government policy continues, it is expected that wholesale energy prices will continue to rise gradually, plateauing at close to $90/MWh.

Wholesale prices are lowest under a CET scheme, followed by an EIS. This is because the incentives provided to low emission energy producers entering the market puts downward pressure on prices. The EIS applies a direct penalty to existing coal-fired generators, and further distinguishes between brown and black coal, whereas the CET simply caps total emissions.

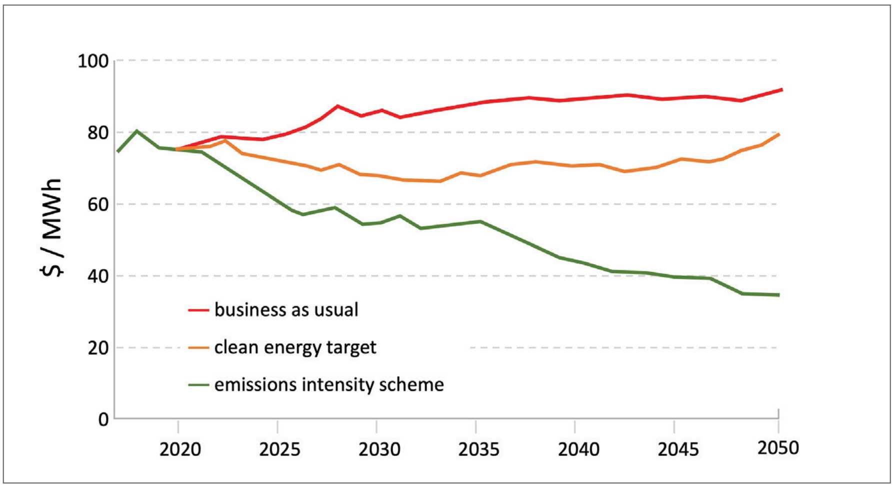


Figure 12. Wholesale electricity prices under different policy scenarios

Derived from: Gerardi and Galansi (2017)[19]

[19] Gerardi W, Galanis P. 2017. Report to the Independent review into the future security of the national energy market. 21 June 2017. https://www.energy.gov.au/. accessed 9-4-2020.

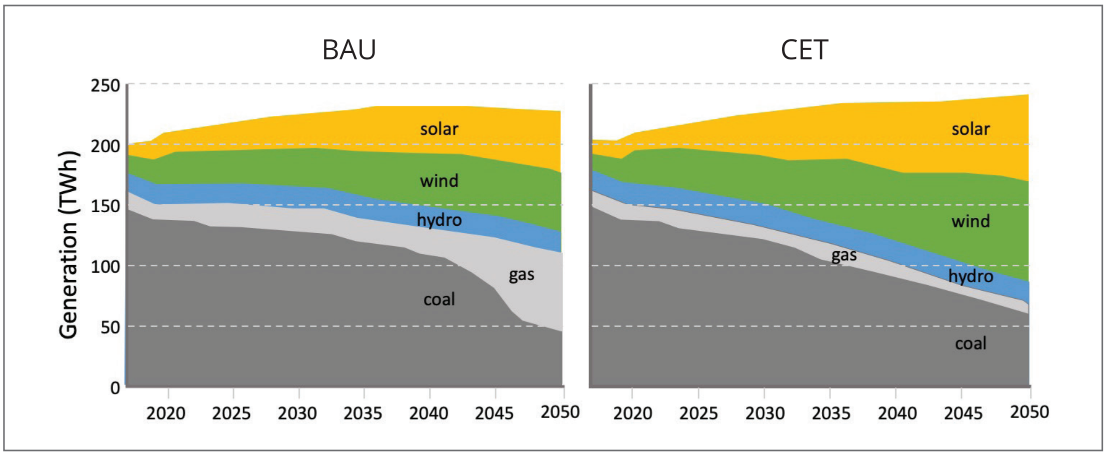


Figure 13. Projected changes in generation type under a business as usual scenario (left) or a clean energy target (right)

Derived from: Gerardi and Galansi (2017)[19]

Coal fired generation falls in all scenarios, with or without government policy. Even under BAU, announced retirements, deterioration of performance and ageing will see most coal fired generators cease operation by 2040. This will be replaced with gas-fired power, wind and solar generation and solar with battery storage (Figure 13).

The report considers it likely that a price will be placed on carbon at some point in the future – as this was policy at the time of commissioning. It was thought this would commence at $25/t CO_2 and gradually rise to $50/t by 2030. It is estimated that a 1% increase in electricity price will drive a 0.2% to 0.4% reduction in demand. Modelling therefore suggests that the carbon price will have minimal impact on demand, particularly during the summer peak where energy is used for air-conditioning.

However, a carbon price would drive major changes in electricity generation technologies. Black coal and, particularly, brown coal are far more expensive sources of electricity under this scenario than solar or wind generation (Figure 14)[20].

These reports suggest that under current government policy electricity prices will continue to increase. However, if a clean energy target is mandated, with or without a carbon price, then wholesale energy costs may fall considerably.

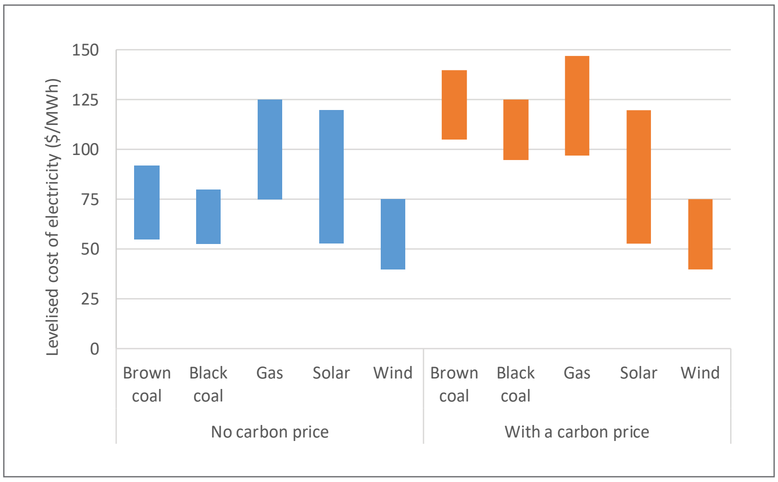


Figure 14. Projected 2030 cost of electricity from different sources with (orange) and without (blue) a carbon price. Derived from: Australian electricity market analysis report.[20]

[20] Brinsmead TS, Hayward J, Graham P. 2014. Australian electricity market analysis report to 2020 and 2030. CSIRO report to the Int. Geothermal Expert group. www.arena.gov.au

06. AVAILABILITY AND QUALITY OF MANURE FOR COMPOST

Likelihood – MODERATE likelihood of changes in manure composition and quality, as well as volumes available.

Impact – Key impact may be the need to re-balance mixtures used to make compost, potentially adding supplements to optimise carbon:nitrogen balance.

Management options – While costs and the need for supplements during compost production may increase, changes in poultry manure composition are unlikely to create major problems for compost producers. It may also be possible to use other sources of manure, such as cattle of sheep manure from feedlots.

Industry vulnerability – Changes in manure availability and composition are not considered to be a major industry vulnerability.

Summary

The effects of feed type and use of antibiotics on manure quality are poorly understood, but are likely to vary due to price and availability. The materials traditionally used for poultry bedding have also changed, for example rice hulls are less commonly used in broiler sheds. Poultry producers may substitute high carbon materials such as wood shavings, nut hulls or tree waste. Whereas bedding used to be changed for each cohort of chickens, the materials are increasingly being re-used for several cycles. These factors will influence both the quantity of litter available for compost production and its C:N balance.

Current practice

All mushroom compost producers use poultry manure, sourced from local farms. There was little effect of drought on the availability of manure, however some poultry farms did switch from rice hulls to sawdust. Two compost producers reported the cost of poultry manure increased during the drought.

The nitrogen content of chicken manure has been steadily decreasing as the poultry industry has developed more efficient feeding methods.

"Chicken manure has changed from a rice hull base to sawdust. This affects structure and reduces nitrogen content, which means we need to use more to create the same volume of compost."

"Since chickens are now raised on hardwoods, the variability in quality has increased, as has the price."

Potential effects of climate change

ANIMAL DIETS

Chicken manure for compost production may be sourced from broiler sheds or barn-based egg production. The mixture can contain bedding material, feathers, blood, eggs etc. as well as manure. Antibiotics added to chicken feed as growth promoters and therapeutic agents are not fully metabolised within the birds so may also be present in the manure. Other aspects of the birds' diet can likewise affect the end qualities of the manure. However, no information on links between chicken diet and manure attributes was found for this review.

There has been more examination on the effects of diet on the attributes of cattle manure, due to its environmental effects. For example, a diet high in corn

distillers grain reduces the pH and nitrogen content in manure[21], whereas adding soybean meal mix to the diet increases nitrogen content along with ammonia production[22]. A high fibre diet such as red clover silage, or inclusion of linseed oil, also reduce nitrogen content of manure compared to cows fed on low fibre corn silage[23]. While cattle manure is not known to be used in mushroom compost currently, it seems possible that changes in the diet of poultry may have similar effects on manure quality.

Bedding materials

Many chicken meat producers previously used rice hulls as bedding material. However, water shortages have seen rice production fall dramatically, reducing availability of this material. While many farms turned next to sawdust and wood shavings, the prices of these materials have also now increased.

A recent study by AgriFutures Australia[24] found more than 65% of chicken meat producers were looking for alternative sources of bedding materials due to cost and supply issues. For example, wood shavings can cost \$22-\$40/m^3 compared to \$10-\$15/m^3 for straw. The study identified a number of alternative litter materials including nut husks, oat hulls, stubble pellets, miscanthus grass and tree-litter. The type of bedding material that is used is likely to significantly alter the C:N balance in the waste product. For example, the change from rice hulls to wood shavings reduces N content, with clear implications for the attributes of the resulting compost.

Another change due to increased cost/reduced availability of bedding materials is the more frequent recycling of the litter by re-use, layering or mixing. In the past, about 70% of Australian broiler chickens were grown on new bedding, with the remaining farms practicing partial re-use[25]. In the US, litter may be re-used for up to two years before the sheds are fully cleared out. This is made possible by windrowing the bedding inside the shed, allowing it to partially compost, before re-spreading for the next batch of birds[26]. Increasing adoption of this practice has clear implications for the volume and composition of material available for compost production.

Figure 9. Bedding for broiler chickens may be recycled several times before disposal.

Source: ABC News 10/5/13

21 Lee C. et al. 2020. Feeding a diet with corn distillers grain with solubles to dairy cows alters manure characteristics and ammonia and hydrogen sulphide emissions from manure. J. Dairy Sci. 103:2363-2372.

22 Edouard N. et al. 2019. Influence of diet and manure management on ammonia and greenhouse gas emissions from dairy barns. Animal. 13:2903-2912.

23 Hassanat F and Benchaar C. 2019. Methane emissions of manure from dairy cows fed red clover or corn silage-based diets supplemented with linseed oil. J. Dairy Sci. 102:11766-11776.

24 Watson K, Wiedemann SG. 2019. Review of fresh litter supply, management and spent litter utilisation. AgriFutures Australia. 128pp.

25 Chinavasagam HN, Tran T, Blackall PJ. 2012. Impact of the Australian litter re-use practice on Salmonella in the broiler farming environment. Food Res. Int. 45:891-896.

26 LeBlanc B. et al. 2005. Poultry production best management practices. Louisiana Ag Centre.

07. PESTS AND DISEASES

Likelihood – LOW

Impact – Moderate

Management options – Ensure Phase 2 temperatures are high, maintain good farm hygiene and biosecurity

Industry vulnerability – Low

Summary

There is a range of important pests and diseases of mushrooms already established in Australia. These can reduce yield and quality and increase costs, in some cases threatening farm viability.

The effects of climate change and variability on pests and diseases of mushrooms are unclear. While warm temperatures may increase insect pests and mite populations on raw materials, dry conditions could offset this effect. It seems possible that hot, dry conditions could increase dispersal of spores, and may increase growth of green mould in Phase III compost. There is some evidence of increased incidence of smoky mould, but it is unclear why this has occurred.

Current practice

ESTABLISHED AND EXOTIC DISEASES

Diseases of mushrooms can be caused by fungal, bacterial and viral pathogens. By far the most persistent and devastating are fungal diseases, primarily Dry Bubble (*Lecanicillium fungicola)* and Cobweb *(Cladobotryum mycophilum).* Unlike bacterial diseases, which can be controlled by water treatment and careful environmental monitoring, management of fungal diseases requires a coordinated IPM approach and, above all, a dedicated effort by all farm personnel.

Fungal diseases of mushrooms are the most difficult to manage as environmental conditions optimise the growth of both the crop and the invading pathogens. Moreover, treating the fungal infection without harming the fungus host is a delicate balancing act, particularly if fungicides are applied to control the infection.

Fungal pathogens also produce extremely high numbers of resistant spores, each one capable of initiating a new infection if there are favourable conditions for germination. Spores are capable of surviving in grow rooms, throughout the farm and within its surrounds for long periods, ensuring a disease reservoir and an ever-present threat of infection. A single Dry Bubble mushroom will produce in excess of 30,000,000 Lecanicillium spores hr^{-1}, yet only 2,500 spores kg^{-1} of casing is sufficient to cause significant yield reduction, while 25,000,000 spores kg^{-1} casing will result in total crop loss[27]. Given that even a moderate Dry Bubble outbreak will result in many symptomatic bubbles developing in a single grow room, the number of spores produced by this pathogen is highly significant.

[27] Beyer DM. 1994. Get ready for summer. AMGA Journal Spring:23-26.

RISKS FROM CLIMATE CHANGE

FACING THE AUSTRALIAN MUSHROOM INDUSTRY

There is a large number of mushroom diseases found in other countries but not yet present in Australia. For example, a risk analysis by the UK mushroom industry found 19 fungi, 11 bacteria and five viruses to be directly pathogenic on Agaricus bisporus, with 21 insects, 22 mites and 28 nematode species also associated with cultivated mushrooms[28]. In comparison, there are five pathogenic fungi, two pathogenic bacterium species, one virus strain and three species of fly that are known to occur within Australian mushroom crops.

	PATHOGEN	COMMON NAME	STATUS*
Fungus	*Cladobotryum mycophilum*	Cobweb	Established
	Cladobotryum dendroides	Cobweb	Unknown
	Cladobotryum asterophorum	Cobweb	Emerging
	Lecanicillium fungicola	Dry Bubble	Established
	Mycogone perniciosa	Wet Bubble	Emerging
	Syzygites megalocarpus	Troll Doll	NR
	Trichoderma spp.	Saprophytic green mould	Established
	Trichoderma aggressivum	Compost green mould	Emerging
Bacterium	*Burkholderia gladioli* pv. *agaricicola*	Bacterial soft rot	NR
	Ewingella Americana	Internal stipe necrosis	Emerging
	Janthinobacterium agaricidamnosum	Bacterial soft rot	NR
	Mycetocola sp.	Bacterial pit	NR
	Pseudomonas agarici	Drippy gill	Emerging
	Pseudomonas fluorescens	Mummy disease	Unknown
	Pseudomonas 'gingeri'	Ginger blotch	Established
	Pseudomonas 'reactans'	Bacterial blotch	Emerging
	Pseudomonas tolaasii	Brown blotch	Established
Virus	La France	La France	Established
	Mushroom virus X	MVX	NR

**Established – present in Australia and commonly expresses; Emerging – has been recorded or is established in Australia but expresses new symptomology or with greater vigour overseas; NR – not recorded in Australia but causes losses overseas; Unknown – has been recorded in Australia but current occurrence or identity uncertain*

Table 3. Summary of diseases of cultivated mushrooms in Australia. *Compiled by Warwick Gill from numerous sources.*

[28] Woodhall JW et al. 2009. A UK commodity pest risk analysis for the cultivated mushroom, Agaricus bisporus. CSL/Warwick HRI, File no. PPP12011A

Costs of disease

Diseases can affect the financial viability of mushroom farms. Growers say anecdotally that the first and second flush yields pay for the costs of growing mushrooms while the third flush yield accounts for the profit. The number of flushes harvested is strongly affected by disease. Approximately 17% of farms only harvest two flushes, while up to 70% will harvest three. However, a number of those commented they would keep the crop for a final flush if disease could be managed.

Costs associated with disease management are manifold and extend beyond the calculable market dollar value. They can be broken down into direct and indirect costs:

DIRECT

- Yield reduction
- Reduced quality and storage life
- Loss of market share
- Pesticides, salts and sanitisers
- Labour and equipment to apply treatments, inspect crops, spot-treat and manage infections. For example, one grower recently reported investing 70 man-hours/week to manage a Dry Bubble infection

INDIRECT

- Additional air filtration
- More frequent cookouts / chemical sanitiser application
- Adjusting cropping environment to provide less favourable conditions for the pathogen, but causing a reduction in quality and yield of product
- Growing a disease 'cycle-breaking' strain which is less susceptible to the pathogen, but which may be of lesser quality and marketability

The arrival of an exotic, unknown pathogen could be potentially devastating to the Australian mushroom industry. In the case of Troll doll disease (*S. megalocarpus*), one author stated that the new pathogen had probably been expressing in crops long before it was formally reported, primarily because the new symptomology had been overlooked or mis-diagnosed as cobweb or merely ignored because "…it does not fit the usual categories", resulting in a build-up of undetected inoculum on exposed farms[29].

Potential effects of climate change

There has not been any (known) research undertaken on the impacts of climate change on pests and diseases of cultivated mushrooms (David Beyer, Penn State University, Pennsylvania United States; Lise Korsten, University of Pretoria, South Africa; Bill Barber, Giorgio Mushrooms, Pennsylvania, United States: pers comm May 2020). Changes in the outside climate are mitigated by environmental control of the grow rooms. However, some potential impacts may be considered:

Dispersal of established diseases

Flies are important vectors of diseases such as Dry Bubble. Warmer conditions may benefit some insects, as their reproduction rate is closely tied to temperature. It may also improve their ability to overwinter in cooler areas[30]. This has already occurred in New South Wales, where Phorid populations are now persisting throughout winter. This is also occurring in Pennsylvania, where flies have been active year-round for the past decade, since winter frosts all but disappeared (Bill Barber, Giorgio Mushrooms, Pennsylvania, United States: pers comm May 2020).

Conversely, mushroom flies require moisture to flourish. Sciarids frequent leaf litter, rotting vegetation and damp areas around the farm. Climate models predict higher temperatures, more intense and frequent heatwaves, and drier conditions. These

[29] Miller R, Spear M. 2014. Four facts you should know about Syzygites disease of mushrooms. Spawn Run March:15-16

[30] Sharma HC. 2014. Climate change effects on insects: implications for crop protection and food security. Journal of Crop Improvement 28:229-259

habitats are therefore less likely to persist, countering any increase from rising temperatures.

For diseases such as Cobweb that are wind dispersed, hotter and drier conditions will create more dust around the grow rooms and farm environment. The dust, incorporating *Cladobotryum* spores, will be aerosolised and dispersed. These diseases may therefore increase.

Invertebrate pests

Mites and nematodes can potentially be introduced into the growing rooms on compost materials. These include wheat straw, but also cotton hulls and poultry manure. Mite populations could feasibly increase in the warmer, drier conditions expected to occur in wheat growing regions.

Under normal conditions these pests are killed during Phase II pasteurisation, where compost reaches at least 60°C for a minimum of three hours. It is only if compost is unevenly mixed and heated that mites and nematodes can shelter in cooler niches in order to survive. It was previously noted that hot conditions decrease composting efficiency by reducing air circulation within compost windrows. It will be essential therefore to closely monitor composting conditions to ensure that these contaminants cannot survive to Phase III.

Weed moulds

Although spawn-run compost should be a relatively pure culture of *Agaricus*, a significant number of moulds are able to be isolated from this substrate[31]. Some pose no risk to crop yield and quality, while others compete with *Agaricus* mycelium for nutrients, reducing yields. Their appearance indicates that the compost is non-selective and susceptible to colonisation by seriously detrimental moulds such as *Trichoderma aggressivum f. aggressivum* (compost green mould), *Penicillium hermansii* (smoky mould) and *Pythium oligandrum* (black compost)[32].

Trichoderma aggressivum f. *aggressivum* sporulates extremely prolifically. When fresh, the spores are encapsulated in a sticky mucilage to aid dispersal by adhering in clumps to a vector. But when dry, the tiny spores readily become airborne, often incorporated with dust. Predicted droughts and heatwaves will drive dispersal of this pathogen by both flies and wind.

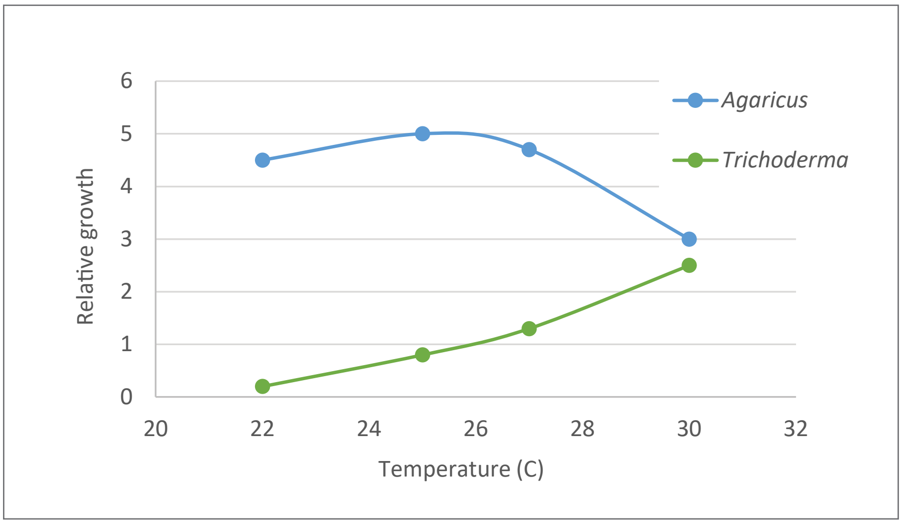


Figure 10. Effect of Phase III temperature on relative growth of Agaricus and Trichoderma mycelia. From Seaby, 1996.[36]

[31] Grogan H, Scruby A, Harvey L. 2000. Moulds in spawn-run compost and their effect on mushroom production. Mushroom Science 15:609-615.

[32] Noble R, Dobrovin-Pennington A, Turnbull W. 2009). Mushrooms: Factors and practices influencing the susceptibility of composts to infection by different compost moulds and to subsequent crop loss. Final Report M47, Agriculture and Horticulture Development Board. pp32

Managing green mould is particularly challenging for bulk spawn run operations. Although green mould normally spreads only small distances during Phase III composting, the process of loading, transporting and filling compost into growing rooms can easily spread the contamination through an entire batch. The issue may be worsened by high temperatures during transport, as 30ºC (or more, perhaps) favours growth of *Trichoderma* while reducing that of *Agaricus*[33].

Smoky mould is another pathogen that may potentially become more prevalent with climate change. Previously uncommon, it has been reported from farms in both Victoria and Queensland in the past two years, with another possible occurrence in NSW.

Smoky mould first appeared in the Netherlands 30 years ago. Its common name is due to the clouds of spores released when the compost is disturbed. Smoky mould has been responsible for a number of outbreaks in the Netherlands, UK and Canada and can cause total crop loss. The disease was attributed to dirty straw, used because of drought-driven supply shortages[34], a situation mirrored in Australia.

The disease is caused by the newly identified species Penicillium hermansii. So far, it has only been found in association with *Agaricus* mycelium, which it is believed to either parasitise or repress[35]. It is therefore unclear whether its incidence is linked to mould on wheat, or purely coincidental.

Research into the changing profile of the weed mould flora of mushroom farms has begun in South Africa (Lise Korsten, University of Pretoria: pers. Comm. May 2020). This will undoubtedly provide useful guidance for the Australian industry.

33 Seaby DA. 1996. Investigation of the epidemiology of green mould of mushroom (Agaricus bisporus) compost caused by Trichoderma harzianum. Plant Path. 45:913-923.

34 Hermans C. 2006. Triggers of Trichoderma and smoky mould. Mushroom Business

35 Houbraken J, Seifert KA and Samson RA. 2018. Penicillium hermansii, a new species causing smoky mould in white button mushroom production. Mycol. Progress. 18:229-236.

Hort Innovation | MUSHROOM FUND
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ahr applied horticultural research