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Agriculture: adapting to a changing climate

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ABSTRACT

Climate change is having a severe effect on agriculture around the world. The seasons are shifting, droughts are increasing, and heavy rains and storms are intensifying. Australia, as a leading agricultural nation, is suffering severely from the impacts of climate change. In the past few decades, Australia has been devastated by prolonged droughts, damaging storms, forest fires, and severe flooding. Farmers, many of who were once sceptical, are now searching for answers. Yet agriculture is a significant contributor to climate change through anthropogenic greenhouse gas emissions and by converting non-agricultural land such as forests into agricultural land. Land cleared for agriculture and stock can no longer support or sustain the heavy stocking of sheep and cattle it once did. Crops are failing and heavy water use crops, such as cotton and rice, need to be reassessed or shifted to alternate areas. The immense irrigation areas where the bulk of Australian fruit is grown may no longer be sustainable. The tillage of soil and planting of broad-acre crops like barley, wheat, and oats, also needs to be managed differently in the future. If farmers are to remain viable in the next decade and beyond, traditional farming practices need to change, and farmers must find ways to mitigate the effects of climate change. While this may be problematic for some, it also opens exciting new ventures and infinite possibilities. This paper looks at the impact of climate change on Australian agriculture along with possible alternatives such as no-till sowing, hydroponic food production in the desert, and the use of red seaweed supplementation to ruminants in order to help mitigate the challenging years ahead.

Keywords: climate-change, mitigation, desert hydroponics, *Asparagopsis*

INTRODUCTION

Australia is a significant world agricultural leader with climatic regions ranging from tropical in the north to cold temperate zones in the south and everything in between. Although blessed with good natural resources and weather, Australia has always been a country of extremes. Recently, however, climate change has increased the risks. Drought is constantly present, as is extreme flooding. Cyclones have become more intense in the tropical regions, and in 2019-2020 Australia suffered the worst bushfires on record. Farmers have endured the burden of all these extremes, with many farms folding, breeding stock reduced or wiped out, and crops were failing. The agricultural sector, with its heavy reliance on water, is particularly vulnerable to climate variability and climate change. If Australia is to continue as a leading agricultural nation, we need to change our farming practices and strategies in order to adapt to a changing climate. Through a review of the available literature, this paper explores how farmers can better use current existing data, models, and information to better understand and adapt to agricultural processes to survive climate change. Two innovative solutions are investigated, including hydroponics in the desert for large-scale tomato production and the use of Red seaweed (*Asparagopsis*) supplementation to reduce enteric methane in ruminants.

Climate change

Climate change may be the greatest challenge farmers will face over the next few decades. Before the Industrial Revolution started in the mid-1700s, the global average amount of atmospheric carbon dioxide was about 280 parts per million (ppm). The global average atmospheric carbon dioxide in 2019 was 409.8 ppm (Figure 1). Today, atmospheric carbon dioxide levels are higher than at any point in at least the past 800,000 years (Lindsay, 2020). This has mainly come from the increased burning of fossil fuels and industrialization, and extensive land clearing for grazing and other agricultural pursuits. Other greenhouse gases (GHG) such as methane are also problematic, with the livestock industry contributing up to 14.5% of GHG emissions (Gerber et al., 2013), with global methane emissions contributing to about 2.1 Gt CO_2 equivalent in 2010 (Smith et al., 2014). The result has been a rise in global temperatures and warming the planet with an increase of 1.41 degrees Celsius (IPCC, 2019). The speed of this change over such a relatively short time period means evolution has not had the time to adapt to the changing climate and atmospheric conditions.

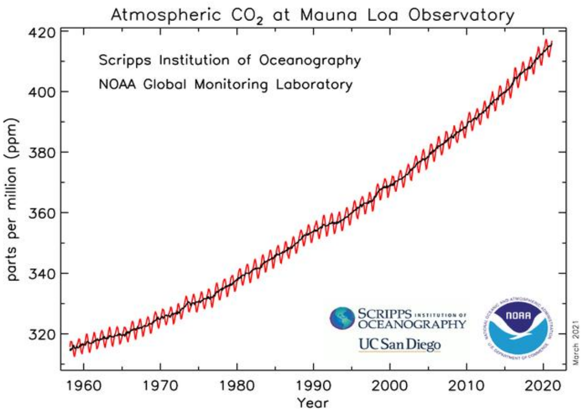

Figure 1. The global average atmospheric carbon dioxide
Source: NOAA (2021)

Drought in Australia

Australia has always been a country prone to drought. With a highly variable climate and low average rainfall, Australian agriculture is subject to more volatility than almost any other country in the world. There have been considerable changes to the Australian climate over the past 20 years, with reductions in average winter rainfalls in the south and increased temperatures (King et al., 2020). Climate models predict lower rainfall in southern Australia along with more severe droughts and floods in the future. (ABARES, 2021). Drought in Australia is commonplace, and it is one of the greatest challenges for any farmer resulting in severe crop failures and reduction in livestock feed. According to the Australian Bureau of Meteorology, drought events have increased and become more severe in recent years (BOM, 2020). With the land so dry, huge plumes of dust descended on the cities and towns, and the whole of Australia started to feel the effects of many long years of drought. Australia is in a difficult position in prioritizing climate adaptation in agriculture and investment because it is unclear how the IOD and El Niño–Southern Oscillation (ENSO) will change in the future and whether these changes will exacerbate drought conditions. Accurate projections of the future frequency of La Niña and negative Indian Ocean Dipole (IOD) events in a warming world will be required to better understand the risks of climate change on the security of Australia's water supplies, persistent droughts and extreme forest fires and how this will affect agriculture. These events may be increasing as the world warms (Zheng et al., 2013), but there remains uncertainty in projections due to model deficiencies. In particular, climate models overstate the amplitude of the IOD (Weller and Cai, 2013) and struggle with the extent of La Niña (Taschetto et al., 2014).

Drought impacts on Australian agriculture in many ways. It reduces production in various agricultural sectors to well below levels experienced in non-drought years. Agricultural production impacts from drought include a reduction in farm income and an increase in farm debt. The drought of 1997 to 2009 caused a significant drop in income of up to 40% for both the grain industry and the beef industry (ABARE, 2004). During the same period, the dairy industry recorded the greatest loss of income in the 27 years that the statistics have been recorded (ABARE, 2005). Previous major droughts have seen income reductions of even greater proportions. Long-term investment losses of drought include removal of permanent plantations, orchards, and vineyards (Ejaz Qureshietal, 2013).

Fires

Climate change is already impacting fire seasons worldwide (Halofsky et al., 2020; Parente et al., 2018). As the number of dry and hot days increases, wildfire seasons are extending. A longer fire season is expected to result in more frequent and severe fires (Di Virgilio et. al., 2019; Matthews et al., 2012). There is emerging evidence from ecosystems worldwide that catastrophic events such as extreme drought and large bushfires can push terrestrial ecosystems past tipping points that result in abrupt ecosystem change (Davis et al., 2019). Given the impact of human-driven climate change on the frequency and intensity of these events there is a need to quantify their effects on plant and animal communities (Belzen et al., 2017) as they unfold. November 2019 was the driest month on record in Australia, and this was believed to be the catalyst for the horrific fires that followed in December 2019 and January 2020. During the summer of 2019-2020, the worst bushfires in recorded history spread throughout much of Australia. At least 18,983,588 hectares were burned, 3,113 houses lost, and 33 people died in the 15,344 bushfires that were collectively called the Black Summer fires. Millions of hectares of natural vegetation along the eastern coast, much of which had already been exposed to prolonged drought and recorded high temperatures, were burnt (Boer et al., 2020). Although it is impossible to provide a definite number, it is believed that over one billion animals died in the fires. On Kangaroo Island alone, around 100,000 sheep were killed by fires.

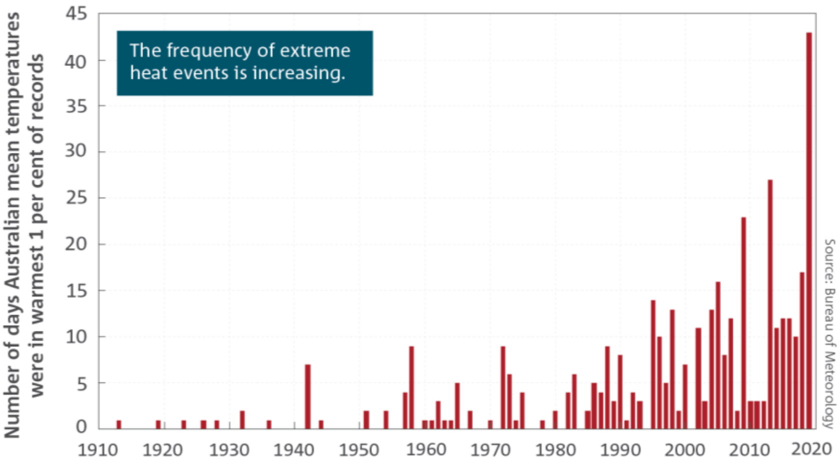

Figure 2. Number of days each year where the Australian area-averaged daily mean temperature for each month is extreme. Extreme daily mean temperatures are the warmest 1 per cent of days for each month, calculated for the period from 1910 to 2019
Source: BOM (2020).

How to mitigate the effects of climate change

Water

It is widely accepted that water is the most universally limiting factor in Australian agricultural production systems. Water efficiency, therefore, is one of the major initiatives in combatting climate change. In order to mitigate the problems farmers are facing due to climate change, they need to change the traditional methods of farming. No longer can Australian farmers rely on rivers and dams to irrigate their crops. Many traditionally irrigated farms may need to plant dry-land crops or use targeted trickle irrigation. The use of moister probes before sowing and during the development of the crops has now become commonplace. No-till sowing has been used for many decades to prevent moisture loss from the soil, compared to traditional plowing, which exposes the soil to dry it out (Robinson, 2021). There has also been much discussion around some tree crops, such as almonds, which are heavy year-round water users. This industry has recently been criticized for its excessive water use to maintain the trees. Almonds use between 12 and 14 megalitres per hectare on mature orchards to produce 3.2 tonnes of the almond kernel and 6 tonnes of hull and shell that is predominantly used for cattle food. In a country where every drop of water counts, this may not be sustainable (Davies, 2019).

No-till cultivation

No-till farming is one cultivation method that has been shown to reduce soil erosion, maintain soil moisture and improve soil structure during the sowing of broad-acre crops and pastures. No-till farming, or conservation tillage, means that the land is not cultivated in the traditional manner prior to sowing. No-till cultivation helps farmers respond to climate change by building up organic material in the soil, reducing water evaporation and runoff, and increasing soil carbon sequestration (Bayer et al., 2006). Other advantages include reduced tractor runs during sowing resulting in a saving on fuel, reduced wear and tear on machinery, and less carbon being emitted (Huggins and Reganold, 2008). For farmers in southern Australia, no-till's ability to help mitigate climate change while also adapting to the drier conditions makes it particularly relevant (Ugalde et al., 2007). The conversion to no-till farming systems in Australia has been both recent and rapid, with around 80-90% of Australia's winter broad-acre cropping farmers using no-till conservation methods (Bellotti and Rochecouste, 2014). The main reason there has been such a large uptake is mostly in response to soil erosion from wind and water (D'Emden et al., 2008).

However, although there are many advantages, there are also some disadvantages. Firstly, the changeover to no-till equipment can be expensive. There is also the issue of the use of herbicides to manage weed control (D'Emden et al., 2008). Many farmers are concerned that the herbicides will become less effective over time. With some herbicide companies controlling seeds, they may be limited in the use of other seed varieties (McRobert et al., 2011). One of the purposes of conventional tilling is to remove weeds, and no-till farming changes weed composition. In Australia, this is usually solved with the use of herbicides such as glyphosate instead of tillage for seedbed preparation. Weeds can also be controlled through winter cover crops, soil solarisation, or burning. Cover crops are sometimes used to help control weeds and increase soil residue. Extra fertilizers may need to be added due to the reduced mobility of nitrogen in the soil

(Bellotti and Rochecouste, 2014). Where herbicides are a problem, such as in organic farms, cover crops can be used. However, cover crops need to be killed to reduce competition and are usually done using rollers, crimpers, or other forms of weed control (D'Emden et al., 2008). Another difficulty can be residue from the previous year's crops lying on the surface of the paddock. This can cause different, more significant, or more frequent disease or weed problems than tillage farming. While the process of no-till cultivation is many thousand years old, the use of technology and innovation has made the practice very competitive, especially for broad-acre cropping, compared to traditional plowing and cultivation (Bellotti and Rochecouste, 2014). The process of innovation in farming is constantly changing, especially with the use of computerized soil management systems. New technologies such as Global Satellite Systems (GPS) and drones have been applied in ways not envisaged at the time of their invention. This type of farmer innovation continues to lead, using new applications and technology in the rapidly evolving domain of agriculture.

Hydroponics in the desert

One solution to the water issue may be using land previously thought unsuitable for farming and use the heat of the sun to help produce fresh water from normally unusable seawater. This is what is happening in the Australian desert. An enormous hydroponic farm has been established in the South Australian desert and now supplies up to 15% of Australian truss tomatoes. Sundrop Farm near Port Augusta in South Australia is the first of its type in the world and started with a small pilot plant in 2012. Now it is fully operational and uses solar energy to desalinate seawater and heat or cool the greenhouses to grow vine-ripened truss tomatoes commercially.

Seawater is piped 5.5 kilometers from the Spencer Gulf to Sundrop Farm in the arid Port Augusta region. A solar-powered desalination plant removes the salt, creating enough fresh water to irrigate 180,000 tomato plants inside the greenhouse (Klein, 2016). The farm uses 24,000 motorized parabolic mirrors arrayed at its base to project the sun's rays to a tower 127m above the ground. The thermal energy produced from this solar plant is used to heat seawater in vast boilers. This generates electricity from the resulting steam and thermal heating for the greenhouses. The steam-generated power also drives a desalination plant, turning constantly circulating seawater from the nearby Spencer Gulf into freshwater. In the greenhouses, 750,000 tomato plants are hydroponically grown in nutrient-filled pipes. The thermal energy harnessed here powers 20ha of adjoining greenhouses, which in turn produce over 350 tonnes of tomatoes each week. The entire system is self-sustainable (Neals, 2016).

The Sundrop System uses the sun's energy to produce freshwater for irrigation in a closed-loop system. It is then turned into electricity to power the greenhouse to heat and cool the crops. The salt from the desalination plant is later sold as a by-product. Sundrop produces high-quality truss tomatoes that are distributed across Australia through a major supermarket chain. The beauty of this system is that it uses land and seawater, previously unusable, into a viable form of sustainable farming, conserving water, and totally free of fossil fuels. With Port Augusta having 320 sunlight days per year, there is no shortage of sunlight to power the system. One of the major costs is the cooling of the greenhouses during the summer. Although the initial cost of $200 million is an extremely high capital investment, it is envisaged that the dramatic savings in running costs will make the investment work. Another facility is planned for Australia as well as facilities in Portugal and the USA in the near future.

Ruminants and enteric methane

Livestock production, particularly that of ruminants, is a large contributor to greenhouse gas emissions (GHG), particularly in the form of enteric methane. A review of mitigation options for enteric methane produced from ruminants showed that some of the effective strategies include increasing forage digestibility, replacing grass silage with corn silage, feeding legumes, adding dietary lipids and concentrates (Hristov et al., 2013). Another method being investigated is the use of red seaweed *Asparagopsis* as a feed additive. The seaweed from the genus *Asparagopsis* is a potent agent that reduces methane production in the digestive process of cattle and sheep. In general, marine algae were found to be more effective than freshwater algae in reducing methane production. Freshwater macroalgae have a similar biochemical composition to decorticated cottonseed meal (DCS); however, the methane output relative to DCS was reduced to 4.4% for Spirogyra and 30.3% for Oedogonium after 72 h incubation. However, there is no correlation between the biochemical composition of freshwater and a reduction in methane. Although methane was reduced, there were no apparent negative effects on fermentation variables. Rather, freshwater macroalgae had a slightly higher total volatile fatty acid (VFA) concentration than DCS with similar organic matter degradability (OMD) demonstrating that fermentation processes had not been compromised (Getachew et al., 1998). The effectiveness of the seaweeds in reducing enteric methane has now been established. However, only

Asparagopsis demonstrated that it remained effective and dramatically reduced the emission of methane, without negative impacts on rumen function. This was found even with a relatively low inclusion level in animal diets (Kinley et al., 2016; Li et al., 2018).

Asparagopsis taxiformis is a species of red algae with distribution in tropical to warm temperate waters. Native to the Southern hemisphere, it has been introduced to the northeastern Atlantic Ocean and the Mediterranean Sea. It is found widely in Australian waters, particularly around Northern Australia to Rottnest Island, Western Australia, and southern Queensland; Lord Howe Island; The Gulf region of South Australia, and Tasmania (Guiry and Guiry, 2021). *Asparagopsis armata* has also been used with good effects in cattle feed trials (Roque et al., 2019). The *Asparagopsis* species of seaweed produces a bioactive compound called bromoform, which prevents the formation of methane (CH4) by inhibiting a specific enzyme in the gut during the digestion of feed. Supplements added to feed have been found to reduce enteric methane production by more than 80 percent in some animals (CSIRO, 2020). Roque et al. (2019) found 'there was no significant body weight change between cows receiving *Asparagopsis armata* at low inclusion compared to control; however, cows receiving the 1% level gained 9.72 kg less than control cows. Milk yield did not differ significantly between cows in the control group and those at a low level of *Asparagopsis* inclusion. However, cows fed at the higher level of *Asparagopsis* inclusion produced 11.6% less milk compared to control ($P < 0.001$). No significant differences were found in milk fat, lactose, solids non-fat, milk urea nitrogen, or somatic cell count with both levels of macroalgae inclusion. The conclusion of this study confirms that enteric methane emissions could potentially be halved by using seaweed as a feed additive to dairy cattle. (Roque et al., 2019). *Asparagopsis* seaweed is characterized by secondary metabolites with antibacterial properties and demonstrates a potent methane reduction effect in livestock digestive fermentation. Using low volumes (less than 1.0%) in a feedlot trial, methane was reduced by over 90%, with positive trends observed for feed conversion and productivity. The *Asparagopsis* species of seaweed produces special substances containing naturally occurring bromine ($CHBr_3$) that prevents the completion of methane construction by reacting with vitamin B_{12} at the last step, which disrupts the enzymes used by the specific gut microbes that produce high energy methane gas as waste during digestion (CSIRO, 2020). The numerous studies on *Asparagopsis* as a feed additive to reduce methane levels in livestock have now gone beyond the experimental phase and are being developed as a commercial product by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia (CSIRO, 2020). Seaweed production globally is increasing, with more than 25 million tonnes (measured when wet) farmed each year. Australia currently has almost 1 million feedlots and 1.5 million dairy cattle. In order to produce enough *Asparagopsis* seaweed to supplement the feed of just 30% of these cattle would require about 25,000 dry tonnes a year and hundreds of thousands of tonnes if it were to be scaled up globally. With the selection and breeding of seaweed varieties for higher bioactivity, this figure is likely to reduce, but perhaps only by half, and it would still require large areas of land and water. With typical seaweed production rates at 30-50 tonnes of dry matter per hectare, this suggests that to supply 30% of the Australian feedlot and dairy industry will require approximately 2,000 hectares of seaweed farms. Seaweed farms in Australia are likely to be part of our increasing demands on the marine environment and will need to be part of integrated ecosystem-wide management and marine spatial planning. Indirect benefits worldwide, include creating alternative livelihoods in developing countries where fishing may be in decline, an alternative enterprise for existing aquaculture operations, and the use of seaweed as a means to filter detrimental nutrients from rivers or effluent from fish farms. In 2020, The Australian Seaweed Institute released its Blueprint for Growth, listing the cultivation of *Asparagopsis* as a key opportunity (Kelly, 2020).

CONCLUSIONS

The aim of this paper is to provide an overview of the effect climate change is having on Australian agriculture, and how through innovation, solutions can be found. Two examples are used to show how originality can be used to overcome seemingly insurmountable problems. Freshwater is a scarce commodity of which many countries do not have enough for drinking water, let alone irrigation for crops. By using the power of the sun to convert abundant seawater into freshwater, not only can this water be used in greenhouses in the desert to produce fruit and vegetables, but other uses, such as desalination plants, could be found for the systems in arid regions. The continuous rise of GHG, including the large contribution from livestock products, has long concerned scientists. The novel use of seaweed supplementation in trials has found that it can decrease the methane produced by ruminants. This will be of great assistance to livestock producers worldwide. Additionally, new opportunities will be developed for seaweed farmers in Australia and worldwide to grow enough supplements to feed the world's cattle. Furthermore, the growing of the seaweed will have additional benefits in lowering GHG from the carbon dioxide used during the growing phase.

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