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The impacts and evidence of Australian droughts on agricultural crops and drought related policy issues--A review article

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Abstract The recurrence of drought spells over the years in Australia has become a frequent phenomenon with significant impacts on agricultural output and productivity. Protracted drought events impacted crop physiology with adverse impact on grain development, hampered chlorophyll production, fruit bearing, number of grains/spikes, ovule fertility, pollen vitality, nodule performance, flowering period, cell growth, photosynthesis and transpiration, seed set and standard seed size. The average winter crop production across various crops in non-drought years was 45,676 kilo tonnes, whereas the average production in drought-affected years was only 25,592 kilo tonnes. In the years 1990, 2002─10, 2003─07, 2006, 2006─07, and 2018─19, drought reduced various crops production in Australia by 51%, 18%, 32%, 58%-56%-50% and 53%, respectively. Crops in general follow three types of adaptive strategies to respond drought: a) drought escape; b) drought avoidance; and c) drought tolerance. Different techniques such as zero tillage, priming, mulching, relay cropping, homestead gardening, dry land farming and pond water harvesting have offered good prospects of reducing drought impacts in various crops. There are fifteen drought adaptation and mitigation practices reported in the literature. These include increasing farm size, changing cropping pattern, selecting tolerant crop, developing tolerant varieties, soil evaporation, CO_2 incorporation, fertiliser application, mulching, supplementary irrigation, relay cropping, homestead gardening, pond water harvesting, priming, dry land farming, and zero tillage. Although, there are fifteen different strategies to manage drought by farmers, using a combination of these measures is suggested to be more effective. The drought policy of the country is fraught with ambiguity as Australian government encourages managing droughts by farm owners at one hand and supports farm owners with a huge amount of public money on the other hand to respond drought events.

Keywords: Australian drought, Crop production, Crop physiology, Drought overcome, Drought policy

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Introduction

Drought may be defined as the lack of water which is harmful for crop production and is associated with alteration in soil characteristics and meteorological status of the locality (Lipiec *et al.*,2013). Particularly, there are four different concepts of drought: agricultural drought, meteorological drought, hydrological drought and socio-economic drought (Khan *et al.*, 2018). Agricultural drought refers to those arid conditions prevailing for some duration during the crop growth and development phase arising out of deficiency in average rainfall and resulting in reduced crop production (Khan *et al.*, 2018). Drought may happen due to the development of disequilibrium in "water flux rate between potential evapo-transpiration (demand) and water transport into the soil-root system" (Lipiec *et al.*, 2013). At present, it is realized that four climatic features such as El Nin˜o/Southern Oscillation (ENSO), Inter-decadal Pacific Oscillation (IPO), Indian Ocean Dipole (IOD) and Southern Annular Mode (SAM) are linked with the droughts in south eastern Australia (Verdon-Kidd and Kiem, 2009). The agricultural sector of Australia suffers due to agricultural drought, as these droughts create a financial burden for agricultural farmers as well as due to shortage of food. FAO (2013) stated that the wheat production of whole Australia was reduced by 46% in 2006 drought. CSIRO (2007) predicted that the chance of drought months in Eastern Australia will be increased by 40% by the year 2070. Therefore, it is very important to know the previous loss of crops production due to drought in Australia to minimise the potential loss due to future drought and also to ensure food security in the country. Drought policy describes the strategy of the government to fight against drought. Therefore, government should adopt appropriate drought policy to reduce the impacts of drought in agricultural food production system. Measures adopted to minimise drought loss determined the vulnerability and resilience to drought (Wilhite *et al*., 2014).

The objective of reviewed article was to explain the effects of drought on various crops and their physiology. The past evidence of occurring drought in Australia was explored to understand the previous drought loss and assume future loss. The drought policy of the Australian government was presented to understand whether the government is on right track to deal with drought, which may be helpful for policy makers.

Materials and methods

To discover a drought effect on various crops and their crops physiology, a considerable number of peer-reviewed journal articles were studied. The main search keywords were 'drought' and 'Australian drought' in combination with the other related keywords 'effect/impact', 'effects on agriculture and economy', 'records', 'policy', 'adaptation by crops/plants', 'adaptation and mitigation measures' were searched in Google Scholar, Griffith University Library, Scopus and Web of Science. Inclusion criteria were 'Australian drought', 'Australian government drought policy', 'drought effects on agriculture/crops'. In contrast, exclusion criteria were 'drought other than Australia', 'drought policy except Australia', 'drought effects on society and health'. To explore drought and agriculture related information in Australia, mainly two Australian government websites such as, Department of Agriculture and Water Resources and ABARES (Australian Bureau of Agricultural and Resource Economics and Sciences) were reviewed. The key focus was on the drought effects on agricultural crops and Australian droughts' impacts in the backdrop of the drought policy.

Resultson drought impacts

The impacts of drought on various physiological functions and physiological characteristics of crops are directly or indirectly reflected on crop yield. Under drought conditions, the physiology of cereal crops is significantly affected (Bowne *et al*., 2012). Australian cotton is susceptible to low irrigation availability and high evapo-transpiration, which result in fruit loss, low production, and a decrease in the efficiency of irrigation use (Bange *et al*., 2010; Williams *et al*., 2015). Timung and Konwar (2017) reported that under drought conditions, the chlorophyll content in rice crops reduces by 3% and 2.57% in tillering and heading stages, respectively. The Table 1 illustrates that drought, increased temperature and the consequent water scarcity caused much harm to wheat, rice, pea, sorghum, cereal crops, maize, and cotton in the agricultural landscape in the country. Among them wheat is the most important crop in Australia, thus, any adverse effect on wheat may cause great loss for the country in terms of agricultural output.

Evidence of droughts in Australian agriculture and economy

The evidence of agricultural loss from drought in Australia from 1990 to 2019 is shown in Table 2. It is clear from the evidence that drought has caused much harm to the economy and agriculture sector of the country. Overall, drought impacted the country in 2002, 2006─07, and 2018 with a GDP loss of around the country by around 1%. In the years 1990, 2002─10, 2003─07, 2006, 2006─07, and 2018─19, drought reduced various crops production by 51%, 18%, 32%, 58%-56%-50% and 53%, respectively. It needs no special emphasis that such huge declines in crop yield would have certainly impacted the food security of the country as well. The economic impact of drought in 2006─07 was estimated at $6.7 billion, which can indicate an extensive financial loss for the country.

Table 1. A list of drought effects on agriculture crops

Sl	Crop/Soil	Harmful effect	Condition	Reference
01	Wheat	Impedes the grain development of wheat	If the temperature prevails at more than 30 degrees in Celsius in a single day	Saini andAspinall, 1982
02	Rice	A reduced amount of chlorophyll of 3% in the maximum tillering period and 2.57% in heading period was noticed	During drought compared to normal state of water	Timung and Konwar, 2017
03	Cotton	Results in fruit loss, low production, and decreased irrigation use efficiencies	Australian cotton is susceptible to low irrigation availability and high evaporation	Bange*et al*., 2010; Williams *et al*., 2015
04	Sorgh-um	Causes much harm	A heat wave with prevailing temperature more than 40° Celsius in 2014	Grains Research and Development Corporation, 2014
05	Pea	Pea crops could not maintain the desired structure, time period or output by their nodules	Drought affected	Lipiec *et al*., 2013
06	Cereal crops	Can causes less yield and less number of grains per spikes	When drought appeared one month earlier of flowering condition	Innes and Blackwell, 1981; Klepper *et al*., 1982
		The physiology of cereal crops is significantly affected	Under drought conditions	Bowne *et al*., 2012
07	Wheat and maize	The yield of wheat decreased by 20.6% and in maize by 39.3%	During 40% deficit of water	Daryanto*et al.,* 2016
08	Rice and maize	Can cause aborted ovule and pollen sterility	If deficiency of water in reproductive stage	Fischer *et al*., 2011
09	Crops	Causes a decrease of flowering for 5 days	An increase of 1°Celsius in temperature	Afzal *etal*., 2018
		Reduces “the turgor pressure of plants” that eventually impedes cell growth		Afzal *et al*., 2018
		Diminishes photosynthesis and transpiration in both irrigated and non-irrigated states	When temperature is 22─32° Celsius	Zhang *et al*., 2010
		Can inhibit fruitful seed set and decrease standard seed size	Increased temperature along with the greater vapour pressure deficit	Nguyen *et al*., 2013; Prasad *et al*., 2008
		Causes seedling mortality	After an extreme drought and a low predominance of fire	Edwards andKrockenberger, 2006
		Affects the grain-filling period of crops and leads to a decrease in the biomass of volume	The rise of temperature	Valizadeh*et al*., 2014
10	Crops and soil	The interactions among soil and roots hampered growth and roots cannot uptake adequate water		Beudez *et al*., 2013

Table 2. Some pieces of evidence of loss due to Australian droughts

Year	Drought loss	Reference
1990	Heat and drought together caused loss of crop production of about 51%	Lobell *et al*., 2015
2002	Affected the country by reducing 1.6% of GDP	RBA, 2006
2002─03	Curtailed farms income in Australia by 58%	Potter, 2003
2002─03	Reduced about 60% productions of the four major winter crops, which are wheat, barley, canola and lupins, compared to the previous year	ABARES, 2003
2002─10	Reduced the productivity of the whole country by 18%	Sheng and Xu, 2019
2003─2006	The GDP of farms collapsed from 24.8% to 18%	Sheng and Xu, 2019
2003─2007	Involved in a fall of summer orange production by 32% compared to 1999─2002	van Dijk *et al*., 2013
2006	Wheat production of the country diminished by 46%	FAO, 2013
2006─07	Expected to reduce agricultural earnings by 72.4%, a reduction from \$9.3 billion in 2005─06 to \$2.6 billion in 2006─07	ABS, 2006
2006─07	Due to the shortage of irrigation water and adverse cultivation conditions, the production of the country significantly declined: wheat 58%, barley 56%, and cotton lint 50%	ABS, 2008
2006─07	Lowered the country's GDP by about 1%	van Dijk *et al*., 2013
2018	Could cut the country's GDP by 0.5─0.75%, which may cost \$8─12.5 billion	Henderson, 2018
2018─19	Anticipated the decrease of agricultural production in eastern Australia by around 53% due to drought	Hatfield-Dodds*et al*., 2018

Australian drought management policy

History and succession of Australian drought policy

The drought policy was intended to secure 'drought proofing' by ensuring irrigation in agriculture sector in the middle of twentieth century (Department of Agriculture, Water and the Environment, 2020). In 1992, drought policy introduced notification of "Exceptional Circumstances (EC)" areas to provide drought assistance and subsidy (Department of Agriculture, Water and the Environment, 2020). The declaration of EC was defined in 1995 and consists of six main criteria, which are "meteorological conditions, agronomic and stock conditions, water supplies, environmental impacts, farm income levels and scale of the event" (White *et al.*, 1998). When the effect of drought is extreme on farmers and when it causes a rare case and when it occurs one in 20-25 year period then the drought is declared as EC (ABARES, 2012). In 2008, it was agreed that EC declaration is not a good idea for providing drought assistance and hence it was held void (Department of Agriculture, Water and the Environment, 2020). In 2013, the State, Territory and Federal Government in Australia signed on an agreement known as the Intergovernmental Agreement on National Drought Program Reform (IGA). IGA presented a new idea for execution of roles and responsibilities of government bodies (Department of Agriculture, Water and the Environment, 2020). In 2018, another agreement called new National Drought Agreement (NDA), was signed by the Council of Australian Governments. The NDA focuses on combined effort to overcome drought with ensuring accountability and transparency (Department of Agriculture, Water and the Environment, 2020).

There are two integral pillars of the modern Australian Government drought policy:

The 1992 national drought policy: This Policy introduced the provision for “exceptional circumstances”, under which, eligible farmers got subsidy through the Rural Adjustment Scheme (Botterill, 2003). The motives of this drought policy are (Department of Agriculture and Water Resources, 2019): i) Motivate growers to take their own initiatives to manage drought; ii) Conserve and protect farming and ecology related resources in climatic stress and iii) Plan and develop programs for restoration of agricultural and rural enterprises (Department of Agriculture and Water Resources, 2019).

The 2018 national drought agreement: An agreement among Federal Government and six States (New South Wales, Victoria, Queensland, Western Australia, South Australia and Tasmania) and two Territories (the Australian Capital Territory and the Northern Territory) regarding the collaboration, consistency and complementarity to support farms to tackle drought was set up (Department of Agriculture and Water Resources, 2019). The agreement signed on 12 December 2018, substitutes “the 2013 Intergovernmental Agreement on National Drought Program Reform”. However, it emphasized the requirement to help agricultural enterprises for adaptation and prevention of climatic stress.

Aims:

i) Make a platform for co-operation towards drought avoidance, management and recovery programs and steps
ii) Harmonization of drought policy and rectify purposes
iii) Complementarity of drought avoidance, management and recovery programs and steps

Outcomes:

i) Attempts may not be duplicated or overlooked
ii) Help agricultural enterprises to equip with drought management programs

iii) Uses of the latest technology, effective decision making and enhancing the of efficiency farms (Department of Agriculture and Water Resources, 2019).

Evidence of drops in crops production in drought affected years in Australia

The year wise production of winter crops in Australia expressed in kilo tonnes is illustrated in Figure 1. The years are represented by blue colours are non-drought years, whereas those by red colours were drought affected years. The winter crops production of various crops of nearly 56,678 kilo tonnes was highest in the non-drought year 2016-17. In contrast, during the drought affected red colour year 2008-09, the winter crops production was lowest, with the production pegged at 34,378 kilo tonnes only.

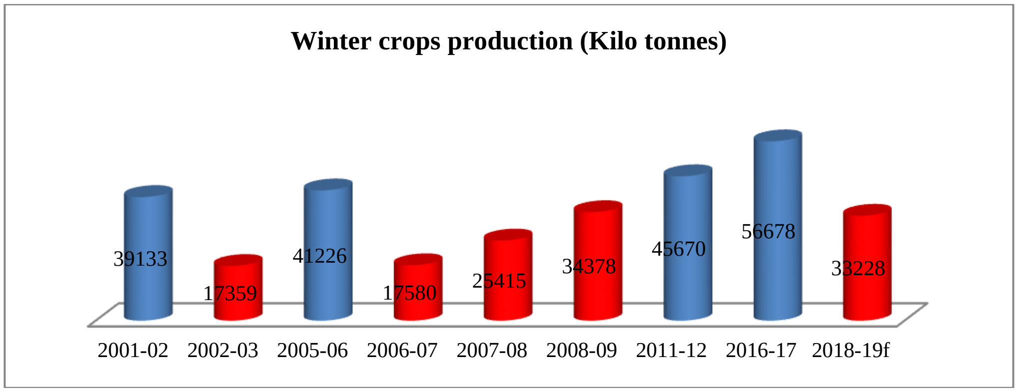

Figure 1. Production of winter crops in different drought and non-drought years in Australia: f means forecast, (Source: Authors based on the information from: ABARES, 2018)

It is noticeable from the above chart that the winter crops production is more in non-drought years than drought years. The average production in non-drought years was 45,676 kilo tonnes, whereas the average production in drought years was only 25,592 kilo tonnes. After analysing the chart, it can be concluded that the droughts were responsible for the less winter crops production in Australia.

Deviation of winter crop production in percentage across different drought and non-drought years in Australia is presented in Figure 2 to appreciate the loss of crops production due to drought. The years highlighted in green colour, such as 2000─01, 2003─04, 2011─12 and 2016─17 are non-drought years in the country. On the other hand, those in red, such as 2000-01, 2002-03, 2006-07, 2007-08 and 20018-19f are drought affected years. It is noticeable that during non-drought years, the winter crop production recorded an increasing trend. In 2003-04, the winter crop production increased about 18% and in 2016-17, it recorded highest with 56%.

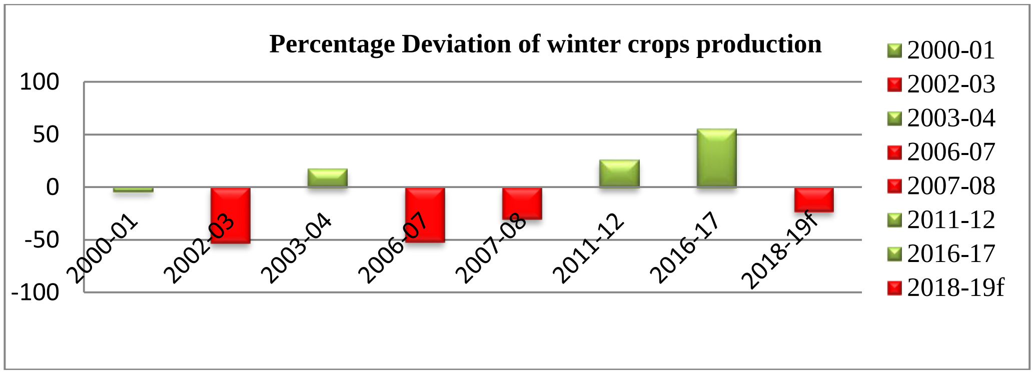

Figure 2. Percentage Deviation of winter crops in different drought and non-drought years in Australia: f means forecast, (Source: Authors based on the information from: Hatfield-Dodds*et al*., 2018)

On the other hand, crops production has a decreasing trend in drought affected years. In 2002-03, due to drought impact, crops production fell by 53%, and in 2006-07, by approximately 52%. Therefore, it can be said that Australian droughts is responsible for less winter crop production.

Drought management strategies of plants/crops

There are three mechanisms that help crops to respond to recover from drought: a) drought escape (for instance, short life cycle); b) drought avoidance (for instance, shedding mature leaves); and c) drought tolerance (for instance, endure during drought) (Barnabas *et al.*, 2008). Plants would be subjected to a varied levels of molecular changes under water stress conditions for a short period of time, as a mechanism of adaptation to drought (Bowne *et al*., 2012). Several techniques have good prospects of helping some crops adapt to drought such as "zero tillage (maize), priming (chickpea), mulching (potato), relay cropping of sweet gourd in potato fields, homestead gardening, dry land farming, water harvesting" (Miah *et al.*, 2013). A number of plants such as barley (Gonzalez *et al.*, 2008), canola (Norouzi *et al*., 2008), and maize (Hajlaoui*et al.*, 2010), have a inbuilt mechanism for osmotic adjustment as well (Bowne*et al*., 2012). Cotton is seemed to be comparatively adaptable to drought, because its yield is comparatively flexible (Loch *et al*., 2013; Prosser, 2011). Many Australian farmers' alleviate drought impacts to some extent by practicing one or other drought adaptation techniques, such as appropriate crop selection, irrigation management and ploughing (Stone and Meinke, 2007). Development and adoption of drought resistant crop varieties coupled with extension of appropriate agricultural technologies seemed to be much effective in overcoming the shortage of irrigation facilities near the Murray–Darling Basin in Australia (Jiang and Grafton, 2012).

Drought adaptation and mitigation measures

Increasing farm size and changing cropping system are among good strategies to mitigate the adverse impacts of drought on crop productivity (Kingwell and Xayavong, 2017). These two strategies provide farmers more freedom in choosing suitable crops. In fact, few crops are more drought tolerant than others. Thus, cropping system may be changed to include crops and crops varieties that can adapt drought conditions. Sekhon *et al.* (2010) mentioned that supplementary irrigation is reported to mark up yield by 75% at the flowering and fruiting stage. A supplemental irrigation at 12% increases wheat yield by 28%, which by 25% favours 88% more production in maize (Li *et al.*, 2000). Provisioning of plant nutrients is also reported to diminish the negative effects of drought. For example, under drought conditions, leaf stomata remain closed, but they can be reopened by supplying potassium fertilizers (Hu *et al.*, 2013). Similarly, mulching not only enhances soil water interaction, but also enhances symbiotic nitrogen fixation, nodule size and weight, besides seed weight (Siczek and Lipiec, 2011).

In Australia, drought can be minimized by reducing soil evaporation, right crop and crop variety selection coupled with good crop management practices (Siddique *et al.*, 2001). As CO_2 level can minimize the surface soil drought, availability of sufficient sub-soil moisture is a supporting feature (Uddin *et al.*, 2018). Drought tolerant crops and crop varieties are part of successful strategies to fight drought events. For example, wheat can respond to drought by osmotic adjustment and transpiration in order to retain moisture during the grain formation stage (Christopher *et al.*, 2008). It also has drought avoidance mechanisms; as such its deep-root feature helping to uptake water from subsoil (Yue *et al.*, 2006). In short, multiple strategies are more pragmatic than a stand-alone approach to increase crop production while mitigating the impacts of drought (Daryanto *et al.*, 2016). After reviewing all literature, the authors have made a 'Drought overcome pathway', which is presented in Figure 3.

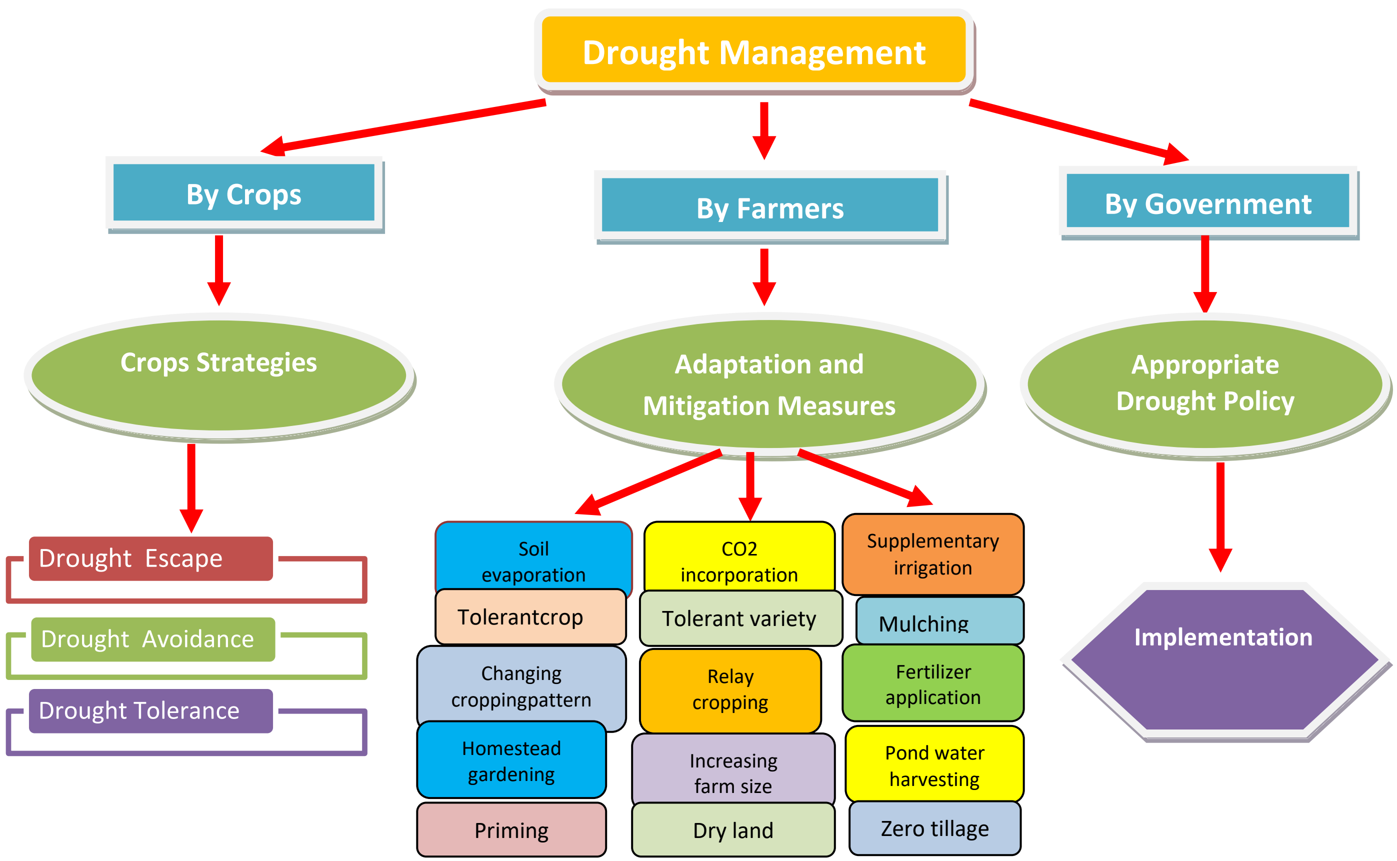

Figure 3. Drought overcome pathway (Source: Authors based the literature review)

The drought policy is intricate and both government and farmers are required to know the extensive context, risk and challenges (Hatfield-Dodds *et al*., 2018). The frequent incidence of drought spells and their impacts on agriculture rendered the drought policy important for both the State and Federal Governments (Wilhite, 2003). Drought policy is connected with subsidies and loans and sometimes blamed by economists who contend that drought is associated with an enterprise risk and farmers should manage it (Kingwell and Xayavong, 2017). As an initiative, Australian government approved the National Drought Program Reform in 2013, which has substantially encouraged farmers to manage drought properly (Kingwell and Xayavong, 2017). Surprisingly, many agricultural farms have shown better recovery of drought without financial support (Kingwell and Xayavong, 2017). A question has been raised by the intellectuals as to: what will the government policy in drought affected areas? Will it, particularly favour increasing subsidies or not? To tackle with 2018 drought the Australian government announced $1.8 billion to be distributed as loans for a four year term besides cash support for farmers, local governments and enterprises (Henderson, 2018). Kingwell and Xayavong (2017) suggested that farms should adopt drought management practices to tackle drought, instead of seeking subsidies. Therefore, the financial subsidies and grants by the Australian government for the farmers often leave the context ambiguous and at times questionable.

Different crops were affected differently by drought events. Farmers should know and apply appropriate drought management strategies to respond to drought spells. It is widely suggested that resorting to a combination of adaptation and mitigation strategies is highly pragmatic to manage drought compared to stand alone measures. Besides, there is a requirement to increase the storage capacity of water in farms in order to improve drought resilience. Australian government should adopt a clearly defined drought policy. The drought policy needs to be highly comprehensive and free from policy conflicts and incoherencies. As drought is a frequent phenomenon in the country, farms should first take adequate drought preparedness approaches and then government may support farms, if needed. This paper summarizes the effect of drought on various crops and their physiology along with a number of evidence of Australian droughts and their impacts on agricultural and economic sectors. Droughts records indicate that Australia has a frequent recurrence of droughts and has long and severe drought spell with considerable financial impacts. The current study reveals that both crop physiology and crop production were adversely affected by drought and consequently, the agricultural production in drought affected areas decreased appreciably. It was also evidenced that drought, increased temperature and water scarcity which adversely affected the productivity of wheat, rice, pea, sorghum, cereal crops, maize, and cotton crops. There is no alternative than managing drought and minimising its impacts on crops to ensure food security.

Review limitation

The focus of this review was mainly concerned on the drought and agriculture. Fairly, the authors made a noteworthy and broad review. The review could be extended more extensive, if social, business, health and cross-sectional part of drought were addressed. Similarly, it would be more informative, if more sources were reviewed.

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