Assessment of Crop Water Requirements for Sustainable Agriculture in Western Australia

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Abstract

As water resources are limited for agriculture in Australia, it is important to provide better water practices and efficient use of water. This study aims to develop guidelines for sustainable agricultural practice in Western Australia. CROPWAT software was utilised in this study. Results indicated that the practical applications of irrigation water are exceeding crop water requirements. Also crop scheduling led to a water saving of 8.5, 0.6, 9.7 and 1.9 ML/ha for Banana, Cotton, Sugarcane and Rice respectively. By scheduling irrigation to meet the crop's water requirements, and universal sowing patterns the water savings proved to be colossal.

Keywords: Climate Change, Evapotranspiration, Crop Water Requirements, Water Use Efficiency, Sustainable Management

1. Introduction

The majority of literature reported that climate change is negatively affecting food production. Studies specified that climate change caused a decrease in crop production (Chowdhury, Al-Zahrani and Abbas 2013; Gohari et al. 2013; Kang, Khan and Ma 2009). Climate change analysis resulted in a significant yield reduction of 2.5-20.7% for wheat, 1.4-17.2% for barley, 2.1-9.5% for rice and 5.7-19.1% for corn. Due to temperature increases, crop irrigation requirements also increased under climate change and therefore the respective water productivity decreased.

Previous research conducted revealed that climate change is the pivotal issue adversely affecting Australia's fresh water supply ([BOM] 2014; Hennessy et al. 2008). For a country that already has the lowest average annual rainfall of all continents, the need to evaluate the effect of climate change on current crop water requirements in rural sectors is evident (Hennessy et al. 2008). Chartres and Williams (2006) stated that Australia is at the crossroads in terms of its ability to cope with increasing water scarcity. The nation has to choose between investing in more expensive capital such as additional storages and desalination plants, or minimise the water use via increased productivity. However the Irrigation Infrastructure Report Card by Engineers Australia (2010), highlights that resources are limited and the previous approaches of expansion by building new dams and desalination infrastructure is no longer sustainable. This presents practical evidence that consequently exposes the theoretical issue at hand and inculcates the need for further research. In particular, Bithell and Smith (2011) declared the need for investigation into crop irrigation requirements in North Western Australia, so that over allocation of resources does not restrict industry expansion.

Review of the literature highlights the need for investigation into Western Australia's water use and the concurrent change in environmental conditions. This study generates conclusions to help influence the Western Australian agriculture industry to acknowledge sustainable techniques in the effort to increase water use efficiency and mitigate the effects of a changing climate.

2. Methodology

This study aimed to evaluate climate change, estimate Australia's current Crop Water Requirements and compare them to practical water applications; to develop more sustainable techniques that reduce the agricultural water footprint. Three locations with different climatic conditions (high and low evapotranspiration zones) were selected to incur variance. Two of which employ irrigated farming practices due to their fortunate locations with nearby resources; these being Carnarvon located on the Gascoyne River and Kununurra on the Ord River. The Gascoyne region's preliminary source of water is groundwater, whilst the Ord region primarily relies on surface water for it's irrigation needs. The other designated location is Cunderdin, residing amongst the Western Australian Wheatbelt and solely relies on rainwater for growth. The Wheatbelt location provides analysis into the non-existent aid of water at times of extreme distress such as drought.

2.1 Evaluation of Climate Change

To evaluate the effect of climate change, two sets of climate data for each location (present and historical) had to be utilised. The first set corresponded to the present climate data, which was in daily form for the five year period of 2009 to 2013. The second set corresponded to the historical climate data which indicated the first ever recorded readings of each climatic parameter at the designated weather station. By using the initial historical data available at each location, it provides the largest span between the data series. This in turn delivers the most accurate evaluation of climate change between the present and historical environmental conditions. For each location, the initial measurements vary according to when the weather station was established and the weather parameters that were able to be measured at the time.

The target of investigating climate change taking place in Western Australia entailed preliminary assessment of rainfall and temperature data, leading to the calculation of evapotranspiration rates. If precipitation is to decrease there is a lower initial water quantity for plant growth, resulting in the need of increased irrigation amounts. If temperature is to rise the evapotranspiration process is stimulated due to the excess energy caused by radiation. Evapotranspiration is the combination of two separate processes that results in a loss of readily available water, by soil surface evaporation and crop transpiration respectively. Reference Evapotranspiration has the greatest effect on a crops water usage, as it directly gauges the amount of water lost to the atmosphere and how much water remains readily available for the cropping systems. The calculation of Evapotranspiration is of the utmost importance in crop weather and irrigation models to evaluate resource allocation, water foot printing and quantification of water use efficiency (Jovanovic and Israel 2012).

2.2 Reference Evapotranspiration

Several methods exist for computing evapotranspiration. Some methods require fewer weather parameters to calculate evapotranspiration rates and consequently result in less accurate estimations (Jovanovic and Israel 2012). Literature review provided a definitive answer that the combined Penman Monteith method is the optimal method for estimating evapotranspiration across the world. Studies in Austria, India and the United States of America all concluded that this procedure had the lowest standard error when modelled against lysimeter field measurements (Praveen et al. 2011; Yoder, Odhiambo and Wright 2005; Eitzinger, Marinkovic and Hosch 2002). Based on the literature and previous deductions, the Penman Monteith method was the only valid option for estimating evapotranspiration in this study.

The Penman Monteith method calculates water losses by computing an initial standard reference of evapotranspiration caused by environmental climate conditions. The reference surface is a hypothetical grass crop and is only affected by climatic parameters such as air temperature, air humidity, wind speed and radiation. The concept of reference evapotranspiration is used to find the evaporative demand of the atmosphere at a specific location and time of year, without taking into consideration the crop type, crop development and management practices. This form of standardisation used in the Penman Monteith method allows accurate results to be calculated according to the imposed environmental conditions.

Following equation was used to evaluate reference evapotranspiration and provides a standardised reference for the comparison of cropping systems at different locations and seasons. By using a standardised reference, the evapotranspiration of any crop can be related..

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_{2)}}$$

To verify estimations, the calculated reference evapotranspiration rates for each location were compared to the Bureau of Meteorology's evapotranspiration values. At the Bureau of Meteorology the availability of reference evapotranspiration values were limited to post 2009, and therefore a five year period was used to verify and validate the Penman Monteith method of calculation. Upon confirmation of an accurate calculation procedure, the estimation of evapotranspiration for historical recordings was implemented.

2.3 Crop Water Requirements.

In order to calculate Crop Water Requirements, reference evapotranspiration has to be converted to crop evapotranspiration (ETC). Modification to the standardised reference is applied through the use of crop coefficients (KC). Crop coefficients incorporate adjustments according to the physical and physiological properties of the plant type being grown. The crop coefficient integrates the vegetation's resistance of transpiration, height, roughness, reflection and canopy cover to calculate the individualised crop evapotranspiration.

Crop evapotranspiration is calculated by multiplying the reference evapotranspiration by the corresponding crop factors (KC). This shows the necessity of implementing crop factors to estimate the water requirements of different plantations.For examination of crop water requirements only the "present" reference evapotranspiration rates were computed, to provide analyses that reflect the current climatic conditions; these being higher water requirements for the Gascoyne and Wheatbelt regions, and lower for the Ord region (Shown in Table 1).

For examination as to whether or not crops are meeting their water requirements, crops were sown at the beginning of their planting timeframes. Where irrigation is available, the application of water supplied to the crop was determined and compared against the vegetation's theoretical water needs. Where irrigation is not available, the crop water requirement was analysed and an assessment as to whether wheat and sorghum are meeting their needs was evaluated.

2.4 Sustainable Agriculture

2.4.1 Crop Scheduling

Sustainable cropping techniques and increasing productivity were completed by iterating planting dates to give the most efficient growing period for each region. To make better use of water, crop life cycles aim to avoid high evapotranspiration periods and are synchronised with high rainfall periods. Examination of critical sowing dates and planting timeframes, allows crop lifecycle scheduling to provide lesser impacts to Australia's water supply. Where irrigation is available, the water rates applied currently in Western Australia are critically compared to the calculated crop water requirements. Where irrigation is not available, the crop water requirement was analysed at the critical sowing date and compared to the preliminary sowing date. This outlines the amount of water saved and determines whether or not wheat and sorghum are capable of meeting their water requirements. The other sustainable method identified and implemented in this study is Rainwater Harvesting.

2.4.2. Rainwater Harvesting

The rainwater harvesting technique applies the critical sowing dates calculated by crop scheduling, to further increase water use productivity. Timeframes subject to high rainfall are to be stored and scheduled to crops during dryer phases. The amount of excess water available to the crop is estimated by recording the rainfall received, and then decreasing the initial amount by water losses. Losses are caused by pan evaporation and seepage, as storages are more likely to be earth retained due to cost.

For analysis, the adaption of seepage rate from CRC Australia's (2011) study was utilised as 2.9mm/day, whereas the pan evaporation was converted directly from reference evapotranspiration using Pan Coefficients (KP) (Allen et al. 1998).

3. Results and Discussions

3.1 .Assessment of Climate trends across rural Western Australia

The assessment of climate change proved vital for analysing the change in cropping conditions. Results shown in Table 1 suggest that water requirements are now higher for the Gascoyne region and therefore excess irrigation will need to be applied to meet crop needs. On the other hand the growing conditions for the Ord region have enhanced over time and not as much water needs to be applied to the crops. For the Wheatbelt region both seasons require larger water requirements. The results obtained in this study reflect the observations made by the Bureau of Meteorology (2014), outlining the need for irrigators to be aware of the changing climate and the associated effects it is having on their farming operations.

Table 1: Effect of Climate Change on each Locations Cropping Season

	Gascoyne		Ord		Wheatbelt	
	Winter	Summer	Winter	Winter	Summer	Winter
Precipitation	Decrease	~ Increase	No Change	Increase	Decrease	~ Increase
Evapotranspiration	Increase	Increase	Decrease	Increase	No Change	Increase
Water Requirement	Higher	Higher	Lower	Similar	Higher	Higher

3.2 Estimated Crop Water Requirements

Literature review led to the adaption of the Penman Monteith method for estimating crop evapotranspiration. The comparison between the Bureau of Meteorology and CROPWAT's evapotranspiration values were negligible, with 0.5mm/day being the largest variance for Cunderdin in November. Table 2 details a total average variance of only 0.1mm/day, and therefore confirmed that the Penman Monteith method was accurately calculating reference evapotranspiration. This provided concurrent results with past research (Praveen et al. 2011; Yoder, Odhiambo and Wright 2005; Eitzinger, Marinkovic and Hosch 2002).

Table 2: Comparison of Reference Evapotranspiration

		Bureau of Meteorology			CROPWAT		
		Carnarvon	Kununurra	Cunderdin	Carnarvon	Kununurra	Cunderdin
Reference Evapotranspiration (mm/day)	January	8.2	6.2	9.5	8.1	6.0	9.6
	February	7.7	5.8	8.7	7.7	5.6	8.9
	March	7.6	5.7	6.6	7.5	5.5	6.9
	April	6.1	5.5	4.8	6.0	5.7	5.0
	May	4.8	5.2	3.0	4.8	5.3	3.2
	June	3.7	4.7	2.1	3.7	4.8	2.2
	July	3.9	5.2	1.9	3.8	5.3	2.0
	August	4.6	5.8	2.4	4.4	5.7	2.4
	September	5.9	7.1	3.7	5.4	7.0	3.6
	October	7.0	7.6	6.0	6.6	7.4	5.6
	November	7.9	8.0	8.0	7.6	7.8	7.5
	December	8.3	7.3	9.0	7.9	6.9	8.9

Irrigated crops are meeting their water requirements by applying as much water as needed. However, by not synchronising crop development periods with rainfall patterns fresh water is possibly wasted. As for the Wheatbelt region, the crops are not meeting their required intake of water. To use water more efficiently crop cycles for both the irrigated and rainfed industries are scheduled, to make better use of rainfall patterns and lower the water deficit.

3.3 Assessment of Sustainable Irrigation and Dry-land Farming Techniques

3.3.1 Effective Water Saving by Crop Scheduling

As displayed in Table 3, the irrigation water use efficiencies increased dramatically by scheduling crop patterns rather than planting at the initial sowing periods. Respectively, 0.4ML/ha and 7.0ML/ha of water was saved in the Gascoyne and Ord irrigation area. In contrast, the rainfed area of the Wheatbelt effectively saved 2.2ML/ha and allocated this to the water deficit. Thus the total water saving of approximately 77380ML in the North West irrigation industry led to a proficiency of over 22%.

3.3.2 Development of Sowing Guidelines

With restrictions placed on timeframes there comes the immanent risk of conflicting schedules. In this investigation the risk has been mitigated by implementing a planting window that provides insight for the agricultural industry, to outline when to plant their crops if the critical sowing date is unachievable. The emergency sowing guidelines are shown in Table 4 below.

Table 3: Amount of Water Saved by Crop Scheduling

	Location					
	Gascoyne	Ord			Wheatbelt	
	Banana	Cotton	Rice	Sugarcane	Wheat	Sorghum
Irrigated or Rainfed	Irrigated	Irrigated			Rainfed	
Critical Sowing Date	5 November	10 November	1 May	17 October	21 April	22 December
Irrigation Required at Critical Sowing Date (mm/ha)	1309.3	37.5	851.8	805.8	202.4	884.9
Irrigation Required at Initial Sowing Date in (mm/ha)	1347.5	577.6	851.8	969.7	235.0	1070.9
Effective Water Saving (mm/ha)	38.2	540.1	0	163.9	32.6	186.0

Table 4: Emergency Sowing Guidelines

Region	Crop Type	Irrigation Required (mm/ha)		
		One Week Prior	Critical Sowing Date	One Week After
Gascoyne	Banana	1313.0	1309.3	1311.1
Ord	Cotton	70.9	37.5	40.0
	Rice	N/A	851.8	862.9
	Sugarcane	807.0	805.8	821.1
Wheatbelt	Wheat	210.9	202.4	207.7
	Sorghum	928.3	884.9	N/A

The cereal, horticulture, fibrous and sugar cropping guidelines are established and provide the initial step in developing effectively scheduled guidelines for growth in the Northern and Eastern regions of Western Australia. The guidelines provide universal applications for any vegetation located in the corresponding region, as long as the crop lengths and coefficients are similar. By implementing these guidelines the major challenges in Petheram et al (2008) are solved. The issue presented recurred around northern irrigation schemes not being able to find crop types suited to the tropical environment, and then later manage the cropping schedules for long term success. Upon confirmation of emergency sowing intervals to provide the most water efficient cropping schedules, formal guidelines issue the solution to the Western Australian agricultural industry in the north.

3.3.3 Critical Analysis of Current Water Usage for Agriculture

Consequent to generating formal guidelines for the Western Australian agricultural industry to adhere to, the effect of the water savings needed to be normalised. In relation to Western Australian irrigator's practical water use; 8.5, 0.6, 9.7 and 1.9ML/ha of water is being overused for the irrigation of Banana, Cotton, Sugarcane and Rice respectively. Assessment of this impact is detailed in Figure 1, where the effect of reducing Western Australia's water footprint in the agricultural industry is highlighted. By scheduling irrigation to meet the crop's water requirements the savings are potentially colossal, in this case reducing the agricultural industry's impact from primary to third in Western Australia.

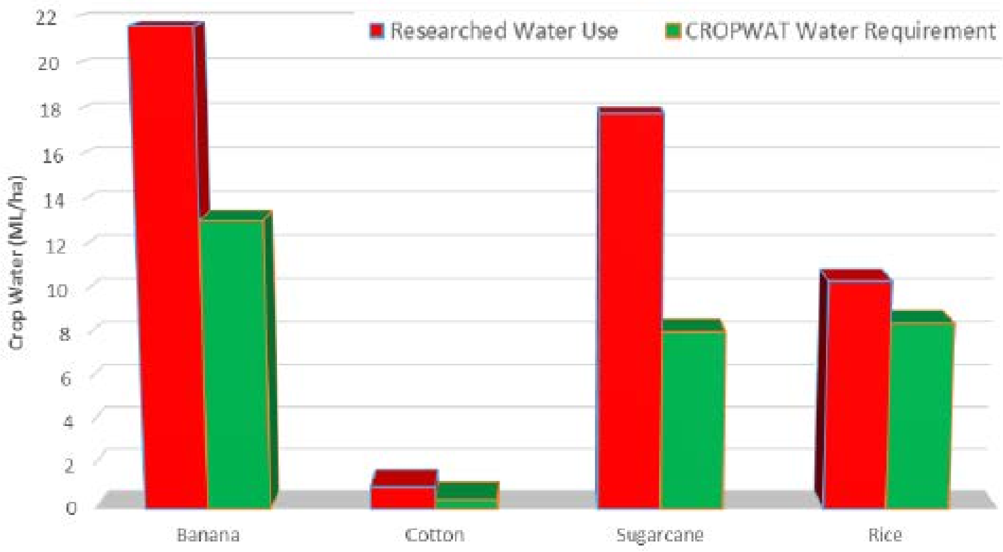

Figure 1: Crop Water Use versus Crop Water Requirement in Western Australia

3.3.4 Effective Water Saving by Rainwater Harvesting

Analysis of rainwater harvesting resulted in the losses caused by evaporation and seepage greatly exceeding the rainfall received. It was evident that when water is stored over a monthly period the losses were extreme. Therefore if water is to be stored on site, it can only be stored for a limited period of time to eliminate the large water losses caused by surface evaporation and seepage.

Despite the innovative idea of being able to supplement a crop thirsts at time of water need, it is proven not to be plausible with Western Australia's current climate. This suggests that the method of rainwater harvesting proved to be insufficient for the locations specified in the scope and the renewable water quantities will not be able to undertake scheduled distribution

4. Conclusions

This research project composed of the central goal to analyse Western Australia's high agricultural water usage and evaluate methods of practice to generate superior efficiency. The key objective was to develop guidelines for sustainable agricultural practice in the northern and eastern farming regions of the Gascoyne, Ord and Wheatbelt. Banana, cotton, rice, sugarcane, wheat and sorghum were the six crops designated for analysis via CROPWAT modelling. CROPWAT was utilised in this study due to its extensive and global use of estimating irrigation requirements for sustainable water management.

This study provides detailed methods to accurately compute crop evapotranspiration in Northern and Eastern regions of Western Australia. Upon crop water requirements being estimated, sustainable techniques such as crop scheduling are implemented to increase the State's water use efficiency. As a part of achieving sustainable outcomes, formal guidelines for sowing crops are presented in a simplistic and easily interpretable form for the unchallenging use by any Western Australian irrigator.

The key result in this research supports Webster et al (2009). Crop scheduling examination proved to be the most significant solution to both meeting crop water needs and reducing the water footprint that the agricultural industry places on Australian water supply. A total water saving of 8.5, 0.6, 9.7 and 1.9 ML/ha was evident for Banana, Cotton, Sugarcane and Rice crops respectively. By communicating this current information through set management processes and guidelines, both efficiency and sustainability in the industry is enhanced. On the other hand, onsite rainwater harvesting did not provide any advantages, as evaporation and seepage water losses greatly exceeded the rainfall received in all areas. The varieties analysed represent cereal, horticulture, fibrous and sugar crops to provide universal applications to any vegetation located in the corresponding region as long as the crop lengths and coefficients are similar. In the event that they are not, computation of the new cropping guidelines can be established following the process designated in the Methodology.

Not only does climate change result in lower water availability for the agricultural cropping industry, but it strips water quantities from the preliminary sources of dams and reservoirs through surface water evaporation. Now that irrigation guidelines have been established for the northern and eastern locations of Western Australia, a future recommendation is to determine the initial quantities of water available in the form of ground and surface water. This will determine the climatic effect on water storages and assess whether the Gascoyne and Ord regions are able to cope with the ongoing infrastructure developments which are causing a more significant pull on the hydrological industry each year.

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