HONOURS SCHOLARSHIP REPORT: 2018-19 SEASON

1. **Project Title** : Estimating soil water use in Australian cotton systems to improve irrigation management

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2.
(Maximum 15 words)

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4. **Honours Scholar and University** : Harry Gaynor, The University of Sydney.

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5. **Organisation & Location for the project** : **CSIRO, Australian Cotton Research Institute, Narrabri, NSW**

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5. **Administrative Contact** : Mrs Jo Cain
Telephone : 02 67991513
Facsimile :
Postal Address :
Email :

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6. **Project Supervisor** : Dr Rose Brodrick
Position in organisation : Research Scientists
Telephone : 02 6218 3465
Facsimile :
Email : rose.brodrick@csiro.au
Postal Address : GPO Box 1700, Canberra ACT 2601

Project Collaborators (Name and Organisation):

Associate Professor Daniel Tan, The University of Sydney.

Dr. Patrick Filippi, The University of Sydney.

Dr. Hizbullah Jamali, CSIRO Agriculture and Food (Narrabri).

HONOURS SCHOLARSHIP REPORT

(Maximum FOUR pages)

1. **Executive Summary:** Irrigation is a key component of cotton production in Australian agriculture, where increasing pressures of water scarcity requires growers to improve their water use efficiency. Monitoring of soil water deficits is a key component of maintaining optimal irrigation management. A number of technologies have been provided over the years to allow irrigators to monitor and predict soil water to better time their irrigation applications. This study compared four different methodologies for measuring and predicting soil water status within an irrigated cotton system. A Neutron Moisture Meter (NMM) device was calibrated to gravimetric soil water measurements. The calibrated NMM readings were then compared to an EM38 device, crop-modelling software HydroLOGIC, and remote-sensing software IrriSAT throughout the 2017-18 growing season. Each methodology produced estimations of PAW Deficits (mm) on 15 separate dates, at 13 sites within a 4.25-hectare field. To enable a fair comparison of the two technologies HydroLOGIC the soil water was not corrected by inputing soil water measurements, with just the crop parameters and irrigation dates entered up until the run date. IrriSAT had slightly higher correlation with NMM readings compared to HydroLOGIC when average across the measurement period. However the accuracy varied significantly during different periods which could signifcantly impact on irrigation timing. During early to peak flowering IrriSAT overestimated NMM deficits by 20 - 30mm, which if relied on would result in irrigating much earlier than required whereas HydroLOGIC run without any soil water inputs underestimated crop water use after cut-out. . The EM38 device did not correlate well with NMM readings but as other studies have found strong correlations further calibration is likely required to test this. Overall, this study demonstrates that collaborative use of proximal devices such as the NMM with specialised predictive software could provide accurate estimations of soil water deficits throughout the full season, whilst saving time and labour.

2. **Background:** Australia's underground and surface water resources are scarce in many of its key agricultural areas, which means that irrigation management requires high efficiencies to remain sustainable. Water management is a key aspect to producing high yielding crops and high quality fibres that drive an attractive profit goal. Various on-farm efficiency measures have been developed to improve their water use productivity, with accurate irrigation application timing being one of them. Modern irrigators aim for 'refill points', levels of Plant Available Water (PAW) whereby beyond a certain deficit, the crop will experience moisture stress. Yield reductions of up to 3% per day can occur in modern varieties experiences water stress (Yeates et al, 2010). This is especially the case with transgenic varieties that occur high fruit retention. Furthermore, excessive soil moisture conditions can encourage excessive and undesirable vegetative growth.

   Quantifying Soil Water Content (SWC) in the form of Plant Available Water Content (PAWC) is a common method used by irrigators. Proximal sensing devices have always been the most common method for attaining such measurements. Neutron Moisture Meters (NMM) have generally been the standard for soil water measurements (Robertson et al, 1996). These devices provide very accurate point source and multi-depth measurements, yet are limited in their portability and abilities to monitor spatial variation. New technologies (e.g. capacitance probes) have largely replaced NMM but can be difficult to calibrate to give an accurate measurement. Electromagnetic Induction devices, such as the EM38 have recently been developed with the ability to monitor SWC.

Ideally irrigators would be able to not only measure soil water but also predict crop water use to enable irrigation scheduling decisions to be made ahead of time. IrriSAT is a cloud-based software which uses remote satellite imagery and weather (historical and forecast) data to estimate and predict ETc and PAW deficits. The program obtains Normalised Difference Vegetation Index (NDVI) data to derive locally calibrated crop coefficients (Kc) for a specified area of crop (Hornbuckle et al, 2015). HydroLOGIC is a predictive software package, using the OZCOT crop model to simulate cotton development based upon agronomic and climatic data inputs (Hearn, 1994). This model can be combined with local weather information and other agronomic parameters to predict outputs such as PAW Deficits.

3. **Aims and Objectives:** This project aimed to compare different methods of estimating soil moisture status within an irrigated cotton system. Four technologies/methodologies were studied and compared: NMM, EM38 device, HydroLOGIC and IrriSAT. The estimation of PAW deficits from NMM was used as a standard, to which the other methods' estimations were compared. The project also aimed to identify operational benefits and limitations associated with each method. Overall we aimed to identify the possibilities for cotton irrigators to confidently utilise these technologies in aiding management decisions.

4. **Materials and Methods:** The field study was conducted at the Australian Cotton Research Institute, Narrabri NSW, over the 2017-18 cotton season. The field was separated into 31 plots, 30m x 16m in size, with only 13 used for this experiment. The field was planted with variety *Sicot 746B3F (*Bollgard III Roundup Ready Flex) cotton on 1st November, 1m row spacing and 14 seeds/m2.

   Twenty-five gravimetric cores to 130cm depth were extracted from the field, over six separate depths, and actual water content was measured after weighing before and after oven drying. NMM, Theta probe and EM38 device readings were conducted near simultaneously at the core sites, and their readings correlated with gravimetric water content to produce field specific calibrations for each machine. Existing soil characteristics (bulk density, crop lower limit and dried upper limit) were used for calibration. The NMM was allocated a separate calibration for its 20cm depth reading, and another for all readings between 30-120cm. Four EM38 calibrations were produced: 0.5m dipole in horizontal and vertical positions (37.5cm and 75cm depth), and 1m dipole in horizontal and vertical positions (75cm and 150cm depth).

   NMM and EM38 devices were used to obtain SWC readings in each plot over 15 dates throughout the season, either 24hrs before or 48hrs after irrigation events. Aluminium access tubes were installed in the middle measurement row in each plot, and NMM readings taken at depths of 20cm, 30cm, 40cm, 50cm, 60cm, 80cm, 100cm and 120cm. EM38 readings were taken in the same measurement row near-simultaneously. Calibrated readings were then converted to PAW deficits (mm). EM38 deficits had to be standardised to 120cm depth, using equal-area quadratic splines (Bishop et al, 1999). Squares, green bolls and open bolls per m^2, as well as LAI readings using a Ceptometer device, were taken on 5 separate dates to feed into the HydroLOGIC software to develop the crop model's growth (73, 83, 93, 105 and 120 days after planting). Only the agronomic data and Simulations of daily soil moisture deficits and crop evapotranspiration were run for each plot on the measurement dates to obtain estimations of PAW deficit. Each plot's boundaries were mapped for GPS coordinates to create geographic boundaries in the IrriSAT program. In crop rainfall and irrigation data was fed into the program manually and estimations of PAW deficit for each plot were extracted on each measurement date. Was HydroLOGIC reset with soil water measurements at each date?e accuracy of NMM and EM38 devices (once calibrated) were compared to gravimetric core measurements with correlation comparison and linear regression. Then each of the technologies' daily estimations of PAW deficit in each plot were compared to that of the NMM (the standard), once again with correlation and regression analysis. Lin's concordance correlation coefficient (LCCC) and root mean square error (RMSE) were used to assess the quality of models in the regression analysis. Statistical means of these residuals were also used to analyse the basis of these relationships, to determine whether each technology was over/under-estimating NMM estimates.

5. **Results:** All plot readings for each methodology were averaged on each date of measurement to gain daily mean estimates for the 'field' over the measurement period. Based on these, IrriSAT had the highest correlation to NMM deficits, followed closely by HydroLOGIC (Table 1). EM38 was inaccurate in estimating NMM on average, yet this was only based on five measurement dates.

	NMM	IrriSAT	Hydrologic	EM38 Splined
NMM	**1.0**	**0.82**	**0.75**	**0.68**
IrriSAT	---	1.0	**0.83**	0.73
Hydrologic	---	---	1.0	0.63
EM38 (Splined)	---	---	---	1.0

The NMM achieved a strong correlation with gravimetric measurements of PAW, with a correlation value of 0.89, and the linear regression developing an R2 of 0.79. The EM38 similarly achieved a strong correlation of 0.86.

IrriSAT and HydroLOGIC's daily ETc estimations were also compared throughout the whole growing season. HydroLOGIC produced larger predictions of ETc during the early stages of crop development, whilst IrriSAT had significantly lower estimations in the first 50 days after planting (DAP). IrriSAT then started to follow the expected rise in ETc with HydroLOGIC throughout the peak flowering to maturity stages. IrriSAT developed higher ETc values during the last 20 days of crop development, whilst HydroLOGIC predicted a fall. Their ETc estimations are presented in Figure 1 for plot 13, the plot that correlated the best with NMM for both softwares.

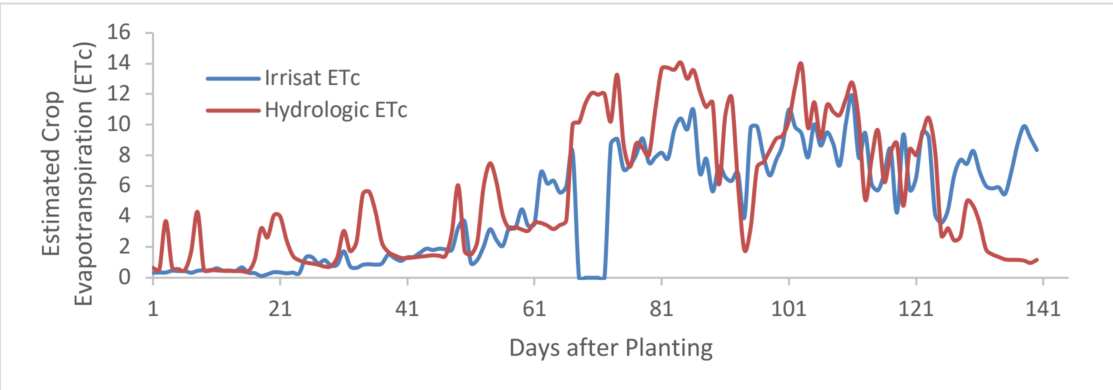

Fig. 13. Daily Crop Evapotranspiration (ET_C) estimated by IrriSAT and HydroLOGIC throughout the season for Plot 13. Note that the sudden drop in IrriSAT ET_C around day 70 occurred due to cloud cover inhibiting the estimation of a crop coefficient (Kc).

Discussion and Conclusions: This study confirmed that the NMM could confidently measure soil PAW deficits, with an R^2 value of 0.79 and RMSE of 27.08. Other studies have similarly found reliable levels of precision from NMM's (Akhter et al, 1998; Tennakoon and Milroy, 2003). The calibration process encountered a significant different curve for readings at 20cm, leading to separate calibration equations for NMM readings at this depth and the use of a theta-probe for the top 15cm measurements. The use of theta probes has been encouraged in previous literature to complement NMM use for the top 10-15cm of soil (Hignett, 1998).
It was evident that IrriSAT and HydroLOGIC outperformed the EM38 device in estimating PAW deficits measured by NMM. When the correlations were analysed throughout different stages of

plant development, HydroLOGIC correlated closer with most NMM readings for the first 70 days of development. The software's underlying crop model, OZCOT, grows the crop on a daily time step and crop growth and development is adjusted with the agronomic and climatic data inputs. Some of its limitations may be due to a lack of agronomic information being inputed into the model . Richards et al. (2008) found that factors not accounted for in the software, such as severe pest damage, may produce inaccurate estimations too. Still, even without being corrected with soil water measurements, it outperformed the IrriSAT program up until peak flowering stages of the crop. The primary input that IrriSAT relies upon to develop its daily ET_C estimations is the NDVI imagery. Between crop emergence and peak flowering (approximately 80 DAP), the crop canopy doesn't produce a full coverage, and so each pixel will encounter a significant 'brown' area that may affect its interpretation of the crop coefficient. This may explain why it develops significantly lower ET_C estimations during earlier crop development. The satellite data in this experiment didn't encounter many issues in terms of visibility, with only one pass-over period encountering zero visibility (due to cloud cover) at 68 DAP, whereby the program overrides to crop coefficient to become zero. The temporal resolution of its sentinel satellite is 5-10 days, and 8-16 days for the two Landsat satellites (Hornbuckle et al., 2016). This could provide issues for irrigators during seasons with significant cloud cover, as repeated pass-overs with zero visibility would give inaccurate predictions of the ET_C and develop an unconvincing estimation of PAW deficits.

When operating the NMM and EM38 devices to obtain in field measurements, there is an increased risk of compaction by human feet, which could affect site specific qualities such as bulk density and infiltration. Such instances may have affected the validity of the NMM, or EM38 accuracy, by affecting the soil's PAWC. Other soil factors have been found to produce error with using the EM38 device for measuring soil water content, such as pH or salinity variation throughout the field. Yet this field was strongly homogenous in all of these factors. One possible source of error may have been from the device's vertical dipole mode, which reaches a peak responsiveness at 0.4m depth. If there was significant variation in soil texture or structure at such depth between measurement points, then this may have affected the device's accuracy.

To conclude, this study used a neutron moisture meter as a 'standard' to compare against other methodologies in estimating PAW deficits in irrigated cotton. The cloud-based IrriSAT program estimated deficits closest to those of NMM, closely followed by the HydroLOGIC software, with the EM38 device yielding poor accuracy. IrriSAT overestimated NMM deficit readings by approximately 20-30mm during early crop development. HydroLOGIC underestimated by similar amounts during later flowering/crop maturity stages. Possibly a more confident calibration for the EM38 device was required to deliver conclusive analysis about the device accuracy for point source PAW measurements.

6. Highlights:

- HydroLOGIC provided better estimates of soil water content until peak flowering at which time IrriSAT was slightly more accurate and after cut-out HydroLOGIC underestimated soil water content. It is important to note that HydroLOGIC was designed to be corrected by soil moisture measurements throughout the season which wasn't done in this study to allow a fair comparison to IrriSAT which has no such functionality. This would have greatly improved the accuracy of HydroLOGIC as demonstrated by Richards et al. (2008).
- This study demonstrated that integrating soil water measurements with both IrriSAT and HydroLOGIC could provide reasonable accurate estimations of soil water deficits throughout the full season, whilst saving time and labour.

Future Research: To compare these different methodologies over more than one season would be useful to assess how different seasonal sources of variation may alter their performance. For example, seasons of excessive or very limited rainfall, significant pest/disease incidences, or periods of heavy cloud cover that may have affected the IrriSAT reliability. A combinational approach that could use continuous sensor data, from devices such as NMM or EM38, to correct the predictive capabilities of IrriSAT or HydroLOGIC throughout the season, may be considered too. HydroLOGIC and IrriSAT estimations in this study produced very strong correlations, suggesting the possibility to link the two. McCarthy et al. (2014) proposed a Model Predictive Control process, combining sensor based and model based approaches. Such approaches may be able to provide irrigators with an irrigation management program that provides accurate and reliable PAW estimations throughout the whole season, whilst also saving labour and time costs that would be encountered through traditional in field measurements or probe operation.

7. **Presentations and Public Relations:** Research proposal and research findings presentations given as part of the honour program at University.

8. **Reference List:**

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