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Using a mobile phone Short Messaging Service (SMS) for irrigation scheduling in Australia – Farmers' participation and utility evaluation

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ABSTRACT

Irrigation scheduling Decision Support Systems (DSS) have seen poor uptake despite proved usage benefits. The failures of some previous systems with proven model accuracy and water savings ability have been attributed to interface difficulties and inappropriate information for end users. Use of the mobile phone Short Messaging Service (SMS) text messages was trialed as an interface to overcome these difficulties. Irrigation system dripper run time scheduling advice was sent daily to 72 Australian irrigators' mobile phones from a water balance system called IrriSatSMS. Irrigators sent back information on irrigations and rainfall, also via SMS, to update the water balance. This trial showed that a complex, water balance-based, DSS could rely on SMS as the sole interface.

All 72 irrigators involved were content to receive messages daily for the entire growing season (200 days). A measure of engagement and utility of the system was determined by those who returned their irrigation and rainfall data; 45 sent in their data all season, 13 for half the season and 14 never sent in any data. Thus we infer that 45 users (63%) found the SMS system of enough utility to use for the whole season. Also, at end of season, 6 of the 13 who had stopped half way through said that in retrospect they wished they had not. Thus overall 80% of irrigators found the system useful.

User interview data showed the simplicity of use, advice and the prompting effects of intrusive delivery (phone ringing) were key features in the resultant strong engagement of irrigators. Success also relied on appreciating that irrigators will only use objective decision support advice as one element in a set of decision making tools that include subjective and unquantifiable elements, such as plant appearance.

This strong uptake reverses the trend in irrigation decision support which has seen poor uptake of sophisticated systems that produce comprehensive scheduling support but which are, or are perceived to be, complex and time consuming to use. Additionally, high participation rates show that much model input data may be collected from irrigators via SMS so it can be used as a very cheap bi-directional communication channel.

1. Introduction

Irrigation scheduling Decision Support Systems (DSS) have experienced poor uptake amongst irrigators in Australia despite much investment and well publicised objective evidence that they can increase water use efficiency. For example, *WaterSense*, a sugarcane irrigation scheduling DSS with proven ability to increase water use efficiency (Inman-Bamber et al., 2005) has fewer than a hundred users among a potential pool of thousands. Australia-wide, a 2005 survey of irrigation DSS found that 21 are in operation but most have only a dozen or fewer users (Inman-Bamber and Attard, 2005).

A survey by Olivier and Singels (2004) of the reasons for not adopting scientific irrigation scheduling techniques by South African irrigators identified two main barriers to adoption. The first was the complexity of use and hence the difficulty of applying them to farm practice and the second was whether their use would actually translate into benefits. Much work in Australia on barriers to DSS adoption (Carberry, 2001; McCown et al., 2006) notes a 'gap' between scientific and industry approaches to scheduling that supports the South Africa experience.

Analysing a typical irrigation scheduling tool such as '*WaterSense*' (Inman-Bamber et al., 2005) we see that it requires Internet access, the entry of much data and a long wait time (40 min) for results to be generated. *WaterTrack Rapid* (Watertrack, 2006), another recent Australian DSS, designed to minimise user effort through limiting data reporting,[1] still requires irrigators to access

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[1] WaterTrack claims to "not require inflow measurements onto the field" and so "only Irrigation dates are required" thus reducing effort of use. See http://www.watertrack.com.au/?menu=about&page=rapid.

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http://dx.doi.org/10.1016/j.compag.2012.03.003

the Internet from a computer, enter in data and then run the system for a response. Given the known rate of adoption of all DSS in Australia, is extremely low (Inman-Bamber and Attard, 2005) and knowing the well understood barriers to adoption, it is clear that in the case of *WaterSense*, the benefits to its use do not outweigh its difficulty of use. In the case of *WaterTrack Rapid*, its use is still not sufficiently easy to result in widespread adoption.

Irrigators who do use some form of decision support do so only in conjunction with many other data sources. Pre-trial interviews with our test group of irrigators showed that all irrigators, including those who had soil moisture probes installed, used vine observations, weather observations and experience to help them irrigate. Many used soil wetting pattern observations and shovel soil testing and a few individuals also used less common data sources, such as infra-red crop images or weather warnings from other locations as a forecast to help them. For many of these data sources there is no objective, deterministic method that can be used to generate irrigation volumes. Invariably, irrigators must rely on heuristics and past experience to do this. Thus DSS such as SOAK (Costigan, 2008), a farm water management software package that tries to coalesce all the irrigation data sources that its designers believe are relevant to irrigation scheduling, must inevitably fall short of providing 'all the answers' for many irrigators both for their inability to include the whole, wide, range of data sources currently in use and their inability to measure the non-quantifiable sources.[2] Since the announcement of the development of SOAK and a prize it won in 2008, there have been no further references to it publicly in the irrigation industry.

The cellular mobile Short Messaging Service (SMS) is increasingly used in many contexts to simply and quickly deliver and gather data from people with mobile phones. One recent example of its' use is by diabetic clinics in managing remote patients' blood sugar levels (Hanauer et al., 2009). In irrigation, SMS has been used to promote the understanding of how a flexible, water budget-based, irrigation schedule can save water and increase productivity over a fixed schedule (Singels and Smith, 2006). In this South African trial messages were sent weekly to 5 irrigators telling them to "stop-", "start-", "continue-" or "do not" irrigate based on a crop growth model using estimated irrigations and measured rainfall. The study concluded that by communicating the model outputs to irrigators in the simple SMS form, water use efficiency was increased by 48%. The authors found that weekly communication was required to assure the participating irrigators that the system was still functioning. They also concluded that it could be advantageous to obtain measured irrigation volumes from the participating irrigators to improve model accuracy (Singels and Smith, 2006).

In addition to its ease of use, the low deployment cost of SMS and its ubiquity of use by many people, even the poorest, in both the developed and developing world means it is a technology that helps bridge the digital divide rather than widen it, thus modified forms of systems used in the developed world may be more easily modified for use in the developing world than Smart Phone or personal computer-based technologies.

This paper describes the use of high-end IT systems for irrigation scheduling and the response of irrigators to an SMS-based, textual, DSS interface for irrigation scheduling. It also reports the utility of such an approach for irrigation scheduling as determined both by system data and interviews with end users. Methods detailing technical aspects of the system, the trial location and participants, interactions with participants, the DSS calculations and the DSS operation in general are given. Results of system performance, irrigation applications and system cost to irrigators are provided from measured data. Results of irrigators' understanding of the system and perceived system utility are provided from interview data. Discussion of user participation and user utility follows and finally a conclusion is given.

The motivation for this research is the desire to improve the utility of DSS to irrigators in order to increase the proportion of them using such tools. Increased use will not only lead to benefits to the individual but also to the irrigation industry as a whole as such DSS also easily function as data collectors for aggregate water use statistics.

2. Methods

2.1. System description, calculations and operation

The DSS used in this trial was called IrriSatSMS, which used satellite derived crop coefficients in a daily water balance approach. The mechanisms of the water balance calculations and crop coefficient generation and use are described in detail in Hornbuckle et al. (2009). An overview of the Decision Support System's (DSS) architecture, as well as the methods of communication used between components, is shown below in Fig. 1.

The central server hosted the DSS calculation code (Microsoft C#.NET[3]), the web page presentation (ASP.NET[4]) and the database (MySQL[5]). The cellular gateway service was a SOAP[6]-based web service that accepted text generated by the DSS and passed it to commercial cellular networks in Australia that distributed the text via the Short Messaging Service (SMS) to users' mobile phones.

The DSS used four streams of data to generate decision support. They were:

1. *Weather data:* Obtained daily from a weather station web server which in turn collected the data from a weather station network using dial-up radio modems.
2. *Irrigation Management Unit (IMU) measurements:* An IMU being a crop area of one or more fields but under a single irrigation management regime – measurements were taken of geographical location, area and the irrigation system application rate. This information was manually entered into the DSS database.
3. *Satellite image data of land surface reflectance values:* Used to estimate crop ground coverage. These data were collected from satellite images and processed to produce one average K_c reading per IMU per satellite pass (as per Hornbuckle et al. (2009)). These were then also stored in the DSS database.
4. *Irrigation application and rainfall data:* These data were sent in by irrigators for their specific IMU to the DSS via SMS. The SMS messages were required to be formatted for ease of processing and, once received, values were automatically time-stamped and stored in the DSS database to contribute to individuals' water balances. Thus the number and frequency of irrigator responses to the system were able to be tracked. Incoming irrigation and rainfall messages were processed automatically with custom software to feed information directly into the water balance model. Messages that were incorrectly formatted and were unable to be processed were automatically responded to via SMS asking the irrigator to re-enter the data and a log of the incorrect message was kept. In cases where the irrigator did not re-enter the data correctly, the irrigator

[2] Even attempting to combine quantifiable but non-absolute data sources, such as the commonly used soil moisture probes, with absolute data sources, such as rainfall or evapotranspiration is problematic and cannot produce absolute irrigation volume advice. SOAK, attempts this and even tries to run sprinklers directly from the DSS output which cannot work without feedback mechanisms requiring expensive in-field sensors.

[3] http://msdn.microsoft.com/en-us/vcsharp/default.aspx.

[4] http://www.asp.net/.

[5] http://www.mysql.com/.

[6] http://www.w3.org/TR/2000/NOTE-SOAP-20000508/.

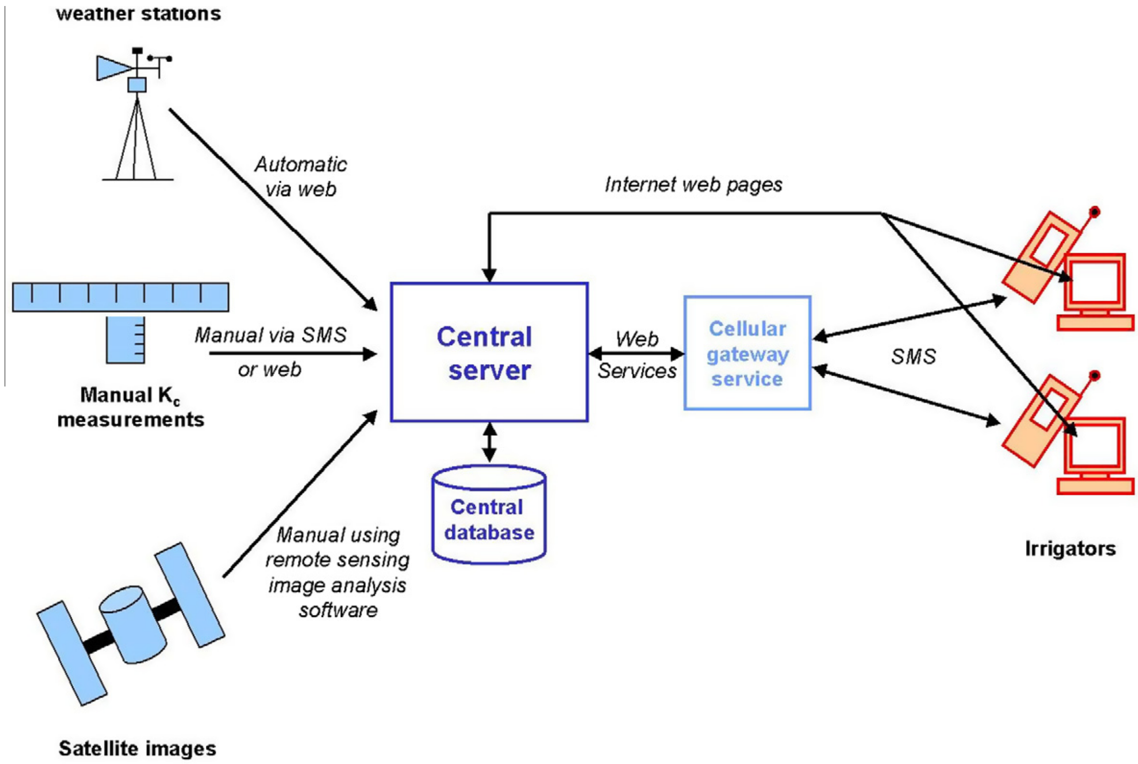

Fig. 1. System diagram of the DSS showing components and communication methods.

Fig. 2. Mobile phone screen showing a typical DSS daily SMS message.

was contacted via telephone in order for their entry to be understood and manually entered into the DSS.

DSS output messages were sent to irrigators at 7:30 am as most claimed to check their crop and irrigation systems in the morning. Only 3 irrigators would have preferred an alternative time, early evening (about 6 pm) as they thought it would allow them to better cater for evaporation from the current day. Fig. 2 shows an example of an irrigator's phone displaying a typical daily message.

As all of the irrigators in this trial were using drip irrigation systems, the DSS calculated a daily dripper run time (DRT), for each IMU, based on a cumulative calculated crop water deficit (CWD) and using measured system parameters, as in Eq. (1):

$$\mathrm{DRT} = \frac{A_e}{\mathrm{Apr}} * 60 * \mathrm{CWD} \tag{1}$$

DRT: dripper run time (min), A_e: area per emitter (m^2), Apr: emitter application rate (l/h). 60: constant, 60 minutes per hour (used for a result of dripper run time in min), CWD: crop water deficit as depth per unit area (mm).

Cumulative (from the start of the season to the current date) crop water deficit (CWD) was calculated from cumulative effective rainfall ($\sum R$ in mm), irrigation ($\sum I$, in mm) and crop evapotranspiration ($\sum ET_c$) as per Eq. (2):

$$\mathrm{CWD} = \sum R + \sum I - \sum ET_c \tag{2}$$

Irrigation values in millimetres were calculated from dripper run times and rainfall values were measured by farmers individually using their own rain gauge. Rain gauges were supplied to farmers who had insufficiently accurate gauges. Rainfall values supplied by farmers were modified to obtain an approximate 'effective rainfall' value using a reducing function developed through local observation of rainfall runoff on a local similar soil type – the laboratory field site which was in the centre of the trial area.

The crop evapotranspiration, ET_c, was determined from reference evapotranspiration, ET_0, and a crop coefficient, K_c, using Eq. (3) following the method outlined in the Allen et al. (1998) but using a modified Penman equation with parameters for the Griffith area provided by Meyer (1999).

$$ET_c = ET_0 K_c \tag{3}$$

ET_c: crop evapotranspiration (mm), ET_0: reference evapotranspiration (mm), K_c: crop coefficient (dimensionless).

The daily ET_0 readings were calculated from local automatic weather station data. Evaporation and transpiration were not separated but were accounted for using crop coefficient K_c values.

Monthly K_c values were determined for each irrigator's individual IMU from remote sensing using Normalised Difference Vegetation Index (NDVI) in a process similar to that described in Johnson et al. (2007). The monthly K_c values were interpolated forward using previous season future month values and then updated when current season values were measured. K_c values were manually uploaded to the DSS by researchers. The resolution of LANDSAT images used was 30 × 30 m which was much smaller than any of the IMUs in this study.

Using the water balance calculations described above each irrigator was sent a daily SMS message which provided a dripper 'run time to zero' in minutes. This was the length of time, calculated from the CWD, that the irrigation system should be run in order to replace the CWD. Since CWD was cumulative (from the start of the season to the current date), irrigators were able to see the positive compound effects of irrigations and rain as well as the negative compound effect of cumulative daily evapotranspiration. In cases of a positive CWD, negative minutes were sent to the irrigator. Care was taken to start irrigators' water balances at a 'zero' point or point in time at which their IMU had a zero CWD. This was realised practically by starting irrigators either after a reasonable rainfall event or after a large, early season, irrigation.

Messages sent by irrigators back to the system containing rainfall and irrigation information were able to be sent at any time. Since the system's calculations ran at 6 am each day with the resultant messages sent at 7:30 am, messages sent after 6am on a particular day were only included in the water balance calculations for the next day. Irrigators were free to choose the timing of their irrigation reporting (before or after events) and rainfall (at stages through long rain events or at their end) but were encouraged to be consistent, whatever their choice.

The approach in this DSS meant that irrigators were not told specifically *when or how much* to irrigate but rather just how much they would have to irrigate, on any given day, to return their CWD to zero. This meant irrigators retained full flexibility of when to irrigate and how much to apply and so were able to continue to adjust their irrigation regimes to suit their own particular conditions and preferences.

The only monetary cost to irrigators associated with participation in this trial was the cost of sending in text messages of irrigation and rainfall.

2.2. Trial participants

The trial was run in the Griffith region of New South Wales, Australia (34°17′24″S, 146°2′24″E). This is a semi-arid region where summers are hot and dry and the winters are mild. Mean annual rainfall is 418 mm, but is highly variable ranging from 140 to 700 mm occurring throughout the year and in isolated stormy bursts during summer. Mean annual potential evapotranspiration (ET_0) is 1800 mm.

The irrigation season for grapes in the Griffith region is from September to April/May. The trial was conducted from September 2008 to May 2009.

Participants were wine grape growers selected for their use of drip systems and mobile phone ownership. Mobile phone ownership was close to ubiquitous amongst all irrigators in the region so this was not a limitation. They were also selected to be representative of the range of drip irrigators in the region by the local grower association technical officers. The reason for this was to ensure as representative cross section of the local irrigation community as possible was used in the trial. The sizes of the grape farms of participants are given in Fig. 3A, their ages in Fig. 3B and their years of irrigation experience in Fig. 3C. All irrigators were fluent in English even though for seven it was not their first language.

During initial interviews irrigators were asked about their irrigation systems and their use of mobile phones, computers and the Internet. They were then asked about their irrigation scheduling techniques in general and their experience with evapotranspiration in more depth. Table 1 gives the number of irrigators who used various methods and tools to schedule before the trial.

Irrigators used more than one method or tool to determine when and how much to irrigate. Some common combinations were visual inspection of the vine and soil moisture determined by digging and soil moisture probe readings with weather forecasts.

Irrigator's previous use of evapotranspiration based methods for scheduling was very limited, indeed only one irrigator could demonstrate use of a water balance approach. To ensure irrigators understood the information they received throughout the season, they had training in evapotranspiration basics (how a simple crop water balance is driven by water in (rainfall and irrigation) and water out (evapotranspiration and drainage) and that the evapotranspiration of particular crop fields can be estimated through measured reference evapotranspiration and satellite imagery of the crop). They also had the phone data they received explained to them on several occasions. It was intended that they should easily understand the information they received.

All irrigators spent 15 min or less, on average, deciding on their irrigation application volume for each IMU, each day, including the time taken to use scheduling tools listed in Table 1. Most irrigators had between one and several (2–5) IMUs meaning a total irrigation decision time of less than an hour was normal. Irrigators all approached the task of deciding how much to irrigate each day having an approximate figure in mind due to the time of the season, a pre-existing schedule, previous experience with that crop or system limitations.

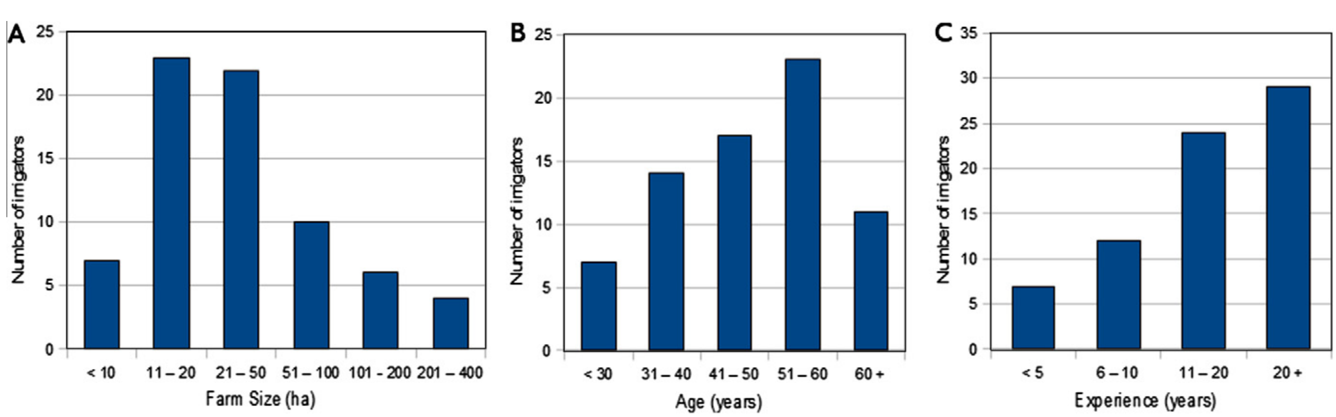

Fig. 3. (A) Participating irrigators' farm sizes, (B) participating irrigators' ages, and (C) participating irrigators' irrigation experience.

Table 1
Irrigation scheduling method and tool use by the 72 trial irrigators before trial commencement.

Tool/method	No. of irrigators[a]
Experience	66[b]
Moisture probes	45
Shovel – to inspect soil moisture	28
Visual plant inspection	26[c]
Fixed schedule	19
Weather (irrigator's estimations of crop water demand)	18
ET_0 – growers using reference ET from a local weather station	5
ET_c – a grower using local weather station ET and his own estimates of crop coefficients	1
Infra-red probe – a grower using an IR camera to tell when vine leaves reach background temperature	1

[a] Numbers add to more than 72 as irrigators used multiple tools and methods.
[b] For some irrigators (9) this was their first year using drip systems and some of those claimed to have little or no experience with drip system schedules.
[c] All irrigators used plant inspections but not all listed it as a scheduling tool.

It is clear from further interview results (see Section 3) that irrigators were more likely to spend time thinking about altering their approximate figure during the peak irrigation season period (late Dec– Feb) than at either the beginning or end of the season.

Researchers interactions with participants varied over the season as indicated in Table 2. Initial meetings with individual irrigators were held to choose a single irrigation management unit (IMU) – one specific block or field managed as a single entity – to be used in the trial. Measurements of their irrigation system parameters – crop type, size location and application rate were also taken during this visit. The system application rate was used to convert the dripper run times sent in by irrigators into millimetres for use in the water balance and to convert millimetres of evapotranspiration into minutes of dripper run time.

Most contact with irrigators during the season was 1–2 weeks after the initial meetings and the following 1–2 months. From then on, they were contacted only as required. Those found to be not communicating with the system were called after 1–2 weeks of inactivity.

Irrigators were asked questions during pre- and post-season interviews. All the interviews were structured interviews. Pre-season questions focused on the collection of factual information, irrigator's knowledge of irrigation concepts and other irrigation DSS use. Post season questions assessed the outcomes of the irrigator's season and the block involved with the trial in particular. They also assessed the irrigators' experience with using the DSS at different points in the season and overall.

These questions were used to determine the utility of the DSS. Utility here was defined as the *usefulness* of the DSS to the irrigator:

1. Compared to other DSS and decision making tools the irrigator used.
2. By the effort of use.
3. In terms of useful behaviour changes.
4. The learning/educational benefits.

Irrigators were asked firstly for their perception of the DSS's utility at various season stages (early, mid-year, late season, post-harvest) compared with other scheduling tools they use such as visual inspection of the vines, soil moisture probes and other tools. They were also asked for their perception of the overall impact that the DSS had on their scheduling regime and the effort required to use the DSS.

Finally, irrigators were also asked an open ended question as to what effect participation in the trial had on their irrigation practice. The resulting unstructured answers were subjected to qualitative thematic analysis.

3. Results

The service began in September 2008 with 23 irrigators and this number increased through the early part of the season. By November 2008, 54 irrigators were enrolled, by December 2008, 67 and from January 2009 onwards, 72.

3.1. SMS system performance

The automated delivery of SMS messages and processing of SMS messages from irrigators technically worked well. However, it was important to test the reliability of the Short Messaging Service as no guarantee of timely delivery of messages is made by cellular phone providers, messages may be delayed up to a week. In practice it was found that mobile phone service provider faults only prevented 1 day's messages from being delivered and did not delay

Table 2
Interactions between trial participants and researchers.

Time period	Interaction	Methods
Pre irrigation season Jul–Aug 08	Initial contact with72 irrigators	Telephone calls polling interest
Pre irrigation season Aug 08	Initial project information session	Group meeting at grower association offices
Early irrigation season Sep–Oct 08	Initial interview of 72 irrigators	Irrigator farm visit and interview by a single researcher. Irrigation system data gathering, trial sign-up and SMS message sending and receiving practice
Early irrigation season Oct–Nov 08	SMS sending and interpretation assistance	Telephone calls and SMS as needed
Mid irrigation season Dec 08–Jan 09	System check up	Telephone calls, one or two farm visits and phone conversation for irrigators as needed. System restart for some lapsed users wishing to re-engage
End irrigation season May 09	System shut-down	SMS alert, some phone calls
Post irrigation season May–July 09	Post season interview	Farm visit and interview for system usage and irrigator season results data gathering as well as an assessment of irrigators' continued interest for future seasons
Post 08/09 irrigation season, early 09/10 irrigation season Sep 09	Post project information session	Overall project results presented to participants, sign-up of past participants for the 09/10 season, information session for new participants

Table 3
Days of faulty messages, shown in brackets, [ ], and days of messages not sent, shown without brackets, for the whole seasons.

Mobile phone service fault	Database or software error	Weather station data error	Season days of messages	Total days of correct messages
3	4, [2]	[6]	238	223 (94%)

any messages for more than a few seconds. Table 3 shows the faulty message counts.

3.2. Results from irrigator interviews

Results from interviews and the water balance database were used to try and understand if the irrigators understood the information they were receiving. They started receiving SMS messages after an initial phone call, a group meeting at grower association offices and a farm visit and interview by a researcher during which general principles of ET-based scheduling and the SMS system overall were explained. However, even after these three explanatory interactions, some of the irrigators apparently still did not understand either ET scheduling or the SMS system. All of these irrigators took some faith in the researchers and enrolled in the service.

Results of early season phone contact with irrigators found that once they saw the minutes of dripper 'run time to zero' increase each day over some time and then decrease when they sent in rainfall or irrigation events, they then understood how the water balance system worked even if they did not understand ET or crop coefficients.

Half the irrigators did not understand the relationship between dripper run times in minutes and depth of water applied in millimetres (see Eq. (1)) or the conversion of millimetres times hectare to Megalitres (100 mm ha = 1 ML), the unit that is used for irrigation metering. Of those that did not already have a working knowledge of these conversions, some came to understand approximate minute to mm conversions for their blocks through explanation and some realised it themselves from seeing daily messages with dripper run times in minutes and water balances in mm. This did not seem to affect their use or understanding of the SMS system as there was no lack of system use on behalf of those irrigators who did not understand the conversions.

Almost all irrigators immediately understood that the dripper run times derived from the water balance were to be used in the context of multiple scheduling data sources (such as shovel inspections and weather forecasts) and thus used the dripper run times as a guide, rather than absolute figures to be followed exactly. Those few irrigators who wished to abandon all other scheduling tools and rely on the SMS messages were asked not to do so.

3.3. Irrigators interaction with DSS

Regarding the mechanics of SMS message use almost all growers had received a message (94%) and read it on their mobile phones before using this system, but much fewer (55%) had created and sent them. While almost no irrigators expressed concern in reading incoming messages, many had trouble initiating message creation and then message typing before sending. Most of the phones used by irrigators in this study allow the user more than one way to create a message and this caused confusion. Typing out the messages presented problems for about 20 irrigators especially regarding phone predictive text functions. In all but 4 cases, sending method and typing problems were overcome by repeated demonstration and advice provided over the telephone in the first month of service. Of the 4 irrigators who could not overcome these problems, 2 delivered their irrigation and rainfall events to the researchers by telephone and 2 stopped using the system. It is possible that the inability to send messages may have stopped another two people from using the system but was not given as the reason by them.

None of the message-sending irrigators found sending in the messages to be an inconvenience. The time taken by irrigators to send in messages was considered negligible after their first few messages had been sent. All irrigators understood the format and were able to send in correctly formatted messages. Three irrigators who took holidays away from their farm during the season needed reminding of the message formats upon return but then resumed message sending with little effort.

Only three irrigators wanted the messages delivered at a time other than 7:30 am and only two irrigators were annoyed by the daily receipt of messages.

The daily receipt of the message had a 'prompting effect' for 66% of growers in actively thinking about irrigation scheduling. All the irrigators checked the message daily, either upon receipt of the message or shortly thereafter. A few moved to checking the messages only every second day or so later in the season, especially post-harvest.

Three quarters of the irrigators referred to each message only once and then either ignored it afterwards or deleted it from their phones. The other quarter either saved all the messages on their phones or recorded the values delivered on paper or using a computer spread sheet.

Irrigators stated that they sent in data using SMS most regularly after receiving the daily morning water balance message and this is backed up with inbound message arrival timestamps showing that 60% of all inbound messages arrived between the morning message (7:30 am) and midday with 7:30–8:30 am being the time most used; 24% of all messages. This was because irrigators found that the incoming message reminded them to communicate back to the system.

The number of messages sent in to the system varied greatly between growers and over the course of the season. Some growers were sending in 15 or more messages per month but the average was 6 messages per month. Fig. 4 shows the number of messages sent in by growers per month over the main irrigation period from November to February.

Irrigators growing wine grapes in this region with drip systems have an approximate maximum interval between watering events, rain or irrigation, of 10 days due to drip system output capacity. This means that for an irrigator to fully participate with the DSS, they must send in at least 3 or 4 messages a month. Thus Fig. 4 shows that during the peak irrigation season, December and January, about 50 irrigators (76%) were participating fully. In February this number reduced as some growers harvested in early February, after which they irrigate less and treat irrigation as less critical. Fig. 4 also shows an increase in the number of irrigators sending in many messages per month in December and January. This indicates irrigators sent more messages during the period of intense irrigation.

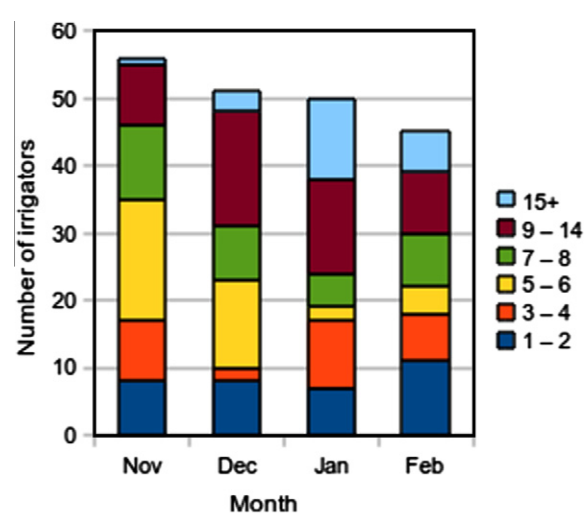

Fig. 4. Count of irrigators sending in certain numbers of messages per month.

Table 4
Number of irrigators who sent in messages for two major rainfall events.

Rainfall period	No. of irrigators using the system	No. of irrigators who sent messages
7th–8th Nov 08	54	51
12th–14th Dec 08	72	54

Rainfall can also be used to help estimate the number of irrigators actively engaging with the system. The system requires that messages be sent in regarding rainfall, thus comparing the number of messages reporting rainfall with known rainfall events can provide an estimate of user engagement with the system. Two significant rainfall events occurred in the peak irrigation season; the 7th–8th November and the 12th–14th December. Table 4 shows the number of irrigators who reported rainfall in or just after these periods. Due to summer rainfall variability, not all irrigators would have received rain however these periods were chosen due to the magnitude of the rainfall events (27 and 41 mm, respectively) indicating widespread rain from a large storm front and thus is can be expected that a large proportion of farms would have received significant rain.

Table 4 indicates a very high response rate after rain of 75–95%. This is a similar estimate to the 76% of growers being fully engaged by assessment of irrigation input SMS.

Only two requests were received to turn off the service; one in early February 08 following an early harvest and the other only 2 weeks before the planned shut-off date. As such it appears that the receipt of daily SMS messages is acceptable to growers; even those growers who at the final interviews stated that they did

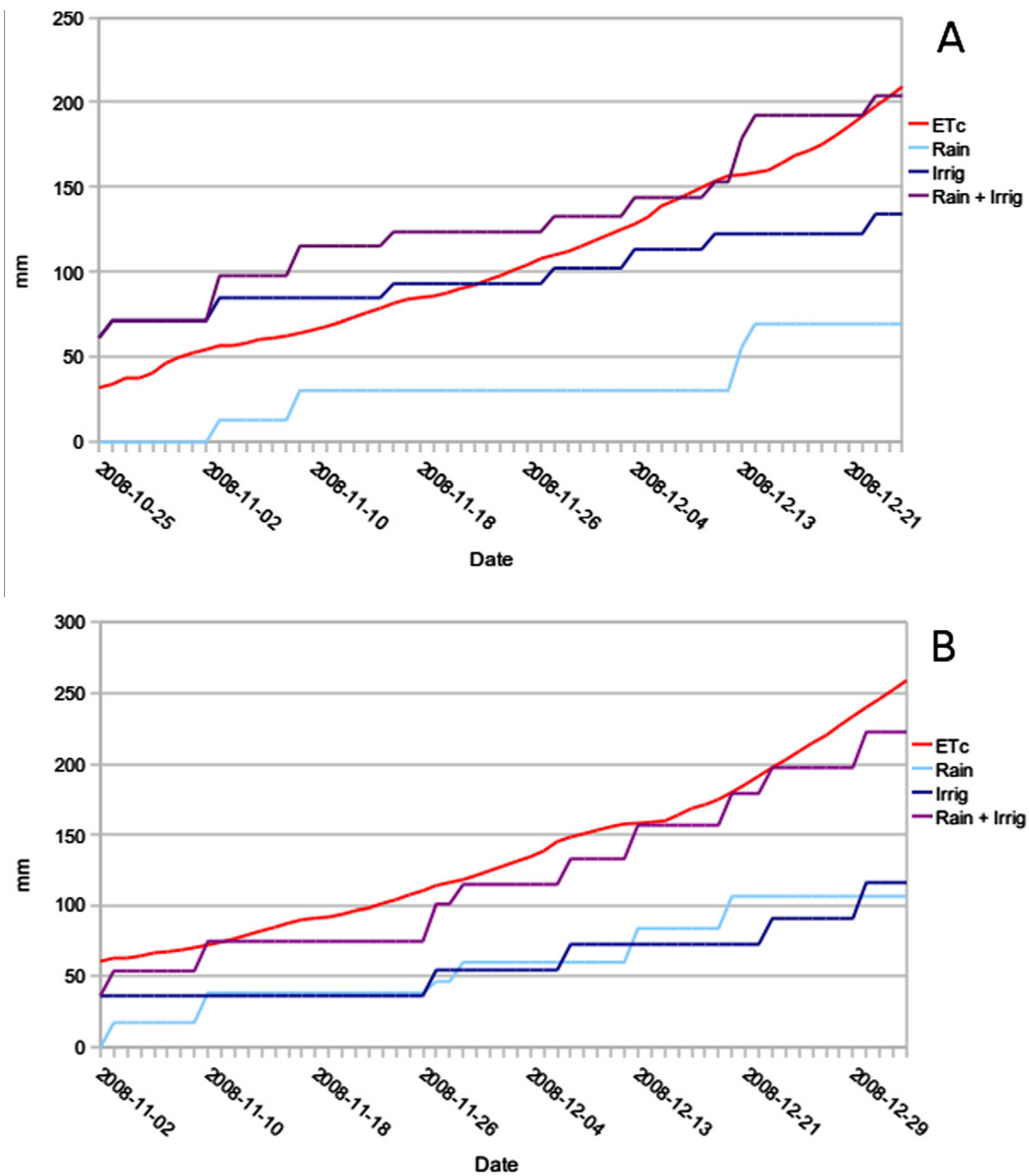

Fig. 5. Partial cumulative CWD graphs for 2 irrigators showing differing responses to the system. The top graph (A) shows the irrigator kept a positive CWD using both rainfall and irrigation while the bottom graph (B) shows the irrigator returning the CWD to zero when it reached a fixed approximate value of about −35 mm.

not use the information much were content to continue to receive the messages.

3.4. Irrigator response to DSS recommendations

The utility of the system can also be quantified by assessing the irrigator behaviour with respect to the graph of daily CWD and constituent components provided by the DSS. Fig. 5 shows two such daily CWD graphs from different irrigators over approximately the same 2 month period: late October/early November to late December. Graph A shows the irrigator maintaining a positive water balance for almost the entire period and irrigating when that water balance reduced below zero on the 10/12/2008 and the 23/12/2008. Graph B shows the irrigator maintaining a negative water balance that reduces until approximately −35 mm, which the irrigator saw as 4000 min dripper run time to zero, at which point the irrigator irrigated or had rainfall to return the water balance to zero such as on the 10/11/2008 and from 26 to 28/11/2008 and again on 13/12/2008.

Fig. 6 shows the daily CWD values for 3 irrigators over the full season. The 3 irrigators followed irrigation patterns that resulted in them using either more than, close to, or less water than recommended. However, in all three cases the information provided was useful to the irrigators. We can see that for the 'more' irrigator, once the rainfall in December had been evapotranspired, his negative cumulative CWD continued to grow slowly for the rest of the season but he engaged with the system until the end of the season nonetheless. This irrigator grew a large *Colombard* crop and was comfortable using what he considered to be a large amount of water as he was aiming for a high yield with quality being of minimal importance. In interviews he stated that he was able to use the SMS messages as a relative guide as to how much to irrigate, due to weather effects and crop life cycle, even though the absolute value recommended was not the same as his practice. The 'close' irrigator used the SMS tool as his main scheduling tool. It was his first year using a drip system and so he looked to the SMS messages to provide him with guidance. The 'less' irrigator did not follow the advice of the system during the January heat wave but then did so for the rest of the season even though there was a legacy of approximately 50mm cumulative CWD that he was not able to recover. He found the advice post heat wave useful in determining exact irrigation volumes taking −50 mm cumulative CWD as a new zero point.

All three irrigators represented in Fig. 6 continued to interact with the tool until the end of the season despite their differing cumulative CWDs and associated suggested dripper run times. All three also chose to participate with using the tool again for the 2009/2010 season which confirms their perceived utility of it.

Fig. 6 shows that irrigators with different objectives and under differing conditions can gain benefit from using the SMS tool. The utility of the tool ranges from a direct to an indirect scheduling guide and that irrigators are able to interpret and use the information received from the tool in ways that benefits their situation.

From the DSS daily CWD graphs, usage can be placed into six named groups:

1. *Close throughout* – those who followed the DSS recommended dripper run time closely, irrigating within 10% of the recommended minutes throughout the season.
2. *Closely mostly* – those who followed the DSS recommended runtime closely until late December 08, then applied less than recommended for 3–4 weeks, then applied as recommended for rest of season.
3. *More throughout* – those who applied more than recommended consistently across the season. Note this was only up to 15% more than the total recommended number of minutes.
4. *Stopped sending* – those who followed the recommended amounts until late December 08/mid January 09 and then stopped sending input data.
5. *Less throughout* – those who those who applied much less than suggested.
6. *Never sent* – irrigators who never sent in any data.

The number of irrigators in each of group is given in Table 5.

Irrigators in Groups 1–3 (68%) can be collectively grouped as full system participants. They engaged with the system until the end of the season, albeit with different watering preferences.

Irrigators in Group 5, *less throughout*, did not ascribe to a single motive for doing so in end-of-season interviews. Two said that they deliberately reduced their watering to stress their crops for quality reasons, two said they did not think it was economically viable to fully water their crop and two said their crop was 'happy' with the amount of water that they had given it.

Group 4, *stopped sending*, all ceased sending messages as they saw their suggested dripper run times increase beyond what they

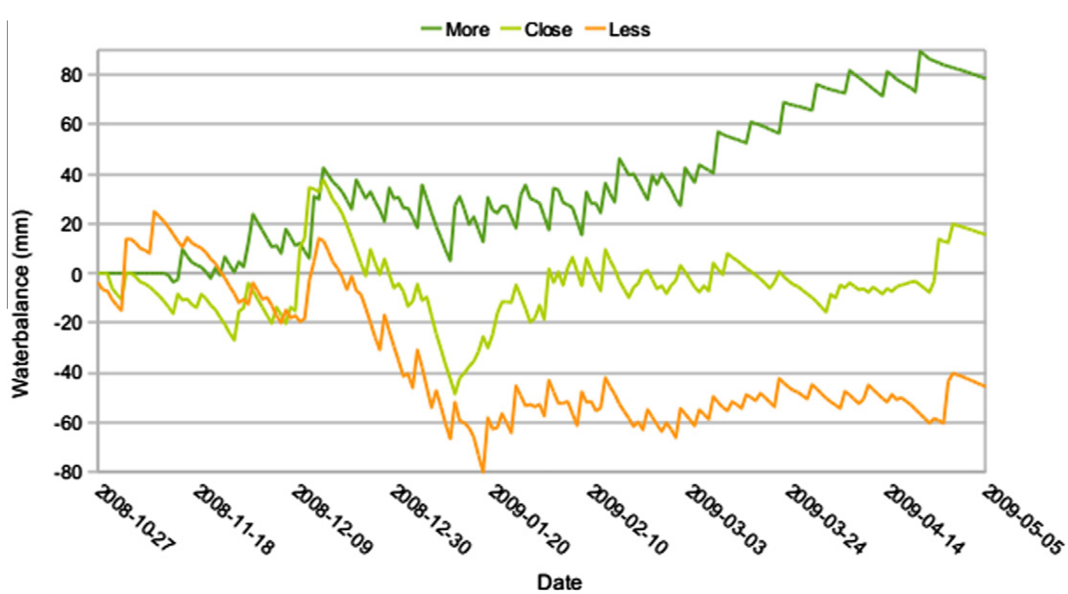

Fig. 6. Full season CWD lines for 3 irrigators: 'More', 'Close' and 'Less'.

Table 5
Number of irrigators per water balance group type.

Group	Number	%
1. Close	26	36
2. Close with step	7	9.7
3. More	3	4.2
4. Much less	6	8.3
5. Stopped	15	21
6. Never sent	17	24
Total	72	100

perceived to be reasonable and so did not persevere. It would seem they lost confidence in the system. Half the irrigators in this group (7/12) stopped after some usage as they felt the system offered them no benefits. Three stopped for reasons unrelated to irrigation such as personal and other family issues.

Some irrigators who were generally happy with their involvement in the trial and whose actual dripper run times differed from the suggested dripper run times and but did not change their behaviour explained that the differences between the volumes were necessarily so due to their blocks being non-standard. One irrigator who watered much more than the suggested dripper run times said that his block was steeply sloped and had unusually sandy soils. Others who watered much less said it was due to their heavy clay soils.

The important message from these responses is that no irrigators that followed the advice were unhappy with having done so and no irrigators that received the advice and monitored it through to the end of the season were unhappy about having done so, indeed many wished they and followed the advice, not just monitored it. This realisation was corroborated both at the post irrigation season group meetings and also through the numbers of irrigators signing up for the service for the 2009/2010 season.

When asked how irrigators translated the DSS advice into action, 25% answered that they allowed minutes to accumulate for a number of days and then irrigated for a time close to that number. The majority (79%) said they took advice from several data sources (such as weather forecast, auger results, vine inspection) and would then come to a final decision based on a fusion of this type of information with the DSS information. None of these irrigators could quantify the implicit weight they ascribed to each data source. Only 6% of the irrigators wrote down approximate dripper run times from each source before making a decision, all the rest carried out this process semi subconsciously in a matter of a few minutes each day. In response to direct questioning, all irrigators stated that the total irrigation decision making process occupied only a few minutes per day.

For the whole group of 72 irrigators, 53 (74%) said they actively considered information from this DSS in their scheduling decision making. This compares closely with the input message analysis that showed 75–76% active usage.

3.5. Perceived DSS utility

Irrigators were asked to list which parts of the SMS interface they used. All irrigators responded that they regarded the dripper run times component as their primary interface. About 34% said they were interested in, and took note of, the rainfall and irrigation totals and 9% said that they regularly noted the ET_c figures. When asked about their use of ET_c figures in more detail, 5% of the irrigators showed a profound understanding of evapotranspiration and crop coefficients and compared this system's figures to ones of their own making. The other interested irrigators were not able to compare the systems ET_c figures to data from any other source.

Of the irrigators who took note of the irrigation and rainfall totals, 8% viewed their water balance graphs online also. These irrigators all responded that the graph better represented the individual effects on CWD due to rainfall and irrigation than did the cumulative totals in the messages.

When asked about how the cumulative rainfall affected their irrigations, no irrigator was able to give a quantitative answer, not even three who specifically recorded cumulative rainfall at different stages in the season. Answers to other questions about the use of rain by irrigators referred to watching the changing dripper run times. Irrigators had been reminded on multiple occasions that both rainfall and irrigation affected their dripper run times.

Fig. 7 shows the utility scores that irrigators gave to the system overall at four points in the season: early (Oct/Nov), mid (Dec/Jan), late (Feb/Mar) and post-harvest (Mar +). Note the lack of '1' responses (not useful) in the first two time periods as well as the downward trend of '5' with time and the increasing '2' and '1' responses with time.

The average utility scores from each of the 4 time periods in Fig. 7 are given in Fig. 8. Note the early increase in utility (the high '4' response for the 'mid' season group) and then the decline over time (increasing '2' and '1' results in 'late' and 'post-harvest').

When irrigators who reported an initial increase in utility were asked why, all responded that their confidence grew with time as they understood how the tool worked and they had seen it in action, however all irrigators also noted the heightened importance of scheduling tools, including this tool, during the peak irrigation period so the increased utility score must be due to a combination of both reasons. The later decline in utility is, in general, due to irrigators focusing less on irrigation in the post-harvest period and more on other farm issues and, in 20% of cases, due to disenchantment with the tool. For the season as a whole, 66% said that this system was not as useful as their primary scheduling tool but that it was still seen as useful.

Of the irrigators actively involved in this trial, 40 irrigators answered the open ended question "*How did the tool affect your scheduling behaviour over all*?". Their answers followed 5 similar behaviour themes which were:

- *Small:* The dripper run times were close to what they were doing so observing and/or following it resulted in little change in their former practice. The tool was still seen as valuable in that it gave them confidence in their current practice and acted as a back-up. The DSS did thus influence their practice by positive reinforcement and resulted in a small change in behaviour whereby a new irrigation data source was considered in coming to a decision.
- *Large:* They perceived the dripper run times to be higher than they believed necessary but they still followed them on trust, resulting in a large change to their practice.
- *Significant:* They used the DSS as their main irrigation scheduling tool but could not describe how this may have changed their practice. Thus the tool can be deemed to have influenced their practice, but the behaviour change is unknown.
- *Marginal:* The DSS information was interesting and educative to them but and changed their understanding but did not change their behaviour.
- *None:* They perceived the dripper run times to be too high and did not follow them, resulting in no change to their behaviour.

Table 6 gives the percentage of respondents who subscribed to the various views described above.

When assessing the total effect of the system on irrigator behaviour we can sum Group 2 and 3 giving 46% as those for whom the DSS has significantly affected their behaviour. We can then add Group 1 to this as those for whom there was some influence on

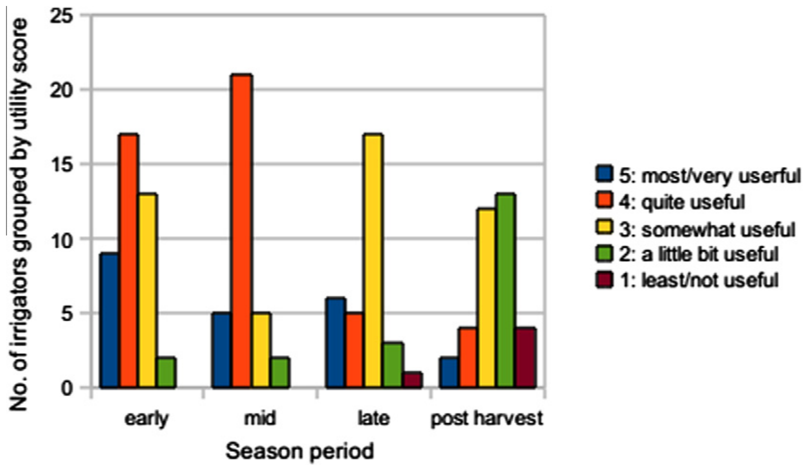

Fig. 7. Number of irrigators grouped by utility scores for different time periods in the season.

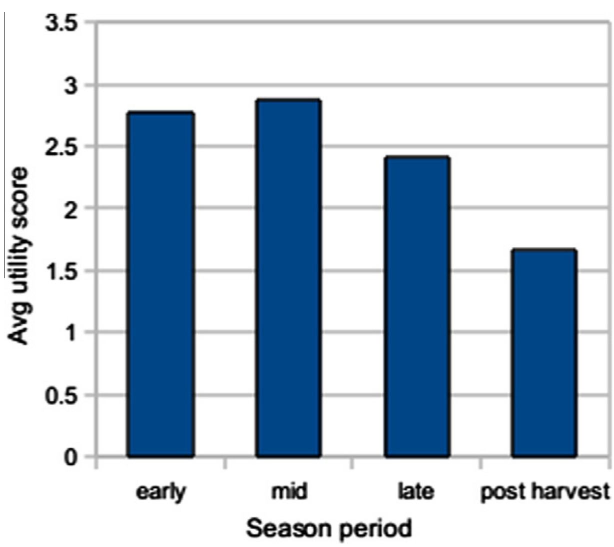

Fig. 8. Average irrigator assessment of utility of the system for different time periods in the season.

Table 6
Number of irrigators per behaviour change type.

Group	No. of irrigators	% of respondents
Small	11	27
Large	10	24
Significant	9	22
None	8	20
Marginal	3	7
Total	41	100

behaviour (73%). Beyond that we can add Group 5 to this to give 80% as those who were educated by the DSS. However, further discussion with Group 4 irrigators found that their post season analysis told them that they could have benefited from following the DSS, and would do so in future seasons. As such we can see that the DSS had a remarkable level of influence on behaviour and educative capability.

After discussing the effect of the DSS on their behaviour the irrigators were asked to reflect upon this. Group 1 all said that using the tool gave them confidence in their current method of operation. No one from Group 2 who had followed the advice of the tool and put on more water than they initially thought necessary was unhappy with having done so in retrospect. Three example responses from Group 2 are given in Listing 1 below:

Group 3 irrigators could not articulate their behaviour change due to:

- inter-seasonal changes in circumstance (e.g. crop age, financial returns, weather variations);
- lack of previous seasons' experience with that particular block;
- this being their first year using drip irrigation;
- insufficient records from previous years.

This confounded efforts to draw comparisons between the trial season and previous seasons however, all of these irrigators thought the DSS useful and did not regret having followed it.

Several Group 4 irrigators said that in retrospect they wished that they had followed the suggested irrigation times that they originally did not follow due to thinking them too high. Listing 2 gives some example responses from this group.

Group 2 and Group 4's responses related to the heat wave experienced by all growers in late January 2009. Due to the system's recommendations for irrigation being higher than average practice from mid December 2008 to January 2009, those that followed the advice had well watered crops that suffered less in the heat wave than the crops of other growers. Some of those that lost crop due to the heat wave thought that they may have avoided doing so had they had followed the DSS's advice.

Group 5 irrigators stated they found the involvement with the DSS interesting for a number of reasons such as learning about crop/weather interactions and quantitatively comparing rainfall and irrigation. All of these irrigators asked to trial the system again in the 2009/2010 season.

3.6. Cost and effort

Trial involvement was free so the total cost for an irrigator was due to messages sent. Eighty seven messages at $0.25 each (largest number sent at a high per-SMS cost) costs $21.75. No irrigators mentioned cost as an issue in interviews. The commercial system costs are reported in Hornbuckle et al. (2009).

Irrigators said they took "just a few seconds" or "no time" or "a minute" to form and send messages to the system. Observations of irrigators sending messages after some coaching suggest a sending time of about 30 s. Cumulative season sending time was therefore

```
Irrigator 1:
- put on a few extra hours
- happy with this
- could/should have put on more
- very useful for learning
- very simple - good

Irrigator 2:
- was sceptical of high readings
- followed anyway
- excellent results
- will continue to follow
- surprised how ETc related to min

Irrigator 3:
- used early on and until pre harvest
- didn't use post harvest (saving water)
- yield was ok
- happy to have used it
- happy to use again next year
```

Listing 1. Example Group 2 responses.

less than 43 min. If the time taken to read the daily messages was also 30 s, total season message time would be 116 min or about 40 s per day.

4. Discussion and conclusions

4.1. Participation

For participants in this trial, cost was virtually non-existent and the labour effort required was very low. Receiving and sending messages throughout the season did not perturb the majority of irrigators, no irrigators that discontinued with the trial cited reading or sending messages as the only issue leading to them not using the DSS. It appears that the effort required for effective participation did not exclude any irrigators from using the DSS. The complexities of ET-based water balance cycles were able to be hidden from end users with only knowledge of water in and water out being required for use.

This trial also indicates that SMS is a cheap, effective and minimally intrusive way of collecting water use data from a large number of irrigators. Such data is close to real-time and was able to be used for regional water use benchmarking. This trial showed that a complex water balance-based DSS could rely on SMS as the sole interface medium.

4.2. Utility

Use of this DSS did not prevent irrigators from using their other information sources and using these conjunctively. Also, as it did not stipulate when to irrigate or the amount, irrigators could be flexible in timing of irrigations to suit their farm management and the DSS could cope with varying management styles. The scheduling DSS advice was used by irrigators in conjunction with their current tools and heuristics. Growers had many and varied approaches to determining when and how much to irrigate and no irrigators reported relying solely on one data source to help them schedule. The simplicity of use of this DSS allowed it to sit comfortably with irrigators' current approaches, adding information to their decision making in a complimentary manner. This we believe was the key to its acceptance.

For this reason and for the overall non-intrusive nature of the support, it appears that most irrigators felt that using the system offered a "can't lose" proposition unlike other, complex/expensive scheduling tools.

Interview results confirmed the authors' initial assumption that scheduling is a small, routine task of a few minutes a day on which irrigators do not wish to expend much energy. This DSS seems to have been able to be used without forcing irrigators to radically change their decision making behaviour. Irrigators who used offices regularly were able to use the web interface easily but for the majority who were more accustomed to spending time outdoors, the portability of access to the DSS via the mobile phone (SMS) interface was regarded as critical and greatly impacted on uptake.

More than 50% of the irrigators interviews showed that the 'prompting effect' of having their phone, which they always carried with them, beeping each morning upon receipt of the DSS-generated SMS message prompted them into thinking more about irrigation matters than they otherwise would have. Many also commented that the somewhat intrusive nature of the DSS' daily interaction also contributed to keeping them involved with the trial.

The presentation of water balance data as drip run times hid the underlying science from the irrigators and indeed although some had trouble understanding rain and irrigation's influences on water balances as well as some of the ET concepts they were still able to use the system (communicate with it and understand it's suggestions) after seeing the water balance results over 1 or 2 weeks.

The utility scores that the irrigators assigned to the tool compare well with their other statements of use, their descriptions of changing use over the season and also their DSS use compared to their other scheduling tool use. As understanding the DSS' function

```
Irrigator 4:
- reduced watering this season due to grape price
- lost lots of yield in heatwave
- retrospect should have kept closer to evap
 [as given by this DSS]

Irrigator 5:
- SMS said too much water
- fell behind due to other crop requirements
- wishes he kept up with it
- will follow closely next season
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Listing 2. Example Group 4 responses.

early was related to continued use and as average perceived utility increased with familiarity, it is thought that a return farm visit to all irrigators one week after their initial farm visit and sign up to further clarify the system would enhance DSS utility and irrigator participation.

Some of the irrigators who discontinued using the tool never really engaged with it and did not understand how it worked. However, some of those who were initially skeptical of it (identified through low starting perceptions of utility and interview comments, see Fig. 7) came to appreciate it more with time. The trend seems to be that familiarity bred trust. It would seem then that if better initial engagement with potential users is undertaken resulting in better explanations of ET-based scheduling and the system's functionality, the rate of discontinuation may be reduced. Since this tool has already achieved a high rate of user engagement in its first year of deployment, if the discontinuation rate is reduced, the system will be able to claim unusually high potential user penetration among irrigation DSS tools compared with those listed by Inman-Bamber and Attard (2005).

The DSS was offered for use by growers in the following season (2009/1200). Of the original 72 irrigators contacted at the start of the 2008/2009 season 69% wished to use it again. Of those irrigators who used the DSS for the full 2008/2009 season 83% wished to use it again. This occurred without any 'marketing' merely a single phone call to find out if they were interested to use the DSS again. This is a remarkable retention rate compared to the usage seen in other irrigation DSS.

Although this system worked only with irrigators using drip systems, if modification can be made for use with other irrigation systems, the approach of intrusive but minimal effort usage via the simple, mobile, interface may be relevant to large numbers of irrigators internationally as its reasons for success seem to be based on aspects of human nature. Such modification would also allow use by irrigators in developing countries with minimal high technology infrastructure.

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