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PROVISION OF IRRIGATION SCHEDULING ADVICE TO SMALL SCALE SUGARCANE FARMERS USING A WEB BASED CROP MODEL AND CELLULAR TECHNOLOGY: A SOUTH AFRICAN CASE STUDY

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ABSTRACT

Adoption of irrigation scheduling techniques in S.A. sugarcane production has been disappointing. The challenge is to use state of the art technology to provide practical and useful advice to farmers and further to convince farmers of the benefits of irrigation scheduling by on-farm demonstration. The purpose of this paper is to describe (1) a high technology system to provide practical, real time irrigation advice and (2) its pilot implementation on a small-scale farm irrigation scheme.

The system consists of a web-based simulation model that estimates the recent, current and future water balance, crop status and yield from field information and real time weather data. The system automatically generates and distributes simple irrigation advice by SMS to farmers' cellular phones.

The system was evaluated on a small-scale sugarcane irrigation scheme at Pongola, South Africa. Indications are that adhering to advice from this system leads to large reductions in irrigation applied (33%), deep drainage (64%) and irrigation costs. Yields are not affected significantly and profitability is enhanced considerably. The main impact is to reduce irrigation during winter and when the crop is young. Results suggest that the phased expansion of the system to more farmers and other irrigation schemes is warranted.

Keywords: SMS, crop model, weather data, irrigation scheduling, water use efficiency

DISPOSITION D'UN PROGRAMME CONSEIL D'IRRIGATION POUR LES PLANTEURS DE CANNE A SUCRE DE PETITE ECHELLE SE SERVANT D'UN MODELE BASE SUR LE WEB AINSI QUE LA TECHNOLOGIE CELLULAIRE: UNE ETUDE EN AFRIQUE DU SUD

RÉSUMÉ

L'adaptation de techniques de programme d'irrigation pour la production de canne à sucre en Afrique du Sud a été décevante. L'objectif est d'offrir un conseil pratique et utile en se servant d'une technologie avancée afin de convaincre les planteurs des bénéfices d'une irrigation controlée par une démonstration sur place. Le but de cette présentation est de décrire (1) un système de technologie avancée qui fournit un conseil d'irrigation pratique et à temps actuel (2) son incorporation en un projet pilote , d'irrigation sur les fermes de petite echelle.

Le système consiste en une simulation de modèle basée sur le WEB , qui estime la balance d'eau récente, courante et future, le statut et le rendement de la récolte aux champs et les données météorologiques actuelles. Le système produit et distribue automatiquement aux fermiers une recommendation simple d'irrigation, par SMS sur leur téléphone portable.

Le système a été évalué sur un programme d'irrigation de petite échelle à Pongola, en Afrique du Sud. Les indications sont qu'en observant les recommendations de ce système, il en résulte une grosse réduction de l'irrigation appliquée (33%) de l'égouttement profond (64%) et du coût d'irrigation. Les rendements ne sont pas affectés de manière significative et la profitabilité est considérablement augmentée. Le but principal est de réduire l'irrigation durant l'hiver et lorsque la plantation est jeune. Les résultats suggèrent qu'une extension en phase de ce système à plus de planteurs et à d'autres systèmes d'irrigation est justifiée.

Mots clefs: SMS (message sur portable), simulation de modele, meteo, programme irrigation, efficacite usage eau.

1. INTRODUCTION

It is generally accepted that the adoption by farmers of scientific irrigation scheduling is far below expectations (Clyma, 1996). Leib et al. (2002) found that adoption rate depended on the value of the crop and on type of irrigation system. Clyma (1996) suggests that farmers need more comprehensive technological support that is simpler to use, and that scheduling needs to be integrated into farm management. Adoption of irrigation scheduling techniques in South African sugarcane production has been disappointing, leading to over irrigation, low water use efficiency and reduced profitably. A recent survey (Olivier & Singels, 2004) concluded that the main reasons for non-adoption were (1) the complexity of technology and the difficulty of applying it in practice on the farm, and (2) the perception that accurate scheduling provides little benefit. This applies especially for small-scale farmers who do not have access to expensive monitoring equipment, computers and the Internet to assist in scheduling irrigation. The challenge therefore is to provide practical and useful advice to farmers using state of the art technology such as crop growth models and weather stations, and to convince farmers of the benefits of irrigation scheduling by on-farm demonstration.

Irrigation scheduling could be defined as a planned programme of irrigation application specified by dates and amounts to achieve given objectives. Typically these objectives could be to maximise profits, maximise water use efficiency, avoid water wastage, avoid plant stress or achieve maximum yields (Lamacq et.al., 1996). Operationally these objectives are often achieved by attempting to maintain soil water content within a target range given the constraints of the soil and irrigation system.

Numerous methods and tools are available to assist the farmer in achieving these objectives. These could be grouped into methods based on water budget calculations or methods based on direct measurement of soil water status. The first group is based on some measure of atmospheric evaporative demand and a crop coefficient that describes the amount of canopy cover and soil surface wetness (Jensen et al., 1990). Either real time or long-term average values could be used for both these variables. Real time values are normally used in conjunction with sophisticated water budget calculators such as crop models and require access to daily weather data (Teixeira et al., 1995; McGlinchey & Inman-Bamber, 1996; Singels et al., 1998), while long-term averages are used in simpler methods such as spreadsheets and do not require access to daily weather data apart from rainfall (George, 1988). Generally, the water budgeting method using models has not been adopted widely (Stephens and Middleton, 2002; Leib et al., 2002).

Olivier & Singels (2004) found that farmers perceived these models as too complex and cumbersome. A possible solution to this is to remove the burden of learning and operating the model and interpreting its complicated output, by centralizing the data processing and model execution. Model output could then be used to generate simple, user specific advice focussed on practical decision-making. This paper describes such an attempt.

The purpose of this paper is to describe (1) a centralized, model based system using weather data to provide practical, real time irrigation advice and (2) its pilot implementation on a small-scale farm irrigation scheme. The system will be evaluated through a case study by:

- comparing the long term simulated performance of two strategies of irrigation (advised and current practice), and
- by assessing the operational implementation of the system on a select group of small scale farms.

2. SYSTEM DESCRIPTION

2.1 Overview

The various components of the *My Canesim* system are shown in Figure 1. It consists of:

- A database (Oracle9i) of model inputs (weather, soil, crop and irrigation data) and outputs (crop water status, yield and irrigation advice)
- A sugarcane simulation model (coded in Oracle PL/SQL) that estimates the recent, current and future water balance, crop status and yield on a reference position in a field from the input data. The Canesim model is a daily time step, point-based simulation model driven by water, temperature and radiation. It requires soil available water holding capacity and daily temperature, rainfall and reference evaporative demand as input. The model accounts for partial canopy conditions and soil water content using a single layer soil profile. Sucrose and cane yield is calculated by combining a radiation use efficiency approach with source-sink principles (Singels & Bezuidenhout, 2002). The water balance of Canesim is described by Singels et al. (1998) and the canopy development by Singels & Donaldson (2000). These publications also report on the validation of various aspects of the model against observed data, indicating the soundness and accuracy of the model for the purpose of this study.
- A module (coded in C#) that (1) extrapolates the water balance at the reference position to estimate the water balance at the driest part of the field and then determines the ideal irrigation schedule based on these two water balances, and (2) automatically generates and distributes irrigation advice to farmers' cellular phones via SMS (short message service).

- An Internet based user interface (hosted on an Oracle Portal Server) for advisors and extension staff to enter field, crop and irrigation system data and to view simulation results.

Insert Fig. 1

2.2 System input data

Weather data: Data is obtained daily from 24 automatic weather stations situated throughout the S.A. sugar industry (solar radiation, min and max temperature, wind, humidity and rainfall). The data is downloaded daily before 6:00 am, processed and uploaded into the model database by 13:00. Data processing consists of infilling missing data and calculating cane reference evaporation (McGlinchey & Inman-Bamber, 1996). These processes are scheduled to occur automatically as part of a system developed by Singels et al. (1999).

Field and irrigation system data: The following information is required by the system:

- Soil: Plant available water capacity (SWC in mm) and plant available water (SW in mm) at the start of the crop,
- Crop: Cultivar, row spacing, plant or ratoon date and planned harvest date,
- Irrigation system: Type of system, irrigation cycle, net irrigation amount per application. The irrigation cycle for dragline systems is calculated by multiplying the number of positions per sprayer by the normal stand time per irrigation event.

2.3 System output

The *My Canesim* system outputs daily values of cane yield and quality, crop and soil water status, canopy cover, cumulative water balance totals and irrigation advice. This data are used, via the user interface, to produce reports that summarize data in numerical and graphical form at the irrigation scheme or field level. Output can be printed as hard copy or exported into Microsoft Excel for further analysis.

2.4 Irrigation scheduling

Here, the aim of irrigation scheduling was to maintain available soil water (SW) of the entire field within a predetermined target range. The lower limit of this range is named the depletion level (DL) and is expressed in units of plant available water in the soil profile. The upper limit of this range (expressed in the same units) was taken as the smaller of SWC or the sum of DL plus the net irrigation amount. DL is determined by taking into account the SW threshold for water stress and the preferred SW deficit to make best use of irrigation (and rainfall). In this case we chose DL as equal to the SW stress threshold, assumed to be 50% of SWC.

In theory, this computation applies to a unit area of land receiving one identical irrigation schedule from a dedicated fixed irrigation system, resulting in a spatially homogenous water balance. In practice, large fields are irrigated by a single moving irrigation system dedicated to multiple sub-areas within the field, such as centre pivot, or, as was the case here, a set of dragline sprinklers. One irrigation event may take several days to complete, causing significant spatial differences in soil and crop water status. This was accommodated by using the concept of a dynamic depletion level (DDL), which accounts for the typical crop extraction during the time it takes to complete an irrigation cycle, at the current stage of development and at the current time of the year (ET_{cycle}). ET_{cycle} was taken as the crop extraction calculated for the previous cycle, implying an assumption that crop extraction during the next cycle would be similar to that of the previous cycle. Thus, DDL was taken as the sum of ET_{cycle}, which varies according to canopy development stage and atmospheric demand, plus DL (defined as ½ SWC), which is constant for a given soil. (Eq. 1). The higher value of DDL (compared to DL) serves to prevent water stress from developing in parts of the field that await irrigation.

$$DDL = 1/2.SWC + f \,.\, ET_{cycle} \qquad (1)$$

where f is a fraction determined by the preference for avoiding water stress or deep drainage. We followed a conservative approach by setting f equal to 1.0, implying a preference to avoid water stress rather than to avoid deep drainage.

Irrigation schedules were determined by considering simulated SW for three situations per field namely the first sprayer position (SW_1), the last sprayer position (SW_n) and a dummy position (SW_{99}) approximating SW of the driest part of the field. The soil water balance of the dummy position is based on that of position number one but without the last irrigation from the current cycle. The model indicated commencement of an irrigation cycle when SW_n dropped below DDL, or SW_1 dropped below ½ SWC. During the cycle the model indicated a stop in irrigation when SW_{99} exceeded DDL as a result of rain, and indicated resumption after SW_{99} dropped below DDL again, due to water extraction by the crop. At the end of the cycle, SW_n is compared with DDL again, to determine whether a new cycle should commence or not.

Towards the end of the growing season a drying off period is simulated by withholding irrigation. Drying off is a common practice in irrigated sugarcane production and serves to save water, prepare the field for harvesting and promote sucrose accumulation by inducing mild water stress which alters the partitioning priorities of the crop. The date for starting the drying off period was determined as follows:

1. Calculate for each day prior to harvest (DPH) the long-term mean daily water deficit (WD) as the difference between the long term mean reference cane evaporation (ECREF) for that day and long term mean daily rainfall (RAIN) for that day ($WD_{DPH} = 1/n\Sigma\ ECREF_{DPH} - 1/n\Sigma\ RAIN_{DPH}$).
2. Accumulate WD_{DPH} over DPH, backwards in time from the date of harvest ($WDCUM_{DPH} = \Sigma\ WD_{DPH}$).
3. Test WDCUM of each day against the available soil water content (SW) on that day. The first date on which $WDCUM_{DPH}$ exceeds SW_{DPH} is taken as the date for drying off to start.

This algorithm is based on a rule of thumb formulated by Donaldson and Bezuidenhout (2000).

2.5 Advice

The content, format and timing of the advice were designed according to user preferences obtained during several workshop sessions. A SMS is sent to farmers on a weekly basis, or when some irrigation action is required. It contains the following information in the language of choice: Date, farmer's name, current yield estimate, yield estimate at harvest, irrigation action required. Table 1 shows the different types of advice sent to farmers.

Insert Table 1

3. System evaluation

The system was evaluated on the Bivane small scale sugarcane irrigation scheme in Pongola, South Africa (27°24'S, 31°35'E, 308m asl). The scheme consists of 47 farmers on 508 ha of land. Soil depth and water holding capcity varies (see Table 3) but all soils could be classified as Oxisols according to the USDA classification. Semi-permanent overhead systems are used on 44 farms. Each farmer farms 7-15 ha and typically has 20 sprayers moving them amongst 20 to 28 positions. The stand time is 11.5 h (two moves per day) and the effective application rate is 3.6 mm per hour giving a net application of 42 mm. The irrigation cycle varies from 8 to 14 days.

Cane yield in 2003/04 varied from 132 to 23 t/ha with a scheme average of 88 t/ha. The average amount of irrigation water used on the scheme in 2004 was 921 mm (pers. comm. Boonzaaier, Impala Water Users' Association). Seventeen farmers (36%) exceeded the annual quota of 1000 mm in 2004. Irrigation costs (quoted in US$ using an exchange rate of ZAR 6.50/US$) for 2004 consisted of (1) water costs associated with scheme operation and statutory levies (US$ 82/ha) and (2) electrical power costs for pumping water from the canal to the small-scale scheme (US$ 169/ha), as well as for operating infield pumps (average of US$ 137/ha). At a water use of 1000 mm these costs translate to US$ 0.39/mm. Exceeding the quota should invoke a fine of US$ 0.48/mm for the excess. At present there is little financial incentive for farmers to cut back on water use. Practical and political constraints have limited the implementation of a volumetric costing structure and the fine for quota exceedance has not been imposed yet. However, it is envisaged to volumetrically apportion the power costs of infield pumping to each farmer and to implement the exceedance fine in 2005/06 (pers. comm., Boonzaaier, Impala Water Users' Association).

The system was evaluated in two ways. Firstly, a simulation study was conducted to compare the long-term performance of the irrigation strategy suggested by the system to that of current irrigation practice. Secondly the system was implemented on a few selected fields and evaluated in terms of crop growth, water use and farmer acceptance.

3.1 Strategy analysis based on historic weather data

Weather data from the SASRI research station in Pongola for the period 1968 to 2003 was used to simulate 12 month crops for each month of the milling season (Apr to Dec) for each year. Four sets of simulations were conducted. These were two soils with different water holding capacities (SWC = 90mm, rooting depth 0.8 m and SWC = 180mm, depth 1.6 m) and two irrigation strategies namely, the standard practice of a fixed schedule (apply 42 mm every 10 days regardless of soil water status) and flexible schedule based on estimated soil water status (apply 42 mm every 10 days only when SW drops below DDL). Towards the end of the growing cycle, irrigation was suspended for both strategies according to the rules described previously.

Results for both soils are summarized in Table 2, while the discussion will focus on results for the shallow soil. On average 33% less water is used by scheduling irrigation using the flexible schedule compared to a fixed schedule. Irrigation with the flexible schedule slightly exceeded the annual quota of 1000 mm. Although the flexible schedule reduced deep drainage by 64%, this was still surprisingly high. The relatively high irrigation and drainage was due to the stated preference to avoid water stress rather than deep drainage. Whole field irrigation could be optimized further by adjusting factor f in Eq. 1. It should also be noted that the marked reduction in drainage probably reduced leaching of nitrogen significantly.

There is no significant reduction in simulated crop water use or cane yield associated with the reduced irrigation of the flexible strategy. The number of stress days (defined as number of days during the active growing period when the available water content was below 50% of SWC) is indicative mainly of the unsuitability of a 10-day cycle to maintain water contents above the stress threshold during periods of peak demand. Long term mean irrigation water use efficiency (IWUE defined as cane yield in t/ha, divided by total net irrigation for the growing season in mm) was 48% higher for the flexible schedule compared to the fixed schedule.

Flexible scheduling on the shallow soil reduced irrigation costs on average by US$ 300/ha to US$ 395/ha under the costing structure envisaged for 2006 (a fixed cost for scheme operation, a volumetric based cost for infield pumping of water and a fine for exceeding the quota).

Intra- and inter-annual climatic variation caused irrigation requirements to vary between crops. The long-term mean irrigation applied using the flexible strategy varied from 865 mm for May crops to 1106 mm for a December crop. The minimum value (of all years) was 672 mm for an April crop and the maximum value was 1386 mm for a December crop.

The deep soil generally required less irrigation than the shallow soil, which resulted in less drainage, less frequent stress, similar yields, higher IWUE and lower irrigation costs than the shallow soil (Table 2).

3.2 Field evaluation

The aims of this part of the project were (1) to expose the system to the practical aspects of farming in order to refine it if necessary, (2) to evaluate the accuracy of the system to predict crop growth and water use, and (3) to evaluate the ability of the system to provide useful advice. This pilot implementation also served to create awareness amongst farmers about the importance of irrigation scheduling and to pave the way for wider implementation in the S.A. sugar industry.

Five farmers were selected to take part in the field evaluation (see Table 3). An area of approximately 5 m x 1.4 m was selected in each field to measure irrigation, rainfall (two gauges) and the depth of the wetting front. The latter was measured by installing two wetting front detectors (Stirzaker, 2003) at 50 cm depth. Crop status was visually assessed (stalk height and density) and canopy interception of photosynthetic active radiation was measured with a SF-80 ceptometer (Decagon Devices, Pullman, WA, USA).

It was found that in most cases, rainfall and irrigation measurements by farmers were unreliable. Therefore, rainfall recorded at the weather station were used for all simulations and analyses. Irrigation amounts were assumed to be 42 mm for all farmers except Mthembu. In his case, available field measurements were used and an amount of 60 mm was assumed for all other events.

Table 3

Results are summarized in Table 3. Farmer Mthembu, who was the first to receive advice from the system, initially ignored advice not to irrigate several times, thereby wasting approximately 350 mm of water. After explaining the consequences of over irrigation and reassuring farmers of the reliability of the service, farmers followed the advice closely, deviating mainly for special reasons such as washing in herbicides or pump breakdowns. Towards the end of the season farmer Nhleko started the drying off too early, thereby missing two important irrigations advised by the system. A discussion with the farmers revealed a firm belief that a two month drying off period was needed for good cane quality. The disadvantages of excessive drying off and the advantage of following the drying off advice from the system, was explained to farmers. Total irrigation amounts were quite high for two farmers and exceed the quota in all cases. This was partly due to the dry conditions that occurred in 2004/05.

The detailed water balance and irrigation advice for the field of farmer Mthembu is shown in Fig. 2. It clearly shows that he ignored advice not to irrigate in July and August of 2004, resulting in SW far above the target range. This period presented the main opportunity in the growth season for savings in irrigation due to low canopy cover and low atmospheric demand. As the season progressed the actual irrigation practice followed the advice more closely, partly because the relatively high DDL did not allow significant cessation of irrigation. Towards the end of the season (April 2005), further intermittent opportunities for savings were realized by the farmer.

The depth of the wetting front often exceeded 50 cm (see WFD in Fig. 2) in the first half of the season. However, irrigation in the second half of the season often was not enough to wet the soil to 50 cm, indicative of the high crop demand for water. The WFD observations seem to correspond with the general pattern of simulated SW through the season. Irrigation measurements suggest that actual amounts were often much more (ranging from 33 to 84 mm, average of 52mm) than was expected from design (42mm). This highlighted the need for field monitoring to determine reliable estimates of the delivery capacity of irrigation systems for accurate model simulations.

Insert Fig. 2

Field observations of crop growth mostly confirmed that crops were growing exceptionally well. The data in Fig. 3 suggest that the model underestimates canopy development during winter (Mthembu) and over estimates it during summer (Dube, Nene). The systematic nature of the discrepancy suggests that the canopy model of Donaldson & Singels (2000) needs some improvement. A possibility is the introduction of an upper limit to temperature that contributes effectively to canopy development. The underestimation of canopy cover for Mthembu was considered significantly large to have an impact on advice and was therefore corrected by adjusting the base temperature for cultivar N25 from 16 to 15 ^{o}C. The over estimations of canopy cover for Dube and Nene had no significant impact on the advice.

4. CONCLUDING DISCUSSION

A centralized, model based system was developed to provide real time, simple irrigation advice to small-scale sugarcane farmers with overhead irrigation systems. The system employs automatic weather stations, the Internet and cellular technology. The system uses a newly formulated concept to manage irrigation on large fields, namely d*ynamic depletion level.* It allows spatial and temporal extrapolation of point simulations to other parts of the field and to future days within an irrigation cycle.

A simulation analysis of irrigation strategies indicated that significant benefits could be gained by applying irrigation according to a flexible schedule based on a daily water budget as compared to a fixed schedule as is commonly practised. These benefits are:

- A saving in irrigation water of 33%,
- A reduction in deep drainage of water from the root zone of 64%,
- An increase in efficiency of irrigation water use of 48%, and
- A potential reduction in direct irrigation costs of US$ 300/ha. This economic incentive for judicious use of water could only be realized if the cost structure envisaged by the relevant water user association is fully implemented.

The field evaluation generally confirmed the potential of the system to provide relevant advice that could impact significantly on water management by farmers. It was found that weekly communication is required to assure farmers that the system is still functional. It was also shown that farmers will benefit from basic education about crop water budgets. This could promote acceptance of advice from the *My Canesim* system.

The results suggest that significant benefits could be gained from implementing the *My Canesim* system in small scale sugarcane production schemes and that there is justification to expand the provision of the service. Results suggest that the system could possibly also be useful for scheduling irrigation with centre pivot systems in commercial farming.

One concern is the reliance of this method on feedback from farmers. Although, it is believed that the advice generated from estimated irrigation amounts is of value, it could be advantageous to obtain actual irrigation amounts applied in practice to ensure that simulations of water status are more accurate. Various technology options to address this concern will be explored.

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Table 1. The five different options of irrigation advice.

English advice	**Context**
Stop irrigation	The farmer was irrigating and the model indicates that he/she should stop.
Start irrigation	The farmer was not irrigating and should start irrigating.
Continue irrigation	The farmer was irrigating and should continue with the next cycle.
Do not irrigate	The farmer was not irrigating and should delay the start of the next cycle.
Terminate irrigation to dry off	No further irrigation required up to harvest.

Table 2. Long term mean seasonal totals of simulated irrigation (IRR), crop water use (ET), deep drainage (DRAIN), number of stress days (SDAYS), cane yield (Y), irrigation water use efficiency (IWUE) and irrigation cost (COST) for two soils with different water holding capacity (SWC) and two irrigation strategies (STRAT). The standard deviation is given in brackets. Long term mean seasonal total rainfall was 694 mm.

STRAT	SWC (mm)	IRR (mm)	ET (mm)	DRAIN (mm)	SDAYS (d)	Y (t/ha)	IWUE (t/ha/100 mm)	COST (US$/ha)
Flexible	90	1007 (147)	1263 (116)	239 (146)	18 (18)	125 (9)	12.4	395
Fixed	90	1496 (43)	1295 (102)	663 (239)	16 (18)	126 (9)	8.4	695
Flexible	180	835 (188)	1271 (111)	75 (96)	13 (19)	124 (8)	14.9	369
Fixed	180	1431 (73)	1343 (102)	534 (225)	8 (16)	127 (9)	8.8	655

Table 3. Field information, total rainfall and the number of actual irrigations for the growing season for each farmer, compared to the number of irrigations advised by the *My Canesim* system. The estimated amounts of water actually applied by farmers (in mm) are given in brackets.

Farmer	Soil SWC (mm)	Irrigation cycle (d)	Cultivar	Ratoon start date	Harvest date	Rainfall (mm)	Actual irrigation	Advised irrigation
Mthembu	90	9	N25	24/4/04	27/5/05	628	29 (1742)	22
Simelane	50	10	N26	3/8/04	4/8/05	582	29 (1218)	30
Nhleko	90	10	N25	11/8/04	15/9/05	608	24 (1008)	26
Nene	200	10	N25	29/10/04	5/12/05	705	25 (1050)	24
Dube	200	10	N25	24/11/04	10/12/05	664	24 (1008)	25

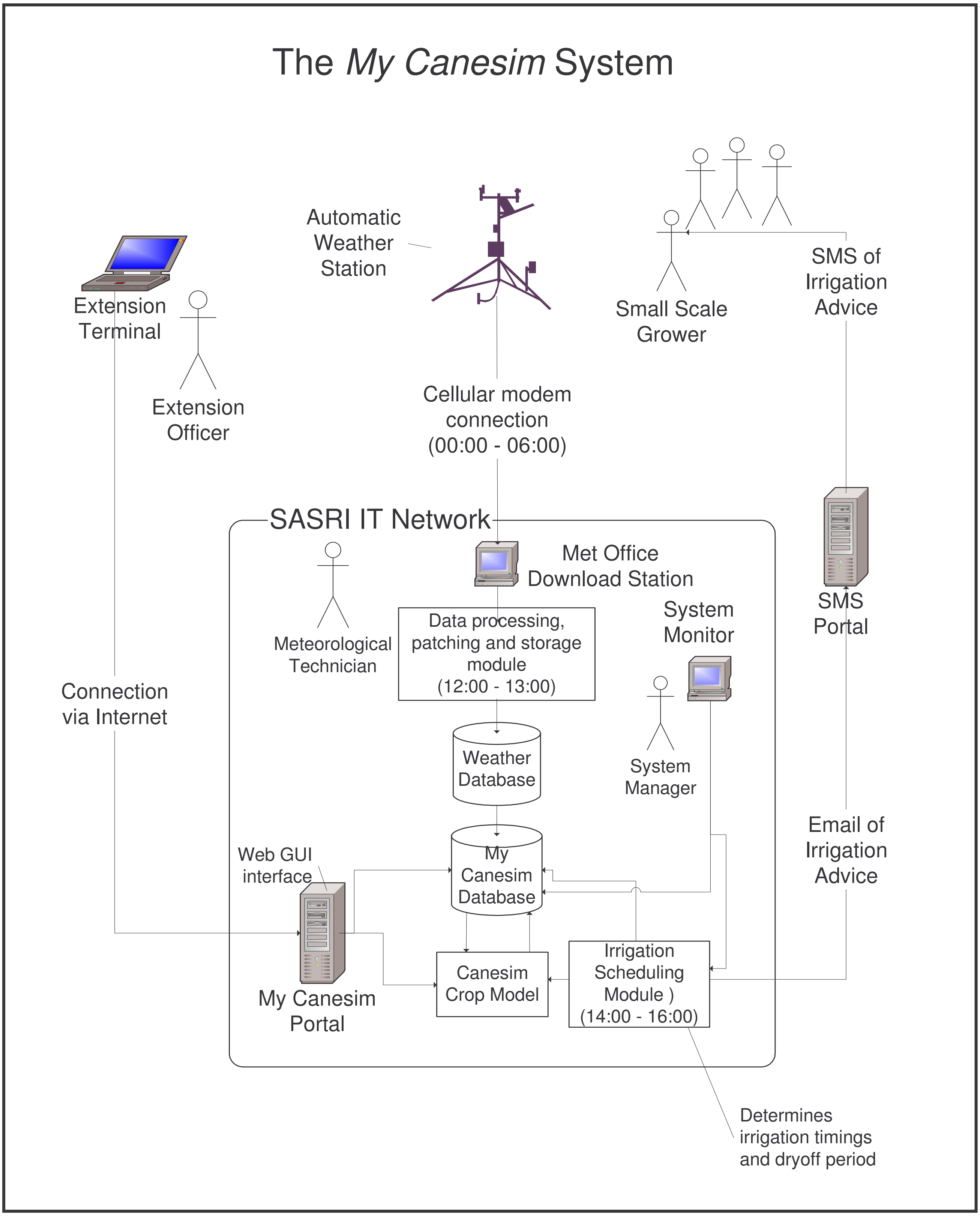

Figure 1. Diagram to show the various components of the *My Canesim* system and the information flow and management thereof.

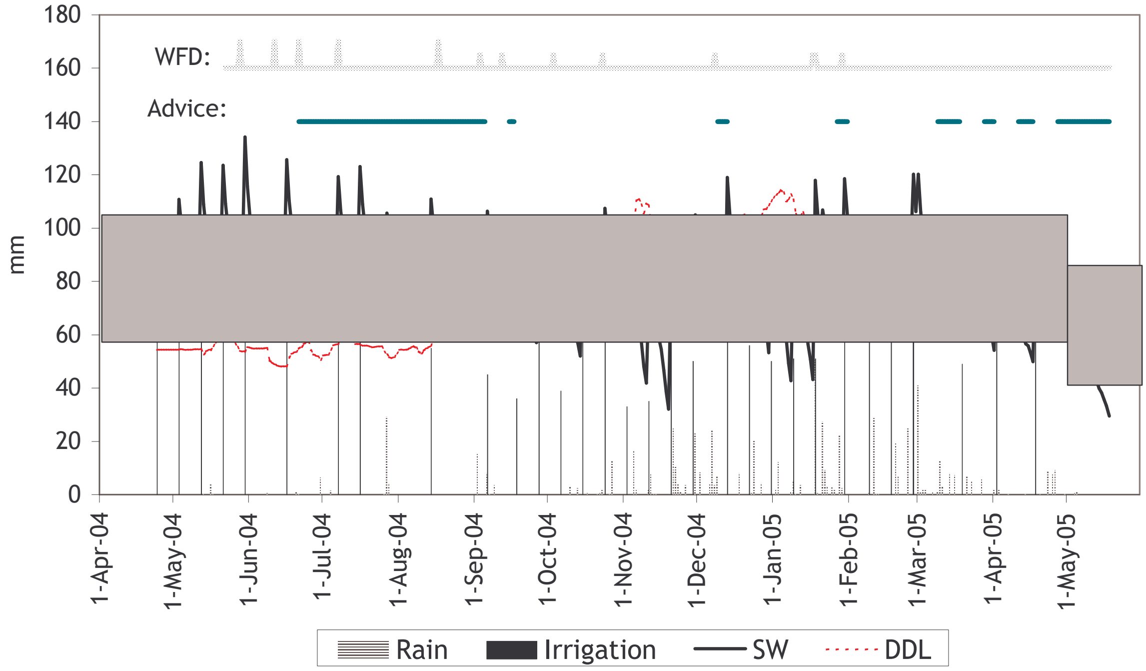

Figure 2. Farmer Mthembu's simulated daily water balance. The figure shows daily rainfall (solid dark bars) and irrigation (dashed light bars) amounts, simulated available soil water (SW, bold solid line), the target SW range (gray block) and the dynamic depletion level (DDL, dashed line). It also shows when the advice was not to irrigate (second from top, solid horizontal line) and whether none (no blip), one (half a blip) or both (full blip) wetting front detectors (WFD, top most light line) indicated a wetting depth of at least 50 cm.

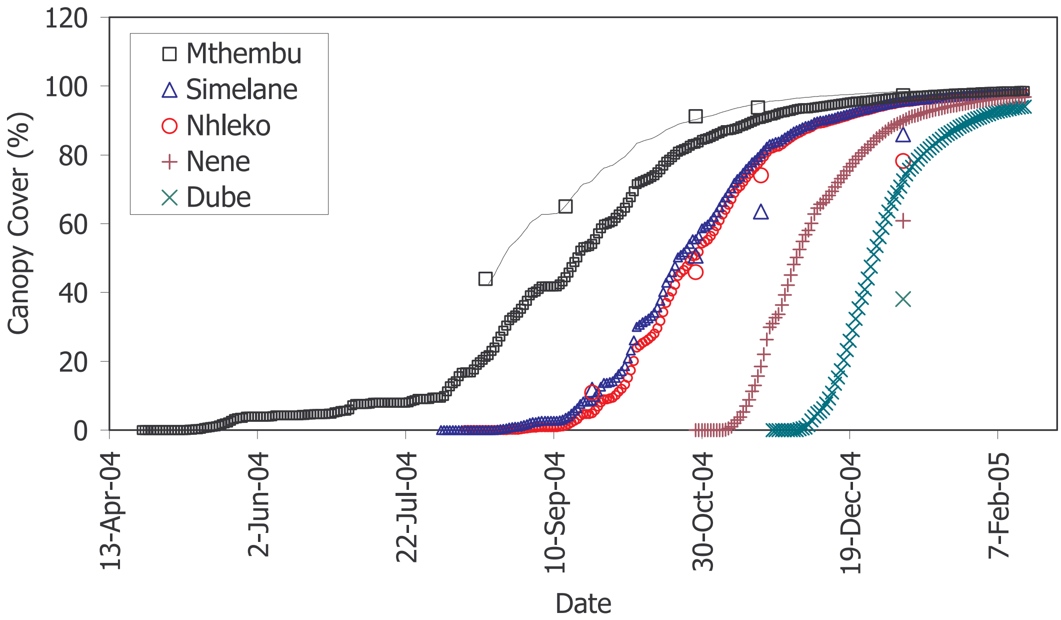

Figure 3. Simulated (lines) and measured (markers) canopy cover for five fields started at different times of the year. The second simulation for Mthembu was initiated in August by adjusting the base temperature for canopy development from 16 to 15 ^{o}C (thin line).

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A NEW APPROACH TOWARDS IMPLEMENTING COMPUTER-BASED DECISION SUPPORT FOR SUGARCANE FARMERS AND EXTENSION STAFF. A *MYCANESIM* CASE STUDY

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Abstract

Sugarcane production regularly requires complex and quick decision-making under ever changing conditions. The uptake of computer-based decision support tools has been disappointing, however. This paper reviews a new approach to developing and implementing decision support for sugarcane production. The main features are (1) use of state-of-the-art technology, (2) limiting users' exposure to system complexity, and (3) participation of users in system design and implementation.

The ***My Canesim*** system consists of a sugarcane model, an on-line weather database and a communication network. The system uses basic field data, initially entered by the user via the Internet, to calculate the soil and crop status for each day of the growing season as the season progresses.

The system was implemented on a pilot scale on two small-scale irrigation schemes in Pongola and Makhathini, South Africa. Farmers, extension staff and mill cane supply management contributed to the design of the web interface, the advice and the reports generated by the system. Irrigation advice and yield estimates are disseminated weekly to 39 farmers using cell phone text messages. Summaries for each scheme are faxed to three extension officers and to mill management. Reports containing detailed information such as current and future cane yield, sucrose content and soil water deficit can be downloaded from the website.

The study revealed various inefficient irrigation practices that could be eliminated and showed that significant savings in irrigation water and costs could be achieved by following the advice. System reports served as a useful benchmark of field and crop status and were used by extension staff as a basis for discussion during field visits, and by mill management as an indicator of crops that are ready for harvesting.

It is believed that a similar approach could be followed to support other aspects of crop production e.g. fertilizer management and harvest scheduling.

Introduction

Successful modern day farming requires frequent and complex decision making to make the best of rapidly changing resource and market situations. Tactical and operational decisions in, for example irrigation and fertilizer management, require accurate and up to date information There are many examples of computer decision support systems (DSS) developed to assist the farmer in this regard (Stephens & Middleton, 2002a). The rapid progression of communications technology (cellular and Internet) enables quick transfer of large amount of data and information, further bolstering the development of DSS. However, the general experience is that the uptake of these systems has been very disappointing due to various reasons (Stephens & Middleton, 2002b). Oliver & Singels (2004) found that irrigation scheduling DSS were too complex and impractical to be useful to South African sugarcane farmers. In practice, farmers tend to use instinct or simple tools that they understand, even though these may be less accurate.

This paper reviews a new approach to developing and implementing decision support for sugarcane production. The main features of the approach are (1) the use of state-of-the-art technology, (2) limiting users' exposure to system complexity, and (3) participation of users in system design and implementation. The paper describes:

- The system and its implementation on two small-scale sugarcane irrigation schemes in South Africa,
- The role of farmers, extension staff and mill management in the development and implementation of the system,
- Examples of how the system assisted extension staff to interact with farmers to improve crop production methods.

The paper further briefly explores the potential of the system to support tactical decisions other than irrigation scheduling.

System description

The *MyCanesim* system uses capabilities offered by modern technology namely the Internet, cellular communication, electronic monitoring of resources, mathematical modelling and computers. It is described by Singels and Smith (2006). Briefly, it consists of:

- An database of model inputs and outputs
- A sugarcane simulation model (Canesim) that estimates the recent, current and future water balance, crop status and yield for a number of positions in a field.
- A irrigation scheduling and advice module that, when activated by the user, (1) determines the ideal irrigation schedule based on the water balance of various positions in each field, and (2) automatically generates and disseminates irrigation advice and yield estimates.
- An Internet based user interface for farmers, extension staff and mill management to enter or edit field, crop and irrigation system data and to view or download irrigation advice, yield estimates and field reports. The interface has a friendly layout with an expandable/collapsible menu tree that, when activated, populates a neighbouring frame with the relevant template or information. An initial prototype of the interface was workshopped with eight prospective users and subsequently refined according to their comments.

The following input data is required by the system:

- Daily weather data downloaded from 24 automatic weather stations situated throughout the S.A. sugar industry.
- Soil: Plant available water capacity and plant available water of the root zone at the start of the crop.
- Crop: Cultivar, row spacing, plant or ratoon date and planned harvest date,
- Irrigation system: Type of system, irrigation cycle, net irrigation amount per application.

The system outputs daily values of cane yield and quality, crop and soil water status, canopy cover, cumulative water balance totals and irrigation advice. This data are used, via the interface, to produce reports that summarize data in numerical and graphical form at the irrigation scheme or field level. Output can be printed as hard copy or exported into Microsoft Excel for further analysis. Output data are also disseminated to farmers via SMS text messages (short message service on cellular network) whenever an action is required (for example to stop irrigating), and to extension and mill staff via facsimile on a weekly basis. Output options are summarized in Table 1.

The format and content of the various reports and advices were designed in accordance with users' preferences obtained during several workshops with all role-players.

The SMS irrigation advice to farmers comprises a suggestion to start or stop irrigation for their field, with an estimate of current and final cane yield. The fax summary of irrigation advice contains information, for each field in a given scheme, on the current irrigation action (irrigating or not), the expected date of the next action (stop or start), the expected date of the last irrigation, current cane yield and rainfall and irrigation totals to date.

Table 1. *MyCanesim* output.

Type	Content	Level	Primary user	Delivery method
Irrigation advice	Current and future yield, irrigation recommendation for a given field	Field	Farmer	SMS
Farm report	A summary of all fields on a farm/scheme in terms of the current water balance, and cane yield and quality at harvest	Scheme		Web
Field report	Comprehensive data containing values for each day of the season of the various water balance components, cane yield and cane quality.	Field		Web
Irrigation report	The date and amount of each irrigation event for the specified block, seasonal statistics	Field		Web
Rainfall report	The date and amount of each rainfall event for the specified gauge, seasonal statistics	Field		Web
Irrigation advice	Summary of current water balance and advice for all fields subscribed to irrigation advice service	Farm, Scheme	Extension	Web, Fax
Yield estimates	Summary of input parameters and final water balance and yield estimates	Farm, Scheme	Extension ,mill staff	Web, Fax

The system was demonstrated to a group of SASRI extension staff and researchers at a DSS workshop in October 2006. A survey conducted afterwards (Pers. comm., van den Berg, SASRI), showed a very favourable response to questions about the system's user friendliness. The average response to its usefulness as support tool for research and extension was neutral with a wide range of opinions. It was regarded as very useful for staff dealing with irrigation scheduling. A need for training was expressed.

System implementation

The system was implemented on two small-scale sugarcane irrigation schemes in northern Kwazulu-Natal, South Africa, namely Pongola (27°24'S, 31°35'E, 308m amsl) and Makhathini (27°24'S, 32°11'E, 69 amsl), with the main aim of assisting farmers with irrigation scheduling.

Pongola

The scheme consists of 47 farmers on 508 ha of land. Semi-permanent overhead systems are used, with an average irrigation cycle of 10 days and an effective application rate of 42 mm.

Discussion with role-players revealed that there was ample opportunity to save water (up to 25%) without jeopardizing yields (Singels & Smith, 2006). The main opportunity for savings were young crops with little canopy cover. The winter period also provided frequent opportunities for delaying the re-start of an irrigation cycle.

System performance was evaluated on selected farmers' fields. Irrigation, rainfall, soil wetting front depth, canopy cover, and stalk properties were recorded with the help of farmers and extension, to verify that the crop model performed reliably. The participants' response to advice was also monitored and discussed with them. Four farmers were monitored in 2004/05, and this group was expanded to eight in 2005/06. Final yield and water balance data are shown in Table 2. Mthembu achieved an acceptable yield but the high water use could be reduced substantially, especially early in the season. Simelane's low yield is due to a poor crop stand and a replant is recommended. The short stalk length recorded for Khumalo and Nene is an indication that yield could be improved by applying more water.

Table 2. Field recorded irrigation, stalk properties and cane yield for four Pongola farmers for the 2005/06 season. Irrigation amounts derived from water meter readings, simulated yield and yield derived from mill delivery data are also shown.

				Irrigation (mm)		Stalks		Cane yield (t/ha)		
Farmer	Harvest Date	Crop age	Rain (mm)	Metered	Sampled	Spop ($/m^2$)	Slen (cm)	My Canesim	Field sampled	Mill
Mthembu	28-Jun-06	397	511	1162	1479	16.7	234	114	167	126
Simelane.	1-Jul-06	322	495	844	877	9.3	222	81	116	72
Khumalo	20-Nov-06	370	645	681	616	14.3	175	99	95	93
Nene	13-Nov-06	370	602	667	827	12.8	161	111	70	79

More farmers were invited to subscribe to the service after proof of concept was established (May 2005). Uptake was positive and by April 2006, 35 farmers received advice from the system. It is believed that the credibility gained through the pilot evaluations in the first year, wide publicization and weekly interactions by extension and mill supply staff with farmers, contributed to the rapid uptake.

Makhathini

Here, 268 farmers grow sugarcane on approximately 3000 ha. Semi-permanent and portable overhead systems are used. The original design is for an irrigation cycle of 7 days and a net application of 35 mm. Actual irrigation cycles vary from 12 to 24 days due to the long-term decrease in the number of serviceable sprinklers.

The system was implemented and evaluated on four fields in 2005, similar to the method used in Pongola. Results suggest that the poorly maintained irrigation systems could only supply, on average, 50% of the crop demand of 1400mm and there was little opportunity for saving water. In fact, farmers should increase their applications to achieve economic yields. The impact of the inadequate systems on yield and income was quantified using the crop model. The average simulated yield for the four farmers was 92 t/ha compared to the average simulated potential of 145 t/ha. This information was discussed with participating farmers and other role-players. Lack of land ownership, lack of cash flow and a 12 hour per day water supply are severe limitations to correcting these problems.

Implementation problems

Irrigation advice is only relevant if farmers follow the advice, and that consequently there is a reasonable match between simulated and actual irrigation and water status. There are various good reasons for farmers not to follow the advice occasionally e.g. pump breakdowns, interruptions of water supply and a need to wash in top dressed fertilizer. The system was refined to accommodate a SMS reply from farmers when they could or would not follow advice. The system interprets the reply in the context of the advice sent and adjusts irrigation input data accordingly. This feature needs to be tested.

System evaluation also showed that the advised date of the last irrigation was too late, compared to the rule of Donaldson & Bezuidenhout (2000) on which it was based. Growers generally did not agree with the advice and dried off for at least 30 to 60 days. This discrepancy was due to a coding error, which was corrected. Another practical challenge was that the harvesting schedule was continually changed, at short notice, rendering drying off advice irrelevant. This was addressed by automatically reminding farmers and their agents by SMS to confirm harvest dates, 8 weeks prior to the last known date of harvest. In addition, weekly meetings were held between mill staff and harvesting contractors to obtain up to date harvest schedules.

Another practical problem was the frequent delay in getting advice out to farmers to stop irrigation after good rains. This was due to (1) a one day delay in post-midnight rainfall data entering the database, or to (2) system downtime due to hardware failures (weather station, computer or cellular network problems) or weekend software crashes.

A challenge at Pongola was that that the majority of growers share pumps, and the associated costs, with one or two neighbours. When all members of a pump group were not subscribed to the service, or did not receive similar advice, it often created conflict and non-adherence of advice. The system was adjusted to allow for synchronization of advice for members of a pump group, when the development stage of the different fields was similar.

Internet and fax access proved problematic for role-players based in rural areas. The very low bandwidth Internet access (dial-up modem) makes it very difficult to use the system user interface efficiently. Internet access was not available in Makhathini. This can be addressed soon as high speed Internet access becomes more affordable. In both study areas, cell phone coverage and ownership were not limiting factors.

Extension

Through regular implementation and evaluation workshops, the project helped extension staff and farmers gain a much better understanding of the important factors that determined the crop water balance and how irrigation can be scheduled to impact positively on productivity and sustainability.

The various reports available from the system provides concrete information (albeit simulated) for extension staff to benchmark irrigation practices, growth and yield of individual fields. This provided a good basis for discussion with farmers during field visits to identify agronomic practices that limited yields such as poor crop stand, insufficient weed control, early cessation of irrigation because sprinklers stands were too short (at Makhathini), erratic movements of sprinklers and excessive sprinkler stand times.

Potential applications

Presently, advice from the system is largely based on weather data, which applies to relatively large areas but lacks some of the detail required for irrigation management at field level. The quality of advice could be improved if the system is integrated with real time electronic monitoring of resources at a field level. This will address the challenge of obtaining accurate feedback from farmers in time. A host of affordable electronic soil water sensors and rainfall gauges are available and could be linked to *MyCanesim* system through wireless data transmission. This data could be used as input to simulations or to reset the model.

The system provides information on cane yield, cane quality and crop water status. These parameters determine the readiness of a crop to be harvested and could therefore be used to assess the readiness of fields on a scheme, or on a farm, for harvesting. The schedule of harvesting could be adjusted to maximize sucrose production at a mill level (similar to Le Gal et al., 2004) or to accommodate other practical considerations.

Another potential application is to provide advice on fertilizer management, especially nitrogen (N). Required N fertilizer for maximum sucrose yield is determined by initial amounts of organic and inorganic N, leached N and N uptake by the crop. Leaching and crop uptake are primarily determined by weather conditions during the current season, while initial amounts are dependant on conditions during the previous season. It seems very feasible to include a simple N model, such as the one proposed by Yin and van Laar (2005), in the system to simulate soil and plant N content and to advise the best application strategy, according to the N management approach advocated by Thorburn et al (2004).

A project is under way to implement the system to provide advice to large-scale farmers. Although their situation and needs are different to that of small-scale farmers (e.g. multiple fields per farm and drip and centre pivot irrigation systems), the system has the capability to deal with it.

Conclusions

The study showed that there is no reason why sophisticated technology cannot be used to assist farmers in managing sugarcane production, but that it was important that the complexity of the technology should be hidden from the users.

Farmers and their agents have to be involved early on in the implementation so that the system could be customised to the preferences of the users. This gives the different role-players some sense of ownership.

The project further highlighted the need for continued and regular face-to-face interaction with farmers to maintain enthusiasm, to clarify the rationale for certain types of advice and to discuss apparent poor agronomic practices. The projects succeeded in focussing the farmers' and extension staff's minds on the water balance of crops and how this impacted profitability.

The system shows great potential to be used as tool to support extension staff to provide assistance to small and large scale farmers.

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