IRRIGATION GUIDELINES FOR ANNUAL RYEGRASS PASTURE

Report to the

WATER RESEARCH COMMISSION

by

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executive summary

1. INTRODUCTION

Ideal pasture management is the production of economically optimum forage yield and quality without compromising the environment. Accurate irrigation scheduling plays an important role in deciding the income of a dairy enterprise by affecting yield and quality; irrigation input and energy usage; and environmental pollution. Improved knowledge of irrigation timing and amount can also be of great value in scheduling other cultural operations.

The current irrigation guideline of most temperate grasses including ryegrass is 25 mm of irrigation water per week regardless of season or region. Evaporative demand obviously differs between locations and over time for a specific location, and as crop canopy cover varies, therefore a rigid guideline of 25 mm per week will lead to over or under irrigation. There is clearly a need to determine irrigation requirements of ryegrass by developing site specific irrigation calendars which are simple guidelines or charts that indicate when and how much to irrigate. Calendar based irrigation scheduling provides irrigators with an inexpensive and convenient strategy to estimate irrigation timing and amount. The irrigation requirements developed can be flexible by deducting measured rainfall since the last irrigation event.

Therefore, the objectives of this research were to determine water requirements of annual ryegrass through testing and evaluation of the model and develop generic guidelines for efficient irrigation management of grass pastures.

2. IRRIGATION SCHEDULING

The most important aspects of irrigation management are: 1) proper functioning of the irrigation system, 2) knowledge of crop water use and its sensitivity to water stress, and 3) proper measurement of rainfall and irrigation. The farmer can manage the soil water balance to his advantage by minimising wasteful losses such as runoff, evaporation and deep drainage. This will leave more water in the soil for crop water uptake which is regarded as a useful loss.

Atmospheric evaporative demand is the driving force for crop water use. Atmospheric demand depends on the prevailing weather conditions at any time in the growing season. Crop water requirements can, as a result of the weather, differ substantially between localities and different seasons for the same locality. Therefore, it should be clear that fixed recipes for irrigation management cannot be applied universally. Site specific irrigation management is necessary for each field, taking into account the factors mentioned above.

2.1. When and how much water to apply?

Plant water usage can be monitored or estimated using several soil, plant or atmospheric based scheduling methods. The irrigator can follow different strategies in making a decision on when and how much to irrigate. The timing can be based on three strategies; namely to irrigate at a fixed frequency (time interval), when a fixed amount (mm) is depleted or when a certain threshold depletion has been reached. After making the decision when to irrigate, the irrigation manager has the following three options in determining the irrigation amount:

refill the soil to field capacity, apply a leaching fraction or a deficit irrigation strategy.

2.2. Irrigation monitoring tools and approaches

Deciding when and how much to irrigate can be made with several approaches or tools. Most methods attempt to measure or estimate one or more components of the soil-plant-atmosphere system. In practice, soil or atmospheric methods are most often used for irrigation management.

2.2.1. Soil based approaches

Soil water content
The most popular soil water content measuring instruments currently used by irrigators are neutron and capacitance probes. These can be very useful to assist the irrigator in monitoring soil water response to current irrigation practices, and how to adjust irrigation amounts and frequencies through adaptive learning.

Soil water potential
Tensiometers and gypsum block sensors are the most popular instruments used for soil water potential measurements. The soil water potential gives an indication of when to irrigate, but does not give a direct indication of how much to irrigate. However, farmers can adapt the optimum management for their own site.

Depth of wetting
The FullStop® Wetting Front Detector (WFD) is a funnel shaped tool that is buried in the root zone and gives a signal to farmers when water reaches a specific depth in the soil. WFDs tell a farmer whether irrigation application was too little or too much. Soil solution can also be extracted from the detector using a syringe and be used for nutrient and salt measurement. WFDs can be very useful for irrigation management and through adaptive management the user can learn how to adjust irrigation amounts and frequencies.

2.2.2. Atmospheric demand

The atmospheric evaporative demand is the driving force for crop water use and depends on prevailing weather conditions. Atmospheric methods are useful to establish the upper limits of crop water use. Automatic weather stations are used to measure the weather variables for different localities. Then evaporative demand can be calculated from the weather data and can be for determining crop water use.

Irrigation calendars
Calendar based irrigation scheduling tools spell out for a farmer in advance when and how much to irrigate. These calendars are based on long-term measurements and modelling. Once developed the calendars require no further input from the developer. Calendars can be developed for different sites and soils to promote easy and ready adoption of improved irrigation management practices by farmers who do not have access to any irrigation scheduling tools.

Real time irrigation scheduling models
Computer models or programs are used to calculate crop growth and water use processes with mathematical equations. Mechanistic models take the supply of water from the soil-root system, the demand from the atmosphere and the crop canopy size into account to accurately calculate crop water use. Simulation models can, therefore, integrate the plant, soil and atmospheric systems to simulate plant water usage. User-friendly models can make accurate, high technology approaches to irrigation scheduling feasible on-farm. This approach can both reduce the costs and increase the benefits of irrigation scheduling.

3. THE SOIL WATER BALANCE (SWB) MODEL

SWB can estimate real-time crop water requirements (day-to-day water use during the growing season) and recommend the irrigation amount and date, based on the current crop water usage and set user preferences. If farmers do not have access to daily weather data, SWB can be used to develop site-specific irrigation calendars. In such instances the long-term temperature, as well as soil and management inputs for a specific locality are used to generate site-specific irrigation calendars for a season. The calendar, which recommends irrigation dates and amounts, can be printed out and used as a guide to manage irrigations. Calendar recommendations must be corrected by subtracting rainfall from recommended irrigation amounts if applicable.

3.1. Input

The model can be used by farmers or consultants to develop their own calendars with relatively few and simple inputs. The model requires input for crop, weather, soil and irrigation management. The minimum required inputs are discussed briefly.

3.1.1 Field/Crop input

Two types of crop models can be selected in the Field form. The Crop growth model is based on the calculation of dry matter partitioning to plant organs and leaf area. Crop specific input parameter data sets for the mechanistic growth model or FAO crop coefficient model are available in the model. Depending on circumstances, calendars for a single pasture can be easily developed with either model.

3.1.2 Weather input

The location and long-term weather data including minimum and maximum temperatures from a nearby weather station are the minimum inputs required. The model will then use daily average weather data for recommending irrigations.

3.1.3 Soil input

The model requires soil input parameters including soil depth, soil type and initial soil water content. Soil water content at field capacity and wilting point and bulk density can be estimated from soil texture.

Soil depth
Depth of soil can be determined by digging profile holes at representative sites in the field.

Soil type
Soil textural class or type can be determined by taking soil samples and conducting textural analyses in any soil laboratory. In the irrigator version of SWB, soils can be grouped as very light (coarse sand), light (sandy), medium (sandy clay loam) or heavy (clay).

Initial water content
Initial soil water content can either be set to dry (wilting point – WP), medium (moist) or wet (field capacity – FC).

3.1.4 Irrigation management

Irrigation management includes irrigation system, delivery rate, irrigation timing and refill options.

Irrigation timing
Irrigation timing can be based on three strategies; namely to irrigate at a fixed time interval, when a fixed amount is depleted or when a certain depletion level has been reached.

Refill option
For refill options, farmers can irrigate to the full point (field capacity), follow a form of deficit irrigation (leave room for rain) or apply water exceeding the storage capacity for leaching salts.

Irrigation system
A range of irrigation systems can be selected including furrow, sprinkler, pivot, micro and drip.

Delivery rate
This depends on the irrigation system:
Sprinkler: mm per hour
Pivot: application rate (at 100%) in mm and hours required for one revolution (at 100%)

3.2. Run options

In order to run the model, the start and end date of the simulation or the intended duration of the irrigation calendar to be developed needs to be specified.

3.3. Output/irrigation recommendations

The recommendation table includes: when the pasture should be irrigated, recommended water requirement in mm, a column to enter rain since previous irrigation in mm and a column to calculate recommended irrigation amount by subtracting rain from water requirement and a column to write comments

4. EXAMPLES OF IRRIGATION REQUIREMENTS

Site specific irrigation and monthly general calendars were developed by excluding rain, for two major milk producing areas of South Africa (Natal Midlands and Southern Cape).

Site specific irrigation calendars were developed using two soil types. These calendars are developed by excluding rainfall and irrigators can develop their own site and crop specific calendars using the user-friendly SWB model, for their own site specific soil and irrigation management conditions.

Monthly general irrigation intervals were developed for a deep, well drained and fertilised, medium textured soil. General irrigation intervals were developed by irrigating the ryegrass when 25 mm soil water was depleted so that 25 mm will be replenished (similar to farmers' recommendation but scheduling the timing according to long-term water requirement). These monthly calendars are very general but simple, and can be used in the absence of site specific irrigation calendars.

5. CONCLUSIONS AND RECOMMENDATIONS

The SWB model can be used by farmers or consultants to develop their own calendars with relatively few and simple inputs. The minimum inputs required for developing calendars are: 1) Weather station nearest to the farm; 2) soil textural class and 3) planting date and rooting depth; and 4) irrigation management including irrigation system, timing and refill options. Therefore, irrigators can follow different strategies for making a decision on when and how much to irrigate depending on particular situations. In this study the model was used for developing irrigation calendars using annual ryegrass as example.

In the absence of irrigation scheduling tools, irrigation calendars developed using a model, would be better than a rigid guideline of 25 mm a week. It needs to be stressed, however, that irrigation scheduling with the aid of real time modelling or measurements is better than calendars developed using a model. The model is available on the web and can be downloaded free of charge.

The mechanistic crop growth model cannot simulate mixed pasture which is commonly planted these days. Owing to differences in numbers, types and proportions of species in mixed pastures the use of an FAO approach would likely be a better option, until mixed pasture management is included in the model. However, for mixed pasture system in which ryegrass is the dominant species, the growth model could still be used. In the future, the model needs to be calibrated and tested for newly planted and already established pastures. Interfaces and code for perennial/established pastures are under development. Hence data sets are required to test and refine the model for the most common irrigated pastures.

contents

figures

tables

CHAPTER 1: INTRODUCTION

1.1 Background

With an increasing demand for food as human populations increase, there is a need to increase the productivity of each hectare of land for milk production to meet the increasing demand. Natural veld cannot fulfil this need, unless it is supplemented with irrigated and fertilised planted pastures. However, water availability is considered to be the main factor limiting pasture production in South Africa (Aucamp, 2000). 62% of South Africa's ground and surface water resources are used for irrigation (DWAF, 2004). This substantial amount of water assigned to irrigated agriculture is facing fierce completion as the water demand of industrial, domestic, municipal and other activities increase. Thus, farmers are facing pressures to decrease their share of water usage, while at the same time producing sufficient pasture to supply the milk demand of a growing population.

Unfortunately, knowing how much water to apply through irrigation and how often is no trivial matter. In addition, nutrient management, especially nitrogen, is inextricably linked to water management, as over-irrigation leaches valuable nitrates from the profile out of reach of the growing pasture. As energy, fertiliser and water costs increase and profit margins narrow, farmers realise the necessity of improved irrigation scheduling to obtain maximum yields for the lowest financial investment. Ideal pasture management is the production of economically optimum forage yield and quality without compromising the environment. Accurate irrigation scheduling plays an important role in deciding the income of a dairy enterprise by affecting yield and quality; irrigation input and energy usage; and environmental pollution. Improved knowledge of irrigation timing and amount can also be of great value in scheduling other cultural operations.

Irrigation technologies may be adapted for efficient and wiser use of limited water supplies. Irrigation scheduling is the main component of water management by which irrigators decide when and how much water to apply. Prudent irrigation scheduling can lead to increased profits without compromising the environment by increasing productive water use and by reducing run off, deep percolation below the root zone with nutrient leaching, and soil water evaporation (Reinders, 2010). Several irrigation scheduling techniques of varying sophistication based on soil, plant and atmospheric measurements are recommended worldwide to address the shortage of irrigation water and maximise yield (Stevens *et al.,* 2005). Farmers can optimise forage yield and quality by applying the right amount of water at the right time by selecting an appropriate irrigation technique. Direct on-farm measurement using various irrigation scheduling techniques (soil, plant or atmospheric) are the best ways to schedule irrigation. However, most South African farmers (about 72%) do not use objective irrigation scheduling methods; instead they rely on their past experience (Stevens *et al.,* 2005). The main reasons for South African farmers not using objective irrigation scheduling techniques are: 1) failure to appreciate the net benefit from irrigation scheduling and the lack of reliable user friendly irrigation scheduling techniques; 2) high cost of equipment; 3) information collecting and processing is time consuming; and 4) some of the equipment needs technical knowledge. Moreover, with

intensive pastures for rotational grazing management, the farm must be divided into plots or paddocks to facilitate efficient fodder flow for the animals throughout the season. Hence, all the paddocks may not be irrigated together; as a result, extra equipment may be required to be installed in different paddocks.

The current irrigation guidelines of most temperate grasses, including ryegrass, is 25 mm of irrigation water per week (Jones, 2006; Macdonald, 2006). Evaporative demand differs between locations and over time for a specific location, and as the crop canopy cover varies. Therefore, a rigid guideline of 25 mm per week will lead to over or under irrigation. There is clearly a need to determine irrigation requirements of ryegrass by developing site specific irrigation calendars which are simple guidelines or charts that indicate when and how much to irrigate. Calendar based irrigation scheduling provides irrigators with an inexpensive strategy to estimate irrigation timing and amount. The irrigation requirements developed can be flexible by subtracting measured rainfall since the last irrigation event.

1.2   Objectives

1. Determine water requirements of annual ryegrass through testing and evaluation of the model.
2. Extrapolate irrigation requirement estimates using the selected model.
3. Develop generic guidelines for efficient irrigation management of grass pastures (for both existing and planted pastures) with specific reference to ryegrass (and kikuyu) and addressing irrigation strategies and pasture management.

1.3   Approach

The model was first calibrated and validated with measured datasets. After satisfactory results the model was used for developing site specific irrigation calendars of pastures for selected sites and soil types using ryegrass as example.

CHAPTER 2: IRRIGATION SCHEDULING

The most important aspects of irrigation management are: 1) proper functioning of the irrigation system, e.g. uniform water application and the actual irrigation amount must match the amount the irrigator intended to apply; 2) knowledge of crop water use and its sensitivity to water stress; and 3) proper measurement of actual amounts of each rainfall and irrigation event.

The farmer can manage the soil water balance to his advantage by minimising wasteful losses such as runoff, evaporation and deep drainage. This will leave more water in the soil for crop uptake which is regarded as a useful loss.

Irrigation scheduling is one of the most important management decisions on the irrigation farm. It is defined as when and how much water to apply. Farmers, to a large extent, are able to manage their water inputs. It is important to understand the different strategies that can be followed to ensure good soil water management including timing, amount and method of irrigation.

2.1 Factors affecting irrigation scheduling

Crops differ in sensitivity to water stress and their management will consequently differ. The crop growth stage also determines canopy size and rooting depth. Canopy size gives a good indication of potential crop water use. Less water is required early in the season when the canopy is still small. Early in the growing season the roots are still shallow and can only extract water from a small portion of the soil reservoir. Therefore, lesser amounts must be applied more frequently in order to avoid water stress. Water requirements increase as the crop grows and canopy size increases. As the crop reaches maturity and leaves start to senescence towards the end of the growing season, crop water use starts to decline gradually.

Soil type determines the plant available water capacity of the soil profile, in other words how much water a specific soil can hold for use by plants. Plant available water is mainly a function of soil texture and rooting depth. Sandy soils hold less water than loamy or clay soil.

Atmospheric evaporative demand is the driving force for crop water use (transpiration and evaporation). Atmospheric demand depends on the prevailing weather conditions at any time in the growing season. The important factors that play a role are temperature, wind speed, solar radiation and relative humidity. Crop water requirements can, as a result of the weather, differ substantially between localities and different seasons for the same locality.

Therefore, it should be clear that fixed recipes for irrigation management cannot be applied universally. Site specific irrigation management is necessary for each field, taking into account the factors mentioned above.

2.2   When to irrigate?

Plant water usage can be monitored or estimated using several soil, plant or atmospheric based scheduling methods. The irrigator can follow different strategies in making a decision on when and how much to irrigate. The timing can be based on three strategies; namely to irrigate at a fixed frequency (time interval), when a fixed amount (mm) is depleted or when a certain threshold depletion has been reached (Steyn and Annandale, 2008a).

- Irrigators sometimes use a fixed time interval between irrigations (e.g. every 7 days). Farmers who receive water allocations on specific days, like those participating in irrigation schemes usually follow this type of schedule.
- The fixed irrigation amount scheduling strategy is employed when the irrigator decides on a certain fixed depletion amount before irrigation is initiated. The fixed amount is usually based on practical on-farm limitations, such as the limited capability of the irrigation system, storage capacity of reservoirs, etc. Irrigation is initiated when the cumulative crop water usage reaches the fixed irrigation amount.
- When a fixed depletion level strategy is followed the crop is irrigated whenever a certain predetermined percentage of plant available water is depleted from the root zone.

2.3   How much water to apply?

After making the decision when to irrigate, the irrigation manager has the following three options when determining the irrigation amount: refill the soil to field capacity, apply a leaching fraction or a deficit irrigation strategy. Several site-specific considerations need to be taken into account when selecting a sensible refill strategy. The more important consideration here is to replenish crop water use, and the challenge now is to accurately estimate daily evapotranspiration. Before a refill strategy can be considered, an irrigator needs to have a basic but quantitative knowledge of the weather, crop, soil and irrigation system (Steyn and Annandale, 2008b). For example, how much water can the soil profile hold, and how full or empty is it? Are there salts in the profile that need to be leached? What is the application rate of my irrigation system, and how much water can be applied during each event (irrigation amount)? How fast is my crop using water? And finally, what are the chances of getting rain, and what is a reasonable amount to expect?

2.4   Irrigation monitoring tools and approaches

Several approaches can be followed or tools available to estimate crop water use can be used to assist the irrigator in the decision of when and how much to irrigate. Most methods attempt to measure or estimate one or more components of the soil-plant-atmosphere system. Irrigation scheduling methods are therefore plant, soil or atmosphere based. Preferably, a combination of more than one approach should be used. In practice, soil or atmospheric methods are most often used for irrigation management. With soil measurements, spatial variability within a field can be a major problem. Site selection for measurement or instrument installation is critical. Measurements should be made in areas that are representative of the field in terms of soil type, irrigation uniformity and plant growth. Proper site selection for measurement position, correct installation and maintenance are important to ensure reliable measurements. Some of the most popular irrigation scheduling methods and equipment are discussed briefly.

2.4.1 Soil based approaches

Soil water content

The most popular soil water content measuring instruments currently used by irrigators are neutron and capacitance probes (Figure 1). These can be very useful to assist the irrigator in monitoring soil water response to current irrigation practices, and how to adjust irrigation amounts and frequencies through adaptive learning. However, if accurate soil water contents are required to enable more precise irrigation deficit calculations, site specific calibration of the instrument is needed.

Figure 1   A neutron water meter (left) and Diviner 2000 capacitance probe (right) for measuring soil water content

Soil water potential

Tensiometers and gypsum block sensors (Figure 2) are the most popular instruments used for soil water potential measurements. These tools give an indication of how difficult it is for plants to take up water from the soil and thus, indirectly, the amount of water in the soil. The soil water potential gives an indication of when to irrigate, but does not give a direct indication of how much to irrigate. However, farmers can adapt the optimum management for their own site.

Figure 2   Tensiometer consisting of ceramic cup (left) and gypsum block type sensor (right) for the measurement of soil matric potential

Depth of wetting

The FullStop® Wetting Front Detector (WFD) is a simple user-friendly device designed to help farmers with irrigation management (Figure 3). It is a funnel shaped tool that is buried in the root zone and gives a signal to farmers when water reaches a specific depth in the soil (Stirzaker, 2003). Wetting front detectors are usually used in pairs. The first is buried about one third of the way down the active root-zone. The second is buried about two thirds the depth of the active root-zone. Wetting front detectors will tell a farmer whether irrigation application was too little or too much. The indicator is the part of the WFD that is visible above ground. If the indicator is up then a wetting front has passed the buried funnel. If the indicator is down then it means that not enough water was applied to produce a wetting front which the WFD could detect. It does not tell the farmer when to irrigate, however, it can help with how much water to apply. Soil solution can also be extracted from the detector using a syringe and used for nutrient and salt measurement. Wetting front detectors can be very useful for irrigation management and through adaptive management the user can learn how to adjust irrigation amounts and frequencies.

Figure 3   Wetting front detector (WFD) for managing irrigation and nutrients

2.4.2   Atmospheric demand

Empirical crop factor

The atmospheric evaporative demand is the driving force for crop water use (ETc) and depends on prevailing weather conditions. Atmospheric methods are useful to establish the upper limits of crop water use. This means that crop water use cannot be higher than the atmospheric evaporative demand dictates. Evaporative demand will be higher on hot, sunny, dry and windy days than when conditions are overcast and still. It should, therefore, be clear that crop water requirements can differ substantially from day to day and from one locality to another depending on the weather. Automatic weather stations are used to measure the weather variables for different localities. When these variables are measured, reference evaporative demand (in mm of water per day) can be calculated with the Penman Monteith equation (ETo). The ETo in combination with water use can be used for determining crop factors (Kc) for a particular crop. Water use can be calculated by multiplying reference crop evaporation with an empirical crop factor as: ETc = ETo * Kc.

Irrigation calendars

Calendar based irrigation scheduling tools spell out for a farmer in advance when and how much to irrigate. These calendars are based on long-term measurements or are developed using crop models. Once developed, the calendars require no further input from the developer. Calendars can be developed for different sites and soils to promote easy and ready adoption of improved irrigation management practices by farmers who do not have access to any irrigation scheduling tools.

Real time irrigation scheduling models

Computer simulation models have become increasingly popular during the past few decades as computers and automatic weather stations have become more readily available and affordable. Computer models or programs are used to calculate crop growth and water use processes with mathematical equations. Mechanistic models take the supply of water from the soil-root system, the demand from the atmosphere and the crop canopy size into account to accurately calculate crop water use. Crop growth and development are simulated from temperature data, while atmospheric demand is calculated from measured weather data as described above. Simulation models can, therefore, integrate the plant, soil and atmospheric systems to simulate plant water usage. Mechanistic models have previously been inaccessible to irrigators because they required great skill to run. Today, however, user-friendly models can make accurate, high technology approaches to irrigation scheduling feasible on-farm. This approach can both reduce the costs and increase the benefits of irrigation scheduling.

CHAPTER 3: THE SOIL WATER BALANCE (SWB) MODEL

SWB is a mechanistic, real-time, generic, crop growth, soil water balance and irrigation scheduling model, which has a user-friendly interface (Annandale *et al.,* 1999). It was developed based on the NEWSWB model by Campbell and Diaz (1988). Simulations can be done with two approaches: 1) an FAO based model that calculates canopy cover using empirical crop factors and 2) a more mechanistic simulation of crop growth. The FAO approach simulates crop water use and growth relatively simply using crop coefficients for various growth stages (Jovanovic and Annandale, 1999). On the other hand, the crop growth model simulates dry matter production more mechanistically. The mechanistic crop growth model has the capability to simulate the effect of water stress on canopy size (Jovanovic and Annandale, 2000), which cannot be done by the simple FAO approach. However, this requires more detailed crop specific model parameters.

SWB estimates crop growth and water balance fluxes and storage using weather, soil and crop units. A detailed description is available in Annandale *et al.* (1999). The weather unit of SWB calculates Penman-Monteith grass reference daily evapotranspiration (ETo) according to FAO 56 recommendations (Allen *et al.,* 1998). Water movement in the soil profile is simulated using a cascading or finite difference approach.

In the Soil Unit of SWB, potential evapotranspiration is divided into potential evaporation and potential transpiration by calculating canopy radiant interception from simulated leaf area. This represents the upper limits of evaporation and transpiration and these processes will only proceed at these rates if atmospheric demand is limiting. Supply of water to the soil surface or plant root system may, however, be limiting. This is simulated in the case of soil water evaporation, by relating evaporation rate to the water content of the surface soil layer. In the case of transpiration, a dimensionless solution to the water potential based water uptake equation is used. This procedure gives rise to a root density weighted average soil water potential, which characterizes the water supply capabilities of the soil-root system. This solution has been shown to work extremely well (Annandale et al., 2000). If actual transpiration is less than potential transpiration, the crop has undergone stress and leaf area expansion will be reduced if the crop is still in the vegetative phase of growth. In other words, there is feedback between the crop and the soil in SWB.

In the crop unit, SWB calculates a daily dry matter increment as either being radiation or water limited. SWB estimates phenological development, growth and yield of a crop from emergence to maturity based on soil water status and environmental conditions. Transpiration is assumed to be equal to crop water uptake, which is a function of soil water potential, leaf water potential and root conductance. The use of thermal time in the more mechanistic growth model negates the need to specify length of developmental stages as crop factors modelling approach to express crop development, which varies for different planting dates and regions (Olivier and Annandale, 1998). Hence in the growth model, water-limited growth is calculated using parameters that directly limit biomass accumulation including a crop stress index and leaf water potential (Annandale *et al.,* 2000). In addition, the growth model enables an accurate description of deficit irrigation strategies, where water use is supply limited (Annandale *et al.,* 1999).

SWB can estimate real-time crop water requirements and recommend the irrigation amount and date, based on the current crop water usage and set user preferences. If farmers do not have access to irrigation monitoring tools, SWB can be used to develop site-specific irrigation calendars. The calendar, which recommends irrigation dates and amounts, can be printed out and used as a guide to manage irrigations. Calendar recommendations must be corrected by subtracting rainfall from recommended irrigation amounts if applicable.

The model has three versions: 1) Irrigator or farmer version used by farmers to develop irrigation calendars, 2) Consultant version is applicable for those who want to use their own user defined inputs (e.g. different soils in different layers) and/or simulate and display crop growth and soil water balance components, and 3) Researcher version used by researchers for complex simulations pertaining to specific research questions. In this report the simple irrigator vision is used to develop irrigation calendars.

The irrigation calendar screen of the irrigator version of the SWB model includes, insert new calendar, edit calendar, generate calendar, view calendar and delete calendar (Figure 4).
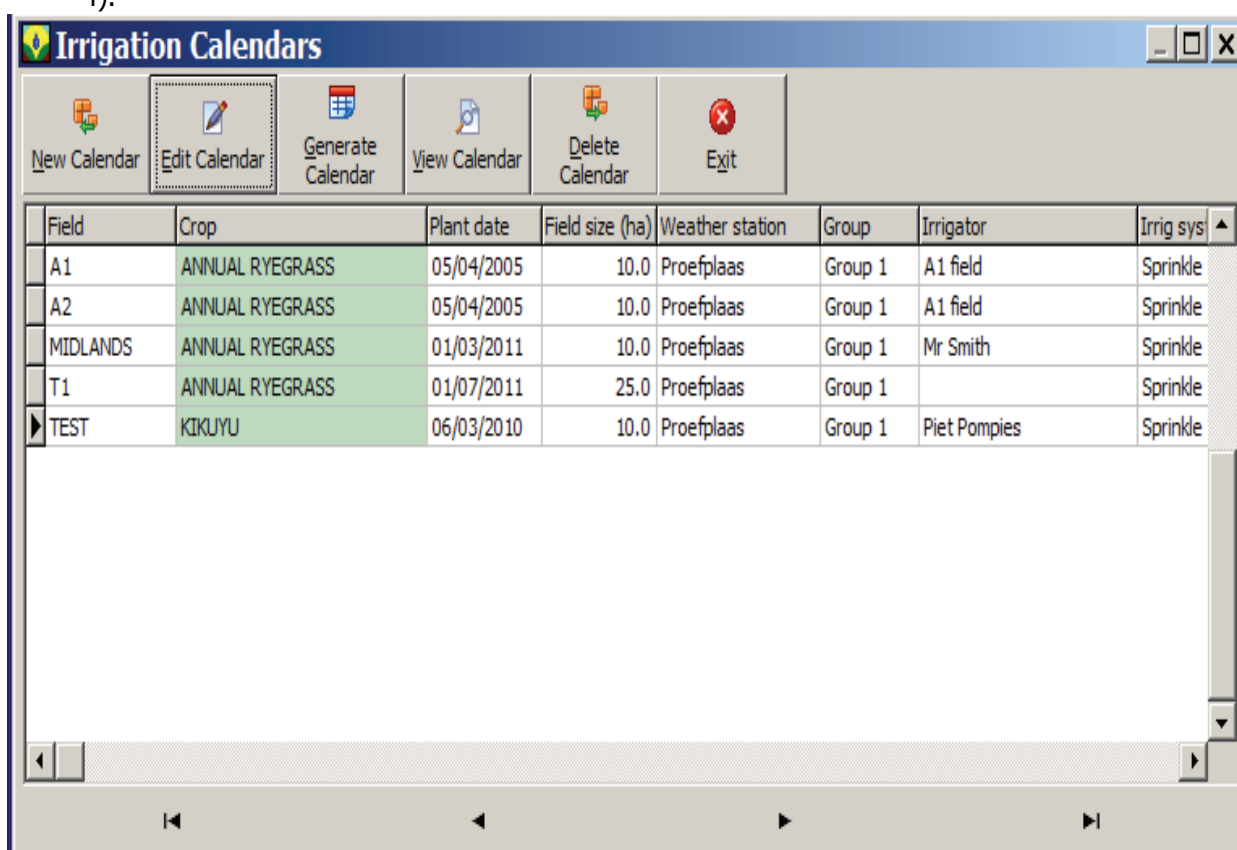
Figure 4   SWB model opening screen showing user-friendly interface

3.1   Input

The model can be used by farmers or consultants to develop their own calendars with relatively few and simple inputs. The model requires input for crop, weather, soil and irrigation management. The minimum required inputs presented in Figure 5 are discussed briefly.

Figure 5   Input screen of the SWB irrigator version model

3.1.1   Field/Crop input

Two types of crop models can be selected in the Field form. The Crop growth model is based on the calculation of dry matter partitioning to plant organs and leaf area. Crop specific input parameter data sets for the mechanistic growth model or FAO crop coefficient model are available in the model. Depending on circumstances, calendars for a single pasture can be easily developed with either model. If crop growth model parameters are not available for a specific crop, the FAO model, based on FAO Kcb basal crop coefficients, may be selected. The model does not simulate growth and water use for mixed pastures. However, for ryegrass dominated pastures, similar water use can be expected to ryegrass, because the canopy cover is similar.

3.1.2   Weather input

The location and long-term weather data including minimum and maximum or mean temperatures from a nearby weather station are the minimum inputs required. The model will then use daily average weather data for recommending irrigations. If available, using other weather input parameters like solar radiation, relative humidity or vapour pressure deficit and wind speed will improve accuracy.

3.1.3 Soil input

The model requires soil input parameters including soil depth, soil type and initial soil water content. Soil water content at field capacity and wilting point and bulk density can be estimated from soil texture.

Soil depth
Depth of soil can be determined by digging profile holes at representative sites in the field.

Soil type
Soil textural class or type can be determined by taking soil samples and conducting textural analyses in any soil laboratory. In the irrigator version of SWB, soils can be grouped as very light (coarse sand), light (sandy), medium (sandy clay loam) or heavy (clay) soils.

Initial water content
Initial soil water content can either be set to dry (wilting point – WP), medium (moist) or wet (field capacity – FC).

3.1.4 Irrigation management

Irrigation management includes irrigation system, delivery rate, irrigation timing and refill options.

Irrigation timing
Irrigation timing can be based on three strategies; namely to irrigate at a fixed time interval, when a fixed amount is depleted or when a certain depletion level has been reached. For example: a) Farmers who receive water allocations on specific days (such as those participating in irrigation schemes), often follow fixed time schedules (eg. irrigate every 7 days). b) Farmers use fixed irrigation amount due to practical on-farm limitations (such as the limited capability of the irrigation system, storage capacity of reservoirs, etc) and usually initiate irrigation when soil deficit reaches a fixed threshold. c) Farmers could also prefer variable timing and amount to avoid crop water stress (depletion level strategy whenever a certain predetermined percentage of plant available water is depleted from the root zone).

Refill option
Several site-specific considerations need to be taken into account when selecting a sensible refill strategy. Such as: How fast is my crop using water? What are the chances of getting rain? What is a reasonable amount to expect? Are there salts in the profile that need to be leached? For refill options, farmers can irrigate to the full point (field capacity), follow a form of deficit irrigation (leave room for rain) or apply water exceeding the storage capacity for leaching salts.

Irrigation system
A range of irrigation systems can be selected including furrow, sprinkler, pivot, micro and drip.

Delivery rate

This depends on the irrigation system:

Sprinkler: mm per hour

Pivot: application rate (at 100%) in mm and hours required for one revolution (at 100%)

3.2   Run options (Generate calendars)

In order to run the model, the start and end date of the simulation or the intended duration of the irrigation calendars to be developed needs to be specified (Figure 6).
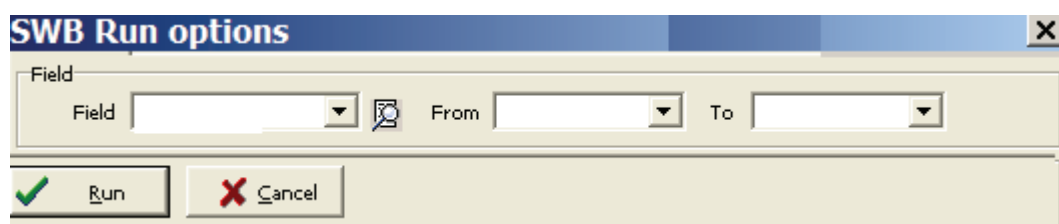
Figure 6   SWB run options screen of the irrigator version

3.3 Output/irrigation recommendations

The recommendation table includes details of the irrigator, crop type, farm location, planting date, weather station, irrigation system and irrigation management (timing and refill options) used (Figure 7). The table has the following four columns:

1. A column when the pasture should be irrigated 'date and day'
2. A column of recommended water requirement in mm.
3. A column to enter rain since previous irrigation in mm
4. A column to calculate recommended irrigation amount by subtracting rain (if more than 3 mm) from water requirement
5. A column to write comments

Figure 7   Irrigation calendar recommendation output

CHAPTER 4: EXAMPLES OF IRRIGATION REQUIREMENTS FOR PASTURE GROWING AREAS

4.1   Site description

Two major milk producing areas of South Africa including the Natal Midlands and Southern Cape were selected (Figure 8). Cedara was selected as a representative weather station for the Natal Midlands and George for Southern Cape.
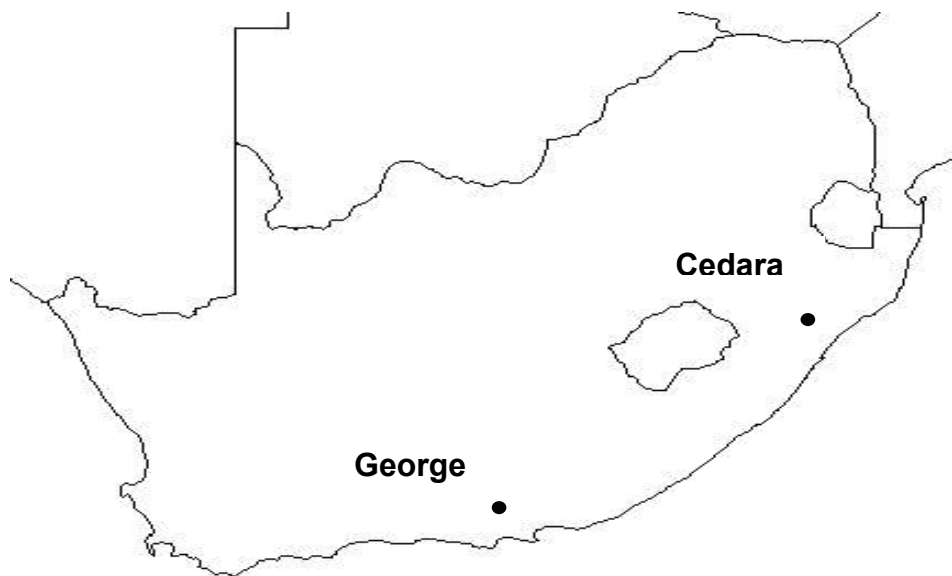
Figure 8   Main ryegrass growing areas of South Africa used in the study

The sites show seasonal variations in rainfall and reference evapotranspiration (ETo) (Figure 9). Long-term (50 years) rainfall and ETo for the two major milk producing areas of South Africa. ETo was calculated according to FAO 56 (Allen *et al.,* 1998) from weather data (including minimum and maximum temperatures).
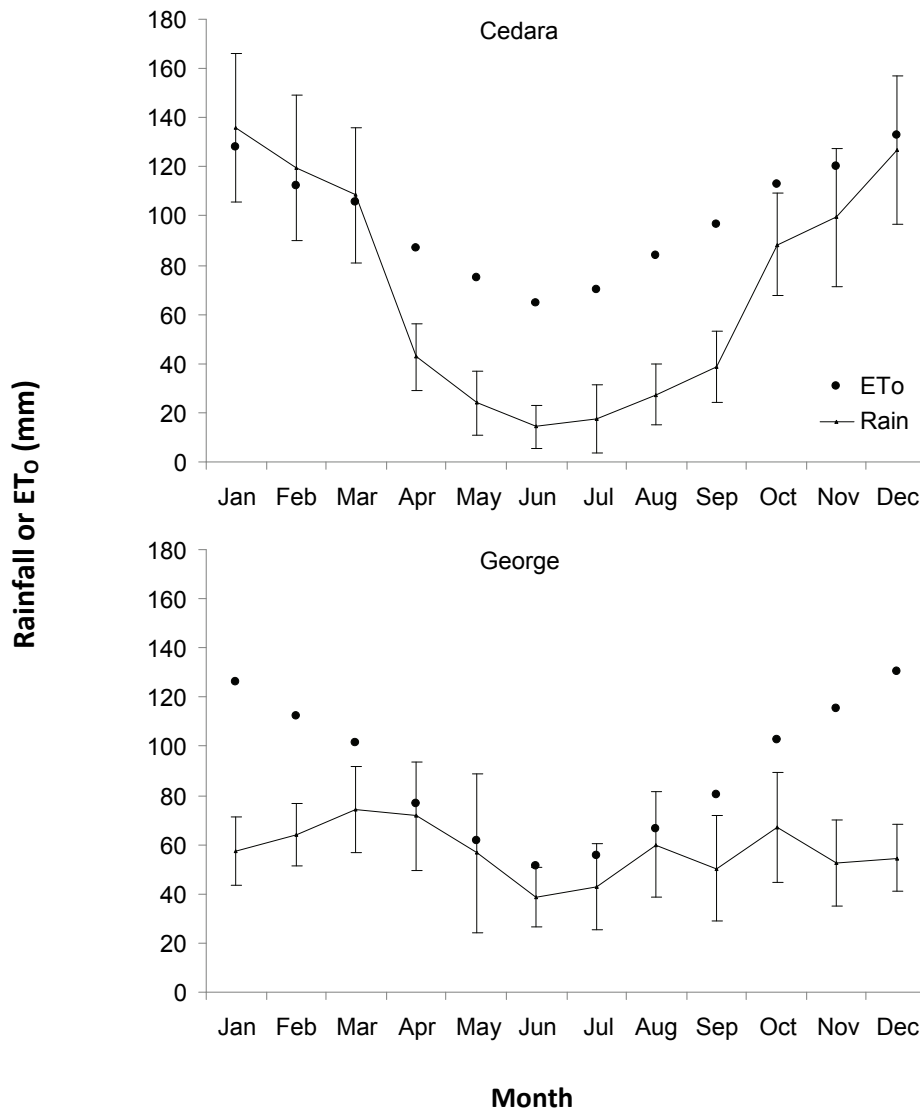
Figure 9   Monthly long-term means (1950-2000) of reference evapotranspiration (ETo) and precipitation in two ryegrass growing areas (vertical bars are standard deviation)

4.2   Methodologies used for developing irrigation calendars

Irrigation calendars were developed using the daily mean long-term weather data. Site specific irrigation and monthly general calendars were developed by excluding rain as examples, to illustrate how farmers can develop their own crop and site specific calendars. Site specific irrigation calendars were developed for two major milk producing areas of South Africa.

4.2.1   Input

4.2.1.1   Crop input

Crop
Annul ryegrass was used because it is one of the most widely irrigated planted pastures in South Africa.

Model
The crop growth model of SWB was used because crop specific input parameters of annual ryegrass were developed from experiments and used for calibration and validation of the model and used to run the simulations.

Planting date
Common management and cultivation practices used by farmers were applied. Annual ryegrass planting date is between mid-February and mid-April each year. Ryegrass seedlings are very sensitive to heat and may die if sown too early during periods of high temperature, while forage yield in the winter may be reduced significantly if planting is too late.

4.2.1.2   Soil input

Soil depth
The maximum soil depth was set to 0.4 m because most pastures are planted on marginal soils.

Soil type
Site specific irrigation calendars were developed for two major milk producing areas of South Africa for sandy loam (medium water holding capacity) and clay (high water holding capacity) soil types. For monthly general calendars, as opposed to site specific a deep, well drained and fertilised, medium textured soil was used.

Initial water content
The initial soil water content at planting was set to field capacity. This assumption was made because planting was at the end of the rainy season and it is usually safe to assume the soil profile is wet. This can also be supported from high rainfall typically received during February (Figure 9).

4.2.1.3   Weather input
Long-term historical weather data (1950 to 2000) including minimum and maximum temperatures of representative sites were used for estimating water requirements and irrigation calendars.

4.2.1.4   Irrigation management
For site specific irrigation annual ryegrass was assumed to be irrigated when 50% of plant available water was depleted which was equivalent to 21 mm for sandy loam and 28 mm for clay loam. Monthly general irrigation calendars were also developed for a deep, well

drained and fertilised, medium textured soil using a common farmers' irrigation application amount of 25 mm per irrigation, but by scheduling the timing according to long-term water requirement.

4.2.2   Run options

Simulations were preformed from 1st March to 6th November (eight harvests). The first defoliation was simulated 60 days after planting and after this first harvest, the pasture was defoliated at four week intervals in autumn and winter and three week intervals in spring.

4.3   Results and discussion

4.3.1   Site specific irrigation calendars

Site specific irrigation calendars developed for two major milk producing areas of South Africa mainly the KwaZulu-Natal Midlands and Southern Cape using two soil types are presented in Table 1. These calendars are developed by excluding rainfall and irrigators can develop their own site and crop specific calendars using the user-friendly SWB model, for their own site specific soil and irrigation management conditions.

Table 1 Simulated irrigation calendars for sandy loam and clay loam soils for the Natal Midlands and Southern Cape ryegrass growing areas of South Africa

Irrigation Events	Midlands				S- Cape			
	Sandy loam		Clay loam		Sandy loam		Clay loam	
	Date	mm	Date	mm	Date	mm	Date	mm
1	07-Apr	23	09-Apr	29	07-Apr	22	09-Apr	29
2	14-Apr	23	18-Apr	31	15-Apr	23	19-Apr	30
3	20-Apr	22	26-Apr	29	23-Apr	24	29-Apr	29
4	27-Apr	25	05-May	28	01-May	23	14-May	29
5	04-May	22	16-May	29	14-May	23	27-May	30
6	13-May	22	26-May	31	24-May	23	13-Jun	29
7	21-May	24	06-Jun	28	03-Jun	22	28-Jun	29
8	29-May	24	19-Jun	29	18-Jun	23	17-Jul	29
9	09-Jun	22	30-Jun	31	29-Jun	22	30-Jul	29
10	19-Jun	23	15-Jul	29	15-Jul	22	15-Aug	29
11	27-Jun	22	25-Jul	29	26-Jul	23	26-Aug	30
12	08-Jul	23	03-Aug	28	06-Aug	22	06-Sep	28
13	18-Jul	23	15-Aug	30	17-Aug	23	16-Sep	29
14	26-Jul	24	24-Aug	32	25-Aug	22	24-Sep	28
15	02-Aug	23	01-Sep	29	02-Sep	22	04-Oct	29
16	12-Aug	23	11-Sep	29	12-Sep	23		
17	19-Aug	23	18-Sep	29	19-Sep	23		
18	26-Aug	25	25-Sep	30	26-Sep	22		
19	01-Sep	22	04-Oct	31	04-Oct	24		
20	10-Sep	24						
21	16-Sep	24						
22	22-Sep	26						
23	30-Sep	23						
24	06-Oct	25						

4.3.2 General irrigation calendars (guidelines)

Water requirements (water use) were estimated for 50 years and calendars were developed using the daily mean of the long-term weather data. Daily average water use of ryegrass for two major milk producing areas of South Africa is simulated using the SWB growth model and is presented in Figure 10. Model simulations showed variation in water use of ryegrass between years. Daily water use ranged from an average of 1.5 mm in winter (June) to 5.5 mm in summer (November). Long-term water use of ryegrass in the Southern Cape was relatively lower than in the Midlands because of a lower vapour pressure deficit in the Cape.
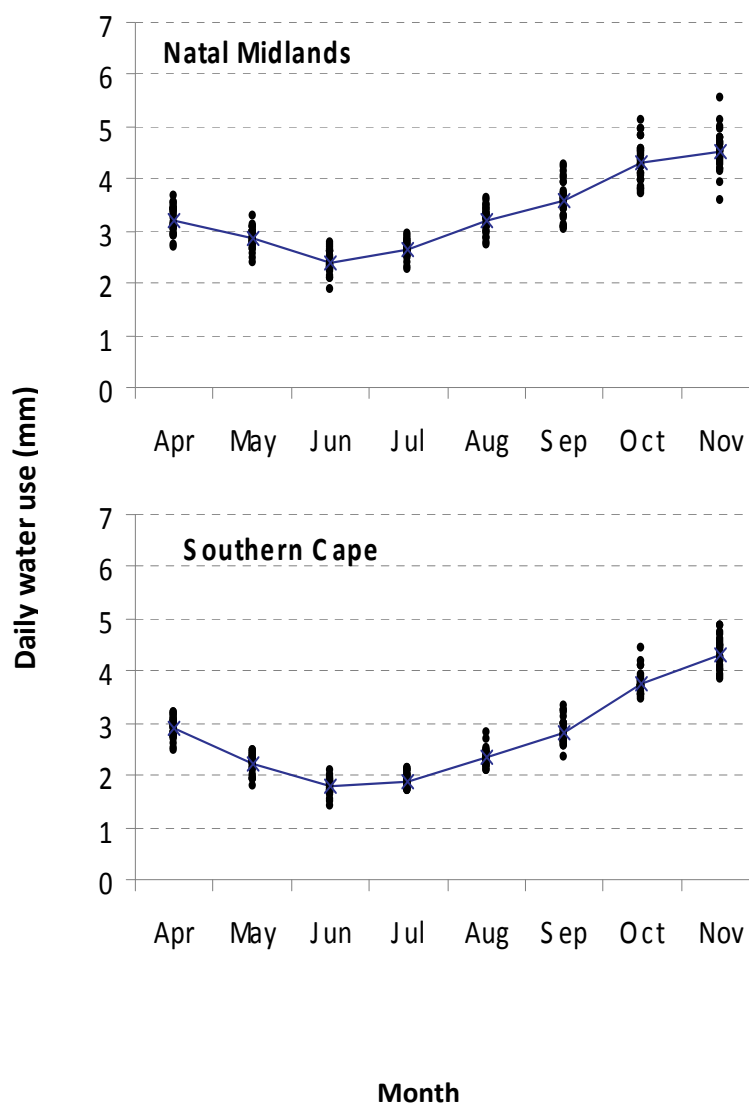
Figure 10 Simulated mean long-term daily water use of ryegrass for major milk producing areas of South Africa (KwaZulu-Natal Midlands and Southern Cape). Points show individual season simulated water use.

Monthly irrigation calendars developed for a deep, well drained, medium textured soil (using the current guideline application rate of 25 mm irrigation event) for major milk producing areas of South Africa are presented in Figure 11. These monthly calendars are general (because they are same for all soil types and only weather is considered) but simple and can be used in the absence of site specific irrigation calendars.
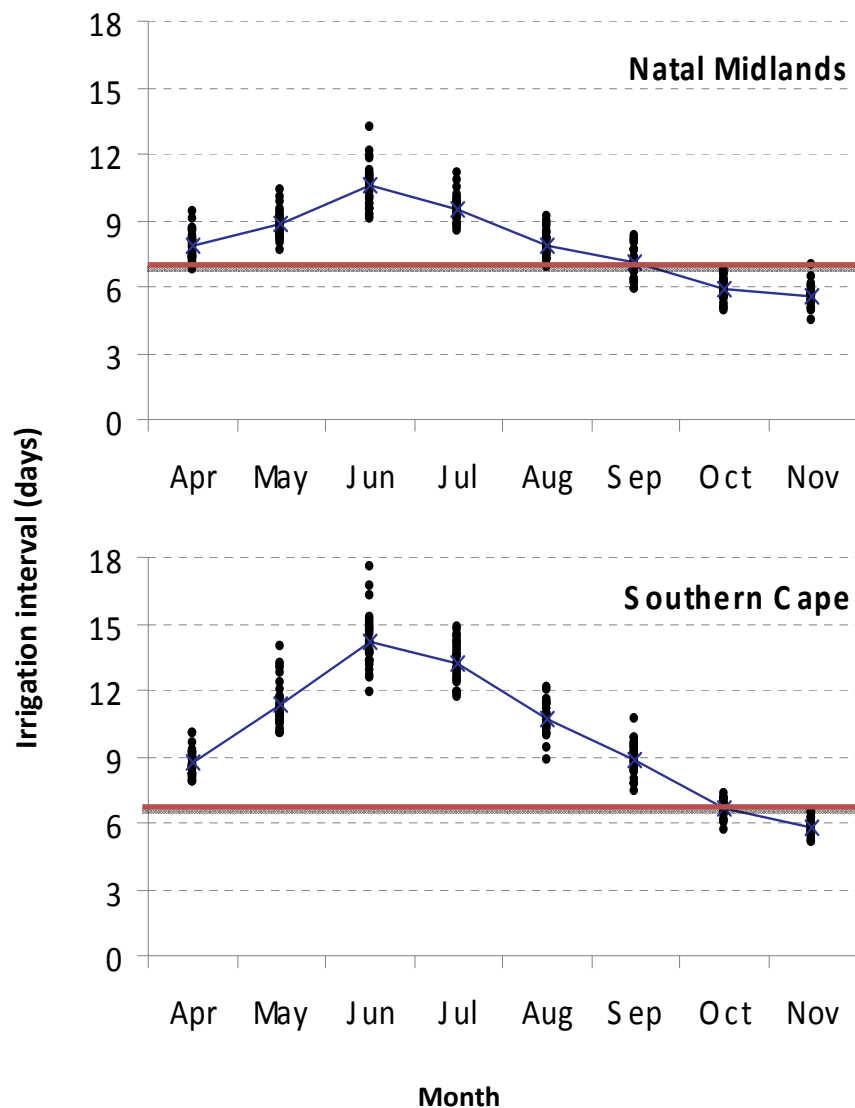
Figure 11 Examples of monthly recommended irrigation intervals (25 mm per event) for milk producing areas of South Africa compared to common farmers practice 25 mm per week. Points show long-term irrigation intervals). Horizontal red line shows common farmers practice of 25 mm per week.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Irrigation calendars can be developed either with the mechanistic crop growth or FAO approaches of the SWB model. Examples of irrigation calendars generated for specific sites by omitting rainfall for different regions and soil types using ryegrass as example are presented in this report.

The minimum inputs required for developing calendars are: 1) Weather station the nearest farm; 2) soil depth and textural class and 3) irrigation management including irrigation system, timing and refill options.

If available, accurate site specific measurements using soil water sensors that represent the whole field could be preferable over model predicted irrigation requirements. In the absence of such measuring devices, site specific calendars can be developed without considering rainfall using the SWB crop growth model. These calendars should be modified when rain falls by subtracting rainfall from the recommended irrigation amount.

These calendars can also be supported with the help of some simple irrigation scheduling tools such as the wetting front detector (WFD). A WFD informs the irrigator when the required wetting depth has been reached, but it does not tell one when to irrigate (Stirzaker, 2003; Geremew, 2008). Therefore, combining the calendars (when to irrigate) and using a WFD (when to stop irrigation) can be more beneficial than using calendars developed using a model alone. However, these calendars, with or without correction, are clearly superior to the common 'recipe' of 25 mm per week.

The model can be used by farmers or consultants to develop their own calendars with relatively few and simple inputs. Therefore, irrigators can follow different strategies for making a decision on when and how much to irrigate depending on particular situations. In this study the model was used for predicting water requirements and develops irrigation calendars using annual ryegrass as example. The model is available on the web and can be downloaded free of charge.

5.2 Recommendations for future research

The mechanistic crop growth model cannot simulate mixed pasture which commonly planted these days. Owing to differences in numbers, types and proportions of species, in mixed pasture the use of an FAO approach would likely be a better option, until mixed pasture management is included in the model. However, for mixed pasture system in which ryegrass is the dominant species the growth model could still be used. In the future, the model needs to be calibrated and tested for newly planted and already established pastures. Interfaces and code for perennial/established pastures are under development. Hence data sets are required to test and refine the model for the most common irrigated pastures.

REFERENCES

ALLEN RG, PEREIRA LS, RAES D and SMITH M (1998) Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56. FAO, Rome, Italy.

ANNANDALE JG, BENADE N, JOVANOVIC NZ, STEYN JM and DU SAUTOY N (1999) Facilitating irrigation scheduling by means of the soil water balance model. Pretoria, South Africa. WRC Report No. 753/1/99.

ANNANDALE JG, CAMPBELL GS, OLIVIER FC and JOVANOVIC NZ (2000) Predicting crop water uptake under full and deficit irrigation. An example using pea (*Pisum sativum* cv. Puget). *Irrigation Science,* 19:65-72.

AUCAMP AJ (2000) The place and role of cultivated pastures in South Africa. In Pasture Management in South Africa (ed. N. Tainton). University of Natal Press, Pietermaritzburg.

CAMPBELL GS and DIAZ R (1988) Simplified soil water balance models to predict crop transpiration. In Drought Research Priorities for the Dryland Tropics (eds. F.R. Bidinger & C. Johansen). ICRISAT, India. 15-26.

DWAF (2004) DWAF's framework and Checklist for the Development of Water Services Development Plans. Department of Water Affairs and Forestry, Pretoria, South Africa.

GEREMEW EB, STEYN JM and ANNANDALE JG (2008) Comparison between traditional and scientific irrigation scheduling practices for furrow irrigated potatoes (*Solanum tuberosum* L.) in Ethiopia. *South African Journal of Plant and Soil,* 25:42-48.

JOVANOVIC NZ and ANNANDALE JG (2000) Crop growth model parameters of 19 summer vegetable cultivars for use in mechanistic irrigation scheduling models. *Water SA* 26:67-76.

JOVANOVIC NZ, ANNANDALE JG and MHLAULI NC (1999) Field water balance and SWB parameter determination of six winter vegetable species. *Water SA*, 25:191-196.

OLIVIER FC and ANNANDALE JG (1998) Thermal time requirements for the development of green pea (*Pisum sativum* L.). *Field Crops Research,* 56:301-307.

MACDONALD CI (2010) Irrigation of pastures. Cedara Agricultural Development Institute available online

<http://agriculture.kzntl.gov.za/portal/AgricPublications/ProductionGuidelines/PasturesinKwaZuluNatal/IrrigationofPastures/tabid/313/Default.aspx>

REINDERS FB (2010) Standards and guidelines for improved efficiency of irrigation water use from dam wall release to root zone application. Water Research Commission Report No TT465/10, Pretoria, South Africa.

STEYN JM and ANNANDALE JG (2008a) Irrigation scheduling strategies: when to turn on the pump. Afgriland, July/August.

STEYN JM and ANNANDALE JG (2008b) Irrigation scheduling strategies: when to turn off the pump. Afgriland, Sep/Oct.

STEVENS JB, DUVEL GH, STEYN GJ and MAROBANE W (2005) The range, distribution and implementation of irrigation scheduling models and methods in South Africa. WRC report No. 1137/1/05.

TAINTON N (2000) Pasture Management in South Africa, University of Natal Press, South Africa.

APPENDIX A – HOW TO DOWNLOAD THE SWB SOFTWARE

The model can be installed on a computer that runs Windows 2000 or higher as operating system.

Step 1 Go to University of Pretoria, Department of Plant Production and Soil Science web site page

Step 2 Go **to** Water Group and then under Software click the instructions how to download

Step 3 If you do not have Firebird 1.5.5 or a later version on your computer it must be downloaded and installed first by selecting the "Firebird 1.5.5 (link)"

Step 4 Click on the SWBPro link and download the zipped file. Place the SWB.exe and WDB.exe files into a newly created folder (c:/Documents/SWBPro) and place the SWB.fdb and WDB.fdb files into a new 'data' folder (c:/Documents/SWBPro/Data).

Step 5 Open the SWB.exe program. Click on 'Database' on the toolbar and select 'Open SWB **database**…'. Navigate to the 'C:/Documents/SWBPro/Data' folder and select the 'SWB.fdb' file.

Step 6 Click on 'Database' followed by 'Select weather database…'. Navigate to the 'C:/**Documents**/SWBPro/Data' folder and select the 'WDB.fdb' file.

Step 7 Click on 'Database' again and select 'WDB.exe path:' navigate and click on the folder containing the WDB.exe file (C:/Documents/SWBPro).

APPENDIX B – EXAMPLE HOW TO DEVELOP SITE SPECIFIC IRRIGATION CALENDARS USING SWB – IRRIGATOR VERSION

1. Irrigation calendar screen

In the Irrigation Calendar screen of the Irrigator Version of the SWB model, new calendars can be created and generated; existing ones can be edited, viewed or deleted.

Field	Crop	Plant date	Field size (ha)	Weather station	Group	Irrigator	Irrig sys
A1	ANNUAL RYEGRASS	05/04/2005	10.0		Group 1	A1 field	Sprinkle
A2	ANNUAL RYEGRASS	05/04/2005	10.0		Group 1	A1 field	Sprinkle
MIDLANDS	ANNUAL RYEGRASS	01/03/2011	10.0		Group 1	Mr Smith	Sprinkle
T1	ANNUAL RYEGRASS	01/07/2011	25.0		Group 1		Sprinkle
TEST	KIKUYU	06/03/2010	10.0		Group 1	Piet Pompies	Sprinkle

Irrigation Calendars — New Calendar | Edit Calendar | Generate Calendar | View Calendar | Delete Calendar | Exit

2. Input screen

The input parameters are grouped into four categories, namely as Field, Soil, Weather and Irrigation management. Step by step procedures used to develop irrigation calendars are described below.

STEP 1 FIELD SECTION

a)   **Irrigator**: insert Irrigator (farmer) name, for example '**Mr Smith**'

b) **Field**: insert field name, for example '**MIDLANDS**'
c) **Field size (ha):** for example enter '**1.0**'
d) **Model**: click the drop down arrow and select, for example '**Growth**'
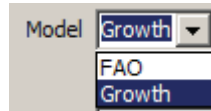
e) **Crop**: click the drop down arrow and select crop type, for example '**Annual ryegrass**'
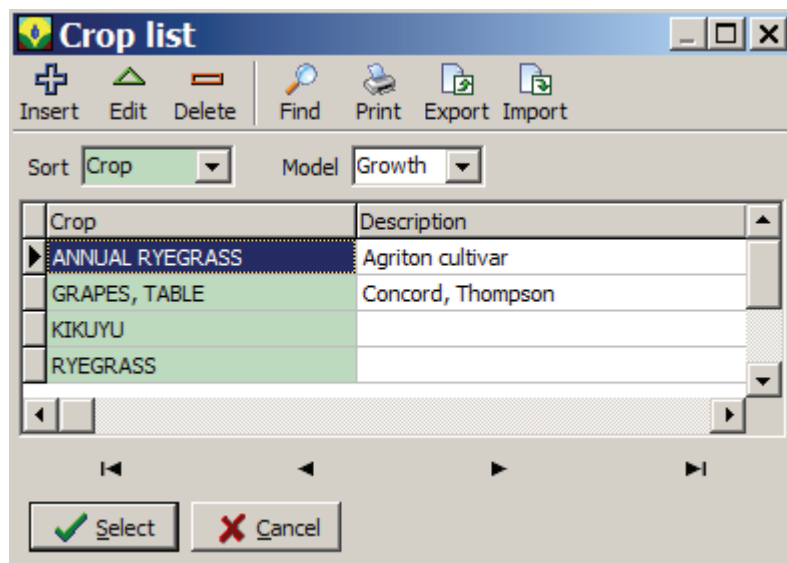
f) **Planting date:** insert planting date in "**year/month/date**' format, for example '**2011/03/01**'
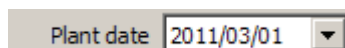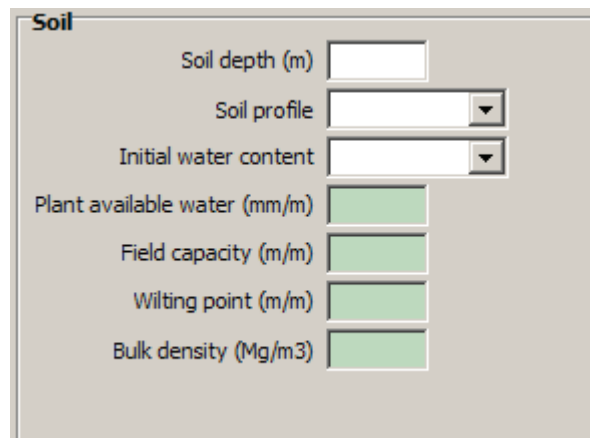
Finally the Field section screen will appear as below:
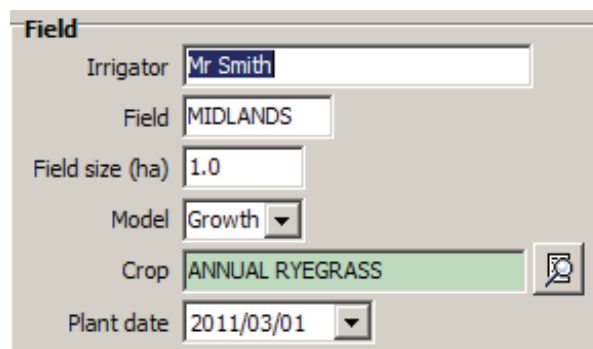
STEP 2 SOIL SECTION
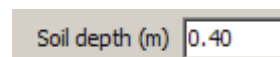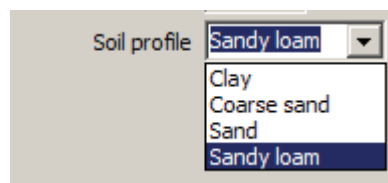
a) **Soil depth (m):** enter soil depth in meters, for example '**0.40**'
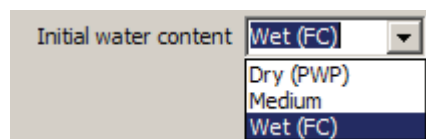
b) **Soil profile:** click the drop down arrow and select soil profile, for example '**Sandy loam**'

c) **Initial water content:** click the drop down arrow and select initial water content, for example a soil starting at field capacity '**Wet (FC)**'

The water holding characteristics (plant available water, field capacity, wilting point and bulk density) of soil will then be calculated automatically and the Soil section screen will appear as below:

STEP 3 WEATHER SECTION
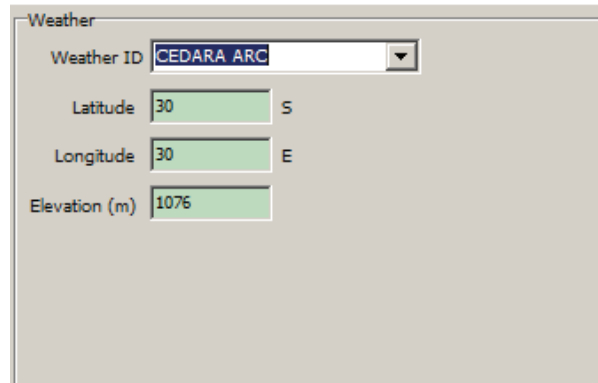
Weather ID: click the drop down arrow and select weather ID, for example '*Cedara – ARC*'. The latitude, longitude and elevation will appear automatically.

The Weather section screen will then appear as below:
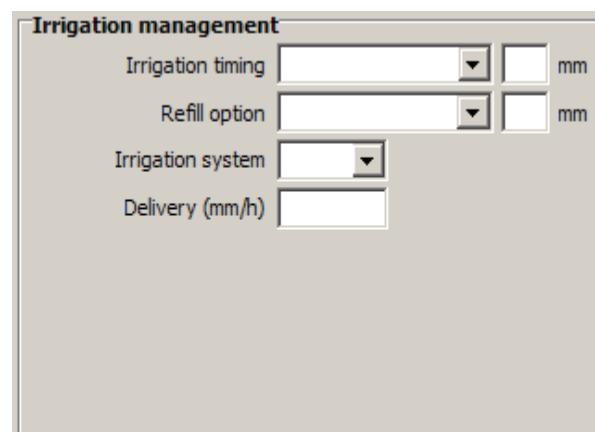
STEP 4 IRRIGATION MANAGEMENT SECTION
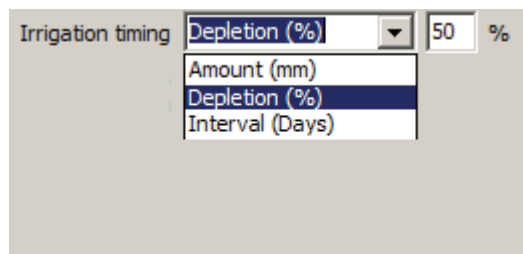
a) **Irrigation timing**: click the drop down arrow and select irrigation timing and enter you chosen threshold depletion level, for example '**Depletion (%)** – "50" %.
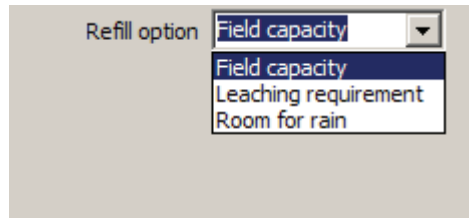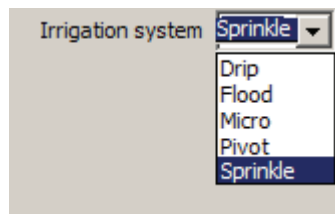
b) ***Refill option***: click the drop down arrow and select refill option, for example '***Field capacity***'

c) ***Irrigation system***: click the drop down arrow and select an irrigation system, for example '***Sprinkler***'
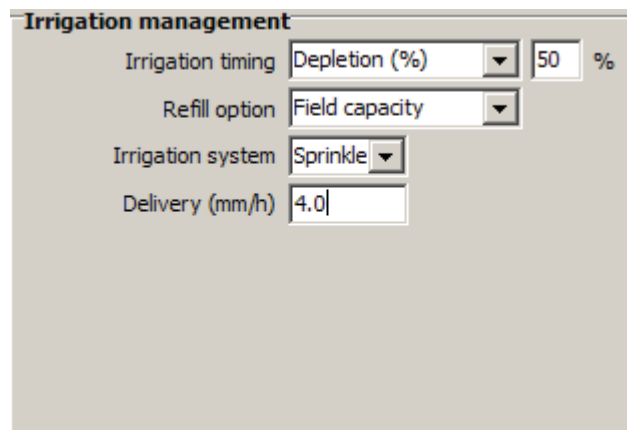
d) ***Delivery (mm/h)***: Insert delivery rate of the irrigation system, for example '***4.0***'
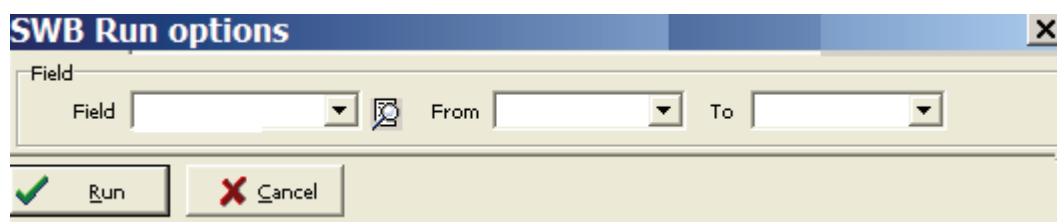
Finally the irrigation management section screen will appear as below:
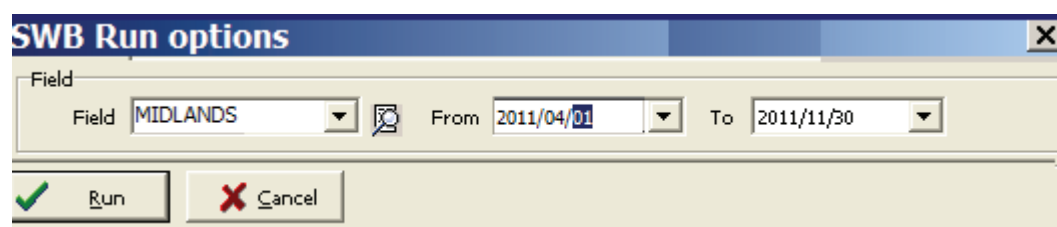
3. Generate calendar (Run options)

Click the drop down arrow and select a Field, for example '***MIDLANDS'***, and fill in the period you want to generate an irrigation calendar, for example From '***2011/04/01***' To '***2011/11/30'***

Finally press run button

4. Calendar output Table

An irrigation calendar is displayed in Table format similar to the example below:

IRRIGATION CALENDAR

Irrigator:	Mr Smith	Irrig system:	Sprinkle
Crop:	ANNUAL RYEGRASS	Irrigation frequency option:	Depletion (%): 50
Field:	MIDLANDS	Management option:	Field capacity

Date& Day	Water requirement (mm)	Rain since previous irrigation (mm)	Recommended irrigation amount = WR – rain**	Comments
07-Apr, Thu	23			
14-Apr, Thu	23			
20-Apr, Wed	22			
27-Apr, Wed	25			
04-May, Wed	22			
13-May, Fri	22			
21-May, Sat	24			
29-May, Sun	24			
09-Jun, Thu	22			
19-Jun, Sun	23			
27-Jun, Mon	22			
08-Jul, Fri	23			

** Notes

- Record rain and empty gauge just before irrigation.
- Subtract rainfall from water requirement to obtain the Irrigation amount.
- If WR - rain < 0, then skip the irrigation, i.e. irrigation amount = 0.

30/09/2011   Page 1

Irrigation calendar includes:

1. A column when the pasture should be irrigated 'date and day'
2. A column of recommended water requirement in mm.
3. A column to enter rain since previous irrigation in mm
4. A column to calculate recommended irrigation amount by subtracting rain (if more than 3 mm) from water requirement
5. A column to write comments