IRRIGATION GUIDELINES FOR MIXED PASTURES AND LUCERNE

Wayne Truter, Omphile Sehoole, Malissa Murphy, Melake Fessehazion, John Annandale, Caren Jarmain, Mpendulo Dlamini and Colin Everson

WATER RESEARCH COMMISSION

TT 697/16

IRRIGATION GUIDELINES FOR MIXED PASTURES AND LUCERNE

Report to the

WATER RESEARCH COMMISSION

compiled by

Wayne Truter[1], Omphile Sehoole[1], Malissa Murphy[1], Melake Fessehazion[1], John Annandale[1], Caren Jarmain[2], Mpendulo Dlamini[1] and Colin Everson[1,2]

[1] Department of Plant and Soil Sciences, University of Pretoria

[2] Centre of Water Resources Research, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal

[3] Department of Geography and Environmental Studies, Stellenbosch University

WRC Report No. TT 697/16

December 2016

Obtainable from
Water Research Commission
Private Bag X03
GEZINA, 0031

orders@wrc.org.za or download from www.wrc.org.za

The publication of this report emanates from a project entitled *Water use and crop parameters of pastures for livestock grazing management* (WRC Project No. K5/2173).

This report forms part of a series of two reports. The other report is *Water Use and Crop Parameters of Pastures for livestock Grazing Management* (WRC Repot No. 2173/1/16).

ISBN 978-1-4312-0839-5
Printed in the Republic of South Africa

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 and legumes 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 in different seasons. There is clearly a need to determine irrigation requirements of Lucerne and common grass/legumes mixtures by developing site specific guidelines or charts that indicate when and how much to irrigate. 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 Lucerne and common grass/legumes mixtures through testing and evaluation of the model and develop generic guidelines for efficient irrigation management of grass/legume 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 DAIRYMOD MODEL

IMJ Consultants in collaboration with Dairy Australia and the University of Melbourne developed DairyMod. DairyMod is a daily time-step model with modules for pasture growth in response to

- climate,
- pasture utilization by grazing animals,
- animal physiology,
- growth,
- metabolism and lactation,
- water dynamics including transpiration,
- soil evaporation,
- runoff,
- infiltration and deep drainage,
- soil organic matter, and
- nitrogen dynamics, including leaching and gaseous losses through volatilization and leaching.

There are flexible options for pasture management, irrigation, fertilizer application, stock management and supplementary feeding strategies.

3.1 Pasture growth module

Includes calculations of :

- light interception and photosynthesis,
- growth and maintenance respiration,
- nutrient uptake and nitrogen fixation,
- partitioning of new growth into the various plant parts,
- development,
- tissue turnover and senescence, and
- the influence of atmospheric CO2 on growth.

The model allows up to five pasture species in any simulation, which can be annual or perennial, C3 or C4, as well as legumes.

3.2 Water module

- accounts for rainfall and irrigation inputs that can be intercepted by the canopy,
- surface litter or soil.

The required hydraulic soil parameters are

- saturated hydraulic conductivity,
- bulk density which is used to calculate saturated water content,
- field capacity or drained upper limit,
- wilting point, and
- air-dry water content.

3.3 Soil organic matter and nitrogen dynamics module

Are defined through the soil profile. Organic matter turnover and inorganic nitrogen mineralization or immobilization, movement in the soil (leaching), adsorption in the soil, and atmospheric losses through volatilization and denitrification are included. The supply of organic matter is from litter, dung and dead roots. There are three soil organic matter pools (in addition to surface litter, dung and live roots): fast and slow turnover, and inert. The only input to the inert pool is through fire.

3.4 Animal module

Describes

- animal growth,
- pregnancy and lactation as well in response to available energy, and includes
    - body protein,
    - water and fat.

Animal protein weight is taken to be the primary indicator of metabolic state, while fat is regarded as a potential source of metabolic energy for physiological processes, such as energy requirements during lactation. Animal intake in response to available pasture and pasture quality is described, as well as intake from supplementary feed. Feed composition has a direct effect on growth and metabolism, including lactation, as well as nitrogen dynamics and the nitrogen contents of dung and urine.

This DairyMod model is comprehensive and has the ability to estimate water requirements of different pasture species very well in relation to expected production.

4 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.

4.1 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.

4.1.1 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.

4.1.2 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.

4.1.3 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).

4.1.4 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%)

4.2 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.

4.3 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.

5 EXAMPLES OF IRRIGATION REQUIREMENTS

Monthly general irrigation intervals were developed for a deep, well drained and fertilised, medium textured soils for most common high producing areas. General irrigation intervals were developed by irrigating the lucerne and common grass/legume pastures 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).

Key production areas for lucerne and mixed pastures were selected for the purpose of this study to illustrate the difference in water requirements of different pastures in response to site specific climatic conditions and pasture management.

6 CONCLUSIONS AND RECOMMENDATIONS

DairyMod and SWB models can be used by farmers or consultants to determine their irrigation requirements 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 models were used for developing irrigation guidelines using annual lucerne and common grass/legume pastures as example.

In the absence of irrigation scheduling tools, site specific irrigation guidelines can be calculated using the models, and 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 the best way of calculating irrigation guidelines using a models. The models are 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. It is also imperative to evaluate the mixed pastures canopy cover rather than focussing on the predominant specie in the mixture. The latter is important because the species composition changes in response to management inputs. These models have been calibrated and tested for newly planted and already established pastures.

Acknowledgements

The research in this report emanates from a solicited project initiated, managed and funded by the Water Research Commission, entitled: "*Water use and crop parameters of pastures for livestock grazing management*".

The research team would like to thank the following reference group members for their interest and their helpful comments:

Dr S Mpandeli	Water Research Commission (Chairman)
Dr GR Backeberg	Water Research Commission
Dr R Mottram	Mottram and Associates
Mr R Findlay	Private
Mr Rob Walker	Intelac
Dr Albert Smith	Stats4Science
Mr Keith Ramsay	Department of Agriculture, Forestry and Fisheries

The project was only possible with the co-operation of many individuals and organisations, and the authors wish to express their gratitude to the following:

Michael van der Laan, Carin for their help with the modelling work.

List of definitions

1. **Adaptive management:** A learning process through which a farmer is able to adopt practices that make sense for his specific conditions to increase profits and reduce environmental impacts at the same time (Lee, 1993).

2. **Crop coefficient:** the crop coefficient is defined as the ratio of ET from any specific crop or soil surface to some reference ET as defined by weather data.

3. **Crop coefficients** are properties of plants used in predicting evapotranspiration (ET). The most basic crop coefficient, K_c, is simply the ratio of ET observed for the crop studied over that observed for the well calibrated reference crop under the same conditions.

4. **ET_o (Reference crop evapotranspiration):** The evapotranspiration rate from a reference surface (Calculated using grass as a reference crop). The reference surface is a hypothetical grass reference crop with specific characteristics was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. The reference evapotranspiration as determined by the Penman-Monteith approach considers an imaginative crop with fixed parameters and resistance coefficients.

5. **ET_r (reference evapotranspiration):** ET_r is defined as the rate at which water would be removed from the soil and plant surfaces expressed as the rate of latent heat transfer per unit area, or as a depth of water per unit time evaporated and transpired from a reference crop. The use of ET_r for a specified crop surface has largely replaced the use of the more general potential crop ET. This is calculated using alfalfa as the reference crop.

6. **Leaf Are Index (LAI)**: is a dimensionless quantity that characterizes plant canopies. It is defined as the one-sided green leaf area per unit ground surface area (LAI = leaf area/ground area, m^2/m^2) in broadleaf canopies.

7. **Mixed pastures:** are pastures comprising of different grasses or grass/legume combinations growing together.

8. **Monospecific pastures:** are pastures comprising of a single species of grass or legume.

9. **Overseeding:** The process by which a seed is broadcast in to existing vegetation irrespective of whether the existing vegetation is a pasture, a standing crop or stubble**.**

10. **Photosynthetic Active Radiation (PAR):** designates the spectral range (wave band) of solar radiation from 400 to 700 nanometers that photosynthetic organisms are able to use in the process of photosynthesis.

11. **Soil water balance**: It is the difference between inputs and losses that reflect a change in soil water storage

12. **Soil water (moisture) deficit:** this is the amount of rain needed to bring the **soil** moisture content back to field capacity.

13. **Water use efficiency:** A quantitative measurement of how much biomass or yield is produced over a growing season, normalised with the amount of water used up in the process. It also refers to the ratio of water used in plant metabolism to water lost by the plant through transpiration.

CHAPTER 1: INTRODUCTION

1.1 Background

Currently, 60% of South Africa's surface and ground water resources are used for irrigation (DWAF, 2004). Irrigated agriculture is facing fierce competition for this substantial share of water as the water demand for industrial, domestic, municipal and other activities are increasing rapidly. There is a need to increase water (and land) productivity, to meet the increasing demand for animal protein as human populations increase and diets become more affluent. Natural veld cannot fulfil this need alone and must be supplemented with irrigated and fertilised planted pastures. This requires intensive use of fertilisers and water, which leads to a higher cost of production and a greater risk of environmental pollution. Sustainable pasture production requires the best fertiliser and water management possible, in order to attain high biomass yield with minimum inputs, which maximises profit whilst the impact on the environment. Thus, farmers are under pressure to decrease their share of water and fertiliser usage, whilst at the same time, produce sufficient pasture to supply the protein demand of a growing population more efficiently. Therefore, innovations are needed to increase the efficiency of water and nitrogen use.

Irrigation water, nutrients and electricity are considered to be the main limiting resources for pasture production in South Africa. These resources can be optimised by selecting the appropriate irrigation type and scheduling technique and pasture (i.e. N fixing legumes and/or crops with high water use efficiency). According to the pasture and livestock budgets of 2009/2010 N and K fertilisers stands for more than 50% of the total input. Fertiliser is the other major input which is directly linked with irrigation water because managing one is also directly or indirectly managing the other. The most appropriate and cost effective management strategy would therefore be to integrate irrigation and nutrient (especially N) inputs, since nitrogen and water cannot be managed independently. This projects focus will be to integrate both irrigation and nitrogen management in order to improve the efficiency of both resources.

In South Africa, returns generated from animal production enterprises make pastures one of the highest value crops produced under irrigation. It is estimated that the total area utilized for irrigated pasture production is approximately 16% of the total area under irrigation. The most common irrigated pastures are ryegrass, kikuyu and lucerne. Irrigated ryegrass and dryland kikuyu with supplemental irrigation are the primary sources of feed in the pasture based dairy industry and are mostly grown in the relatively higher rainfall areas.

The Water Research Commission initiated and funded a 5-year project to study the irrigation management of ryegrass/kikuyu pasture under different pasture management conditions (WRC K5/1650). From this project, irrigation guidelines of ryegrass including calendars for the major pasture growing areas of South Africa were developed. In addition, a simple irrigation scheduling model has been parameterised and tested and is now available to be used by farmers for their own specific conditions (Fessehazion et al., 2012). However, only limited research was conducted on kikuyu and kikuyu/ryegrass mixtures. Hence, in this project, we would like to focus part of our research on these irrigated pastures in conjunction with important legumes such as clovers and lucerne and relevant mixtures thereof.

The use of mixed grass/legumes is becoming integral in pasture based grazing systems. This will reduce nitrogen inputs, which is the most limiting resource in pasture production after water. It also balances forage nitrogen content, causing less bloat than pure legume pastures and is therefore safe to graze by livestock. Due to the high cost of N fertiliser, some South African farmers have started planting temperate legume/tropical grass- and temperate legume/grass mixtures in the Southern Cape coast (Labuschagne, 2005) and KwaZulu-Natal (Eckard, 1994). Therefore, in this project, this promising practice of temperate legume with tropical grass or temperate grass mixture and the most commonly practised grazing mixture of kikuyu/ryegrass will be researched.

With respect to pure legume pastures, lucerne is regarded as the most important pasture legume produced in the drier parts of South Africa for its high quality roughage (hay). This roughage is extensively used in many animal production systems, including feedlots, dairy systems, the animal feed industry and the wildlife industry, to correct for poor quality natural veld especially in winter. Lucerne is planted on 240 000 to 300,000 ha (Gronum et al., 2000; National Lucerne Organization, 2011), about 80% of which is irrigated. It is mostly used for making hay, and selective grazing for cattle, sheep, ostriches and other livestock in the game industry. It provides high yields with excellent forage quality (high protein) compared to other legumes and tropical grasses. Its versatility in utilisation and adaptation to a wide range of climatic and soil conditions, its capability of soil improvement and symbiotic N2 fixation makes it the preferable choice for intensive forage production systems (Truter et al., 2015).

Despite the above benefits, however, lucerne is known for its high water usage compared to other pastures. Annual water requirements of 1100-1200 mm are quoted by the pasture handbook (Kynoch pasture hand book, 2004), and various Provincial Departments of Agriculture and various seed companies. According to Green (1985), water requirement ranges between 1200 2100 mm per year depending on weather conditions. The current guideline of irrigation amount for lucerne is a very rigid 150 mm per cutting cycle, applied in two equal applications of 75 mm, with the first applied after hay making and the subsequent application 14 days later. Due to complications with the harvesting, raking and baling processes, the second irrigation has to supply sufficient water for the cutting cycle under consideration and the initial stages of the following growth cycle, because normally the first irrigation will only take place 5-7 days after cutting (depending on the time required for harvesting, raking, baling and bale removal).

In addition, the rate of lucerne stand mortality may increase as a result of disease (e.g. scald) when irrigated immediately after harvest (especially when the temperature is high). Lucerne is also very sensitive to over- irrigation during establishment and early growth may be affected through damage to the tap root, which may turn to excessive yield reduction in subsequent years. There is a need, therefore, to study irrigation management of lucerne, by addressing crucial management practices (such as type of irrigation system and irrigation scheduling technique), which may have a direct or indirect effect on water use of lucerne.

There is a close link between biomass production and water use of lucerne as studied in South Africa by Landsberg (1967), De Kock (1978), Beukes and Weber (1981) and Beukes and Barnard (1985). Reductions in lucerne transpiration due to water deficits were associated with decreases in biomass production. Hence, it seems there is little opportunity to reduce its water consumption without affecting yield. According to Tanner and Sinclair (1983), there is a direct relationship between biomass production and transpiration when corrected for vapour pressure deficit. The need therefore exists to study more efficient ways to increase yield and possibly improve quality of lucerne with less water, so as to ensure more efficient use of, and higher returns from, each unit of water. Since lucerne is a perennial pasture, it is possible to avoid or reduce its production when there is excessive evaporative demand. Imposing stress during different growth stages or using rainfall strategically to optimise yield and quality in a period of water scarcity could also be an option. Therefore, a basic understanding of the effects water stress on the physiology and dormancy of lucerne production is prerequisite for the development of sound water management strategies.

From the challenges listed above, despite the latest fertiliser and irrigation application equipment and scientific guidelines, it can be seen that there are knowledge gaps between research and lucerne farming practices. There is lack of data and reliable information pertaining to water requirements of this valuable pasture legume. Methods to address these gaps, therefore, need to be devised and applied in order to increase water use efficiency at farm level.

Therefore, water use of kikuyu/ryegrass, clover/ryegrass and lucerne will be monitored at research stations representing summer rainfall and winter rainfall areas and commercial farms within the selected regions. Detailed studies will include energy, nitrogen and water balances of kikuyu and lucerne with soil water balance, micro-meteorological or remote sensing methods. Data collected from controlled research sites and compared field measurements will be used to develop practical on-farm strategies for monitoring irrigated pasture performance. Pasture systems are highly temporal and spatially complex, as they involve interactions amongst crop growth, nutrient dynamics between soil, plant and animal and pasture management systems. Hence, it is difficult to evaluate the whole system with short-term monitoring experiments. Development of site-specific pasture and irrigation management practices requires costly long-term trials. It is expensive and impractical to test multiple irrigation and other pasture management strategies in all pasture growing areas.

Models can be used to extrapolate research findings (irrigation and other pasture management requirements) to pasture growing areas. Models can also be helpful in selecting best management practices for specific sites and environmental conditions. However, models need to be parameterised, calibrated and tested with measured data. In recent years, a wide range of soil-plant-atmosphere type numerical models with different degrees of complexity have been developed. In general, complex models have a wide range of input parameters and hence intensive data sets are needed to run them accurately. A thorough survey of the current soil-plant-atmosphere continuum type models was conducted during the previous WRC Pasture Project (WRC K5/1650). Based on scope, input data requirements, adoption by farmers and consultant, and accessibility, the SWB and the DairyMod crop/pasture models were selected. In this project, these two models will be parameterised, tested and validated (Truter et al., 2012). Data sets collected in this project will also be used to parameterise and test the SAPWAT model (irrigation planning model).

Currently, satellite-based remote sensing is showing promising results in estimating irrigation requirements of fruit trees in the Western Cape. In the near future, this technology could become a more affordable tool for managing irrigations of pastures. This study will take opportunity of an on-going remote sensing satellite-based crop water use measurement project funded by the WRC (K5/2079/4). The accuracy of the technology for pasture management will hereby be assessed. This can therefore inform any potential future use of this technology for real time irrigation scheduling for pasture management.

The studies to be conducted under controlled environments and at representative research stations and commercial farms will be to: 1) determine water use and irrigation requirement of most common farmers practices including kikuyu/ryegrass, clover/ryegrass mixtures and lucerne; 2) evaluate applicable irrigation systems (such as flood, sprinkler and sub-surface drip) for lucerne production; 3) conduct detailed physiological studies of lucerne as affected by different water stress treatments, and 4) parameterise, test and validate selected crop growth/pasture model(s). As end products, databases of irrigation requirements of kikuyu/ryegrass, clover/ryegrass mixtures and pure lucerne under different pasture management practices will be developed. The validity and practicality of irrigation tools developed will finally be assessed in conjunction with pasture production stakeholders.

1.2 Problem Statement

Cultivated pastures play an important role in livestock production by providing roughage throughout the year, improving fodder flow, carrying capacity of the farm and performance of individual animals. Input costs in the pasture based systems are much lower than with a total mixed ration system. However, availability of irrigation water cost of fertilisers and energy for producing pastures may limit the pasture based system. Hence, there has been a movement of milk producing enterprises from the central part of the country to the high rainfall areas of the KwaZulu-Natal Midlands, and the Southern, Eastern and Western Cape Coasts.

In these regions, however, there are still limitations to pasture based systems due to irrigation water availability. Despite the latest fertiliser and irrigation application equipment and scientific guidelines, it can be seen that there are knowledge gaps between research and animal farming and lucerne farming practices. There is lack of data and reliable information pertaining to water requirements of valuable pasture legumes, such as lucerne and clover species which are often used in mixed pastures. Methods to address these gaps, therefore, need to be devised and applied in order to increase water use efficiency at farm level.

Irrigation technologies may be adapted by commercial and emerging rural farmers for more-effective and wiser use of limited water supplies. Knowing how much water to apply through irrigation and how often is no trivial matter. Irrigation scheduling is the main component of water management by which irrigators decide when and how much water to apply. Proper scheduling can lead to increased profits without compromising the environment, by increasing productive water use and reducing unproductive water loss through run off, deep percolation below the root zone with nutrient leaching and soil water evaporation. However, the tools required are relatively expensive and complicated making the implementation of irrigation scheduling for the average farmer difficult. Some monitoring tools may also not provide the most reliable method of scheduling due to soil spatial variability or by giving little information either on the amount or when water is to be applied.

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 are realising 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 (Truter et al., 2015).

Nitrogen fertiliser continues to be a major input influencing yield and quality of irrigated pastures in South Africa. Improved productivity has been reported with the application of N fertiliser in high rainfall areas and under irrigation in low rainfall areas. It has been increasingly used on pastures as an effective and flexible management tool to help farmers meet the feed requirements of livestock. According to the Food and Agriculture Organisation (FAO), N fertiliser use has increased by 7-fold from 1960 to 2000. Commercial fertilisers are normally used as sources of nitrogen in pasture production, but because of increasing energy costs and international demand, N prices continue to escalate. Therefore, new ways for reducing N applications in order to have sustainable and economical forage and animal production are required.

To date, leguminous pastures have been used with great success, often to exclude the cost of N to provide high quality and not necessary high quantity forage. These leguminous pastures had also been included in mixtures with other grasses, so as to benefit from this biological N fixation process legume species are responsible for. This pasture management practice was not always very economical from both a quantitative and qualitative perspective, but is becoming more economical especially in the light of sustainability. Not only is there a free source of N being produced, but this is often responsible by a more palatable, digestible and more nutritional pasture species than grass species. The management of these species, especially in a mixture, is however more intensive and challenging. The challenge however, it remains to establish how much N is available under different irrigation scenarios in a mixed pasture of grass and legumes.

Sustainable pasture production requires optimal fertiliser and water management practices in order to attain high biomass yield with minimum inputs to maximise profit. As a result, a basic understanding of the effects of N and water stress in pasture production is a prerequisite for the development of sound N and water management strategies. However, pasture systems are highly complex involving interactions between crop growth, soil and plant nutrient dynamics, and animal and pasture management systems. Considering temporal and spatial complexity, it is difficult to evaluate the whole system with short-term monitoring experiments. Development of site specific optimal N and irrigation management practices requires costly long-term trials. Since it is expensive and impractical to test multiple irrigation and N application strategies, the use of models can provide great insight and better understanding of the behaviour of the pasture system. Models can also be helpful in selecting best management practices for specific sites and environmental conditions.

1.3 Species evaluated

Figure 1.1 Lucerne (*Medicago sativa*)

Figure 1.2 Tall fescue (*Festuca arundinaceae*)

Figure 1.3 White clover (*Trifolium repens*)

Figure 1.4 Kikuyu (*Pennisetum clandestinum*)

Figure 1.5 Mixture 1 – Lucerne/kikuyu

Figure 1.6 Mixture 2 – Tall fescue/Lucerne

Figure 1.7 Mixture 3 – Tall fescue/White clover

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.

2.1.1 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.

2.1.2 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?

2.1.3 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.

2.1.4 Soil based approaches

2.1.4.1 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 2.1 A neutron water meter (left) and Diviner 2000 capacitance probe (right) for measuring soil water content

2.1.4.2 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.

2.1.4.3 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.

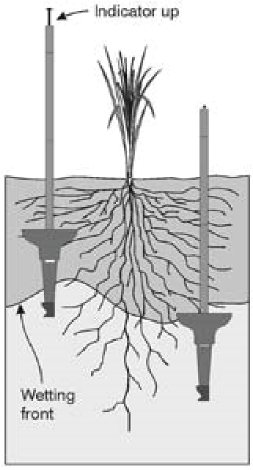


Figure 2.2 Wetting front detector (WFD) for managing irrigation and nutrients

2.1.5 Atmospheric demand

2.1.5.1 Empirical crop factor

The atmospheric evaporative demand is the driving force for crop water use (ET_c) 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 (ET_o). The ET_o 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: $ET_c = ET_o * Kc$.

2.1.5.2 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: DAIRYMOD MODEL

Dairy Mod is a model that has been developed by and for IMJ Consultants, The University of Melbourne, Dairy Australia and Meat and Livestock Australia under the leadership of Prof Ian Johnson. The model has a strong focus on the integration of the soil, plant and animal factors (data) to have a better understanding of how the entire grazing system functions (Figure 5.1) (Johnson et al., 2008).

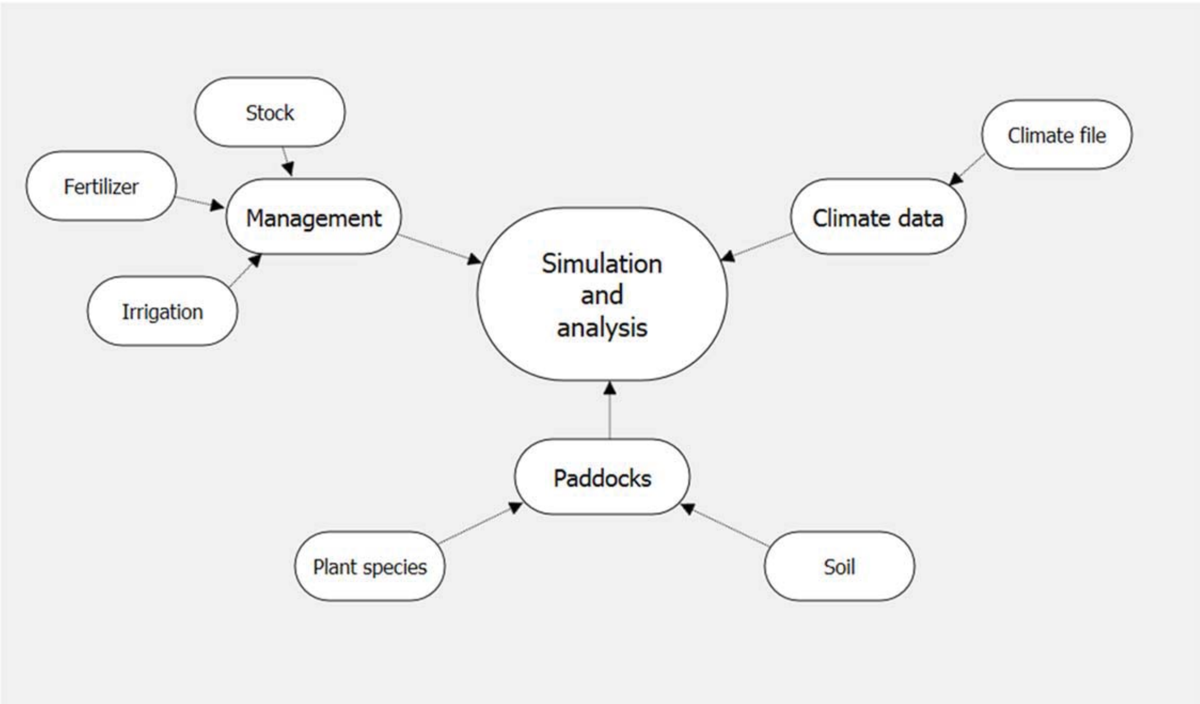


Figure 3.1 Overview of the parameters used for the model simulations (DairyMod http://imj.com.au/dairymod/)

The model has the ability to incorporate local weather data and to adjust specific parameters related to either the soil, pasture growth and animal management factors. It also has the option to have nine different output screens (Figure 2) that provide simulations of the expected soil, water or vegetation responses to climate and management factors.

Figure 3.2 Output from Dairy Mod simulation (DairyMod http://imj.com.au/dairymod/)

The model provides the option of changing the Biophysical parameters where possible, but also provides the opportunity to rely on well tested basic growth parameters of a range of species. Figure 3 illustrates which parameters can be changed according to data sets available locally.

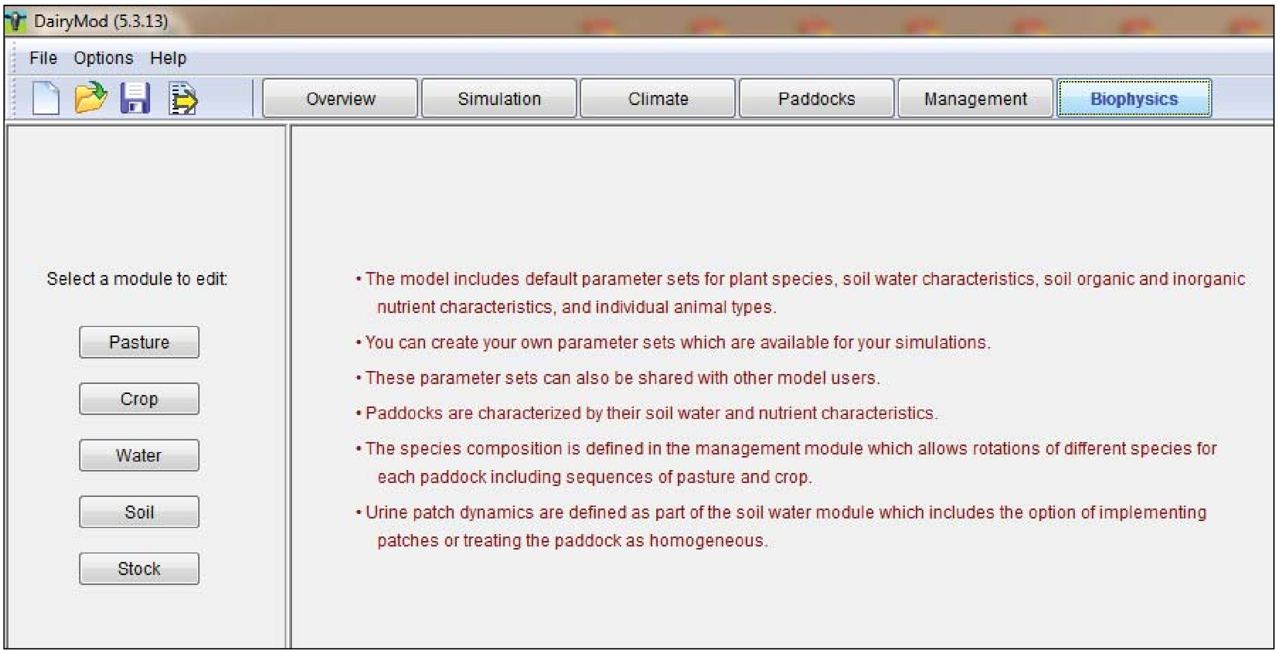


Figure 3.3 Biophysical input parameters. (DairyMod http://imj.com.au/dairymod/)

3.1 Biophysical parameters

The biophysical parameters that can be changed include:

- Pasture
- Crop
- Water
- Soil
- Stock

3.1.1 Pasture

With regards to the pasture parameters, the options exist to use templates for the different species and adjust their values according to the data you have available (Figure 4). Plant parameter sets can be defined for different plant characteristics. The new plant parameter sets are created by changing all the individual parameters of each plant characteristic. These include:

- Canopy Structure
- Roots
- Photosynthesis
- Nitrogen
- Temperature Stress
- Transpiration
- Grazing
- Regrowth

If local data is unavailable for a parameter set, the template used provides well tested values that one can rely on.

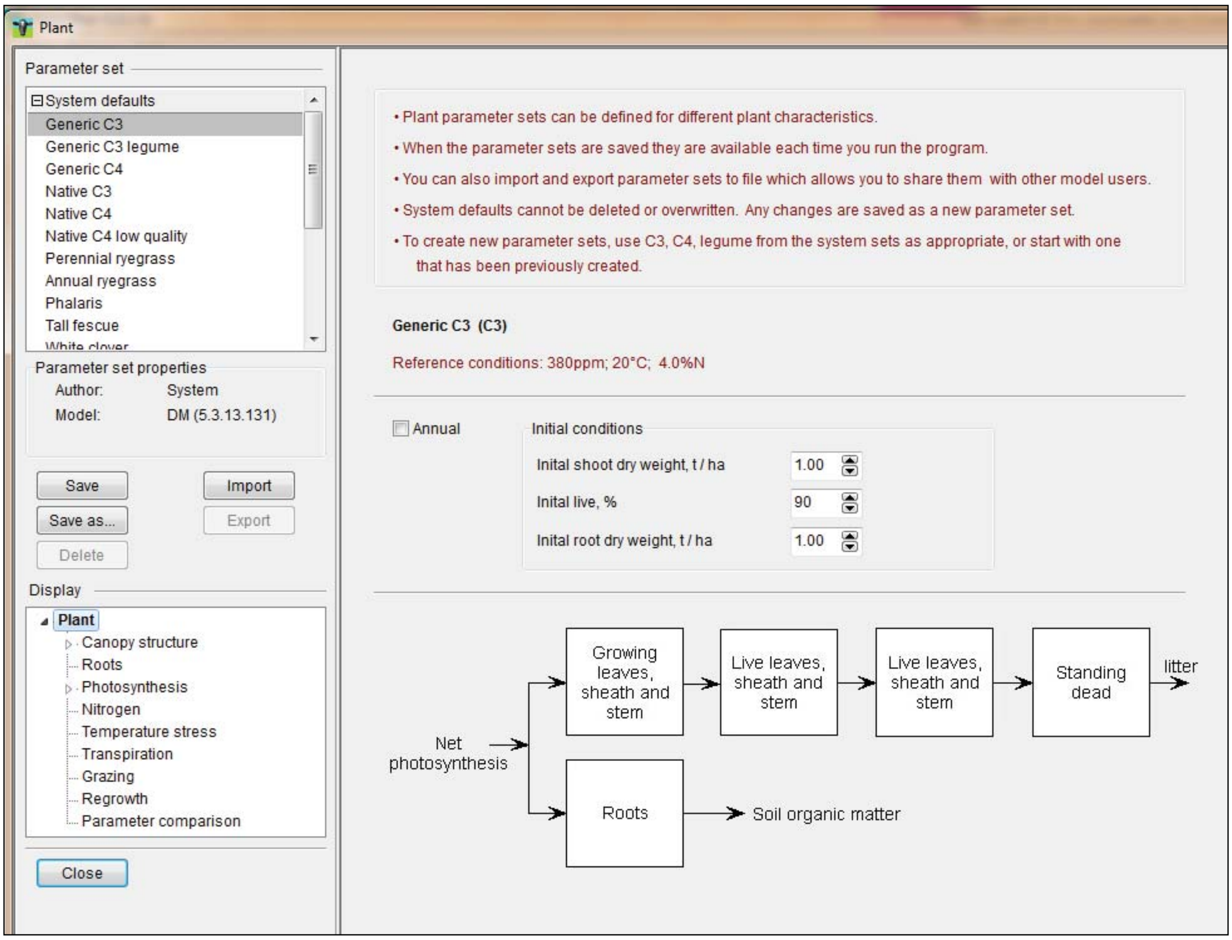


Figure 3.4 Plant parameter set options (DairyMod http://imj.com.au/dairymod/)

The following section discusses the different plant characteristics that can be adjusted for better simulation of the pasture responses.

a. Canopy Structure (Figure 3.5)

This parameter set includes:

- Canopy structure
  - Plant structure during new growth
  - Plant senescence
  - Plant Height
- Plant nitrogen composition

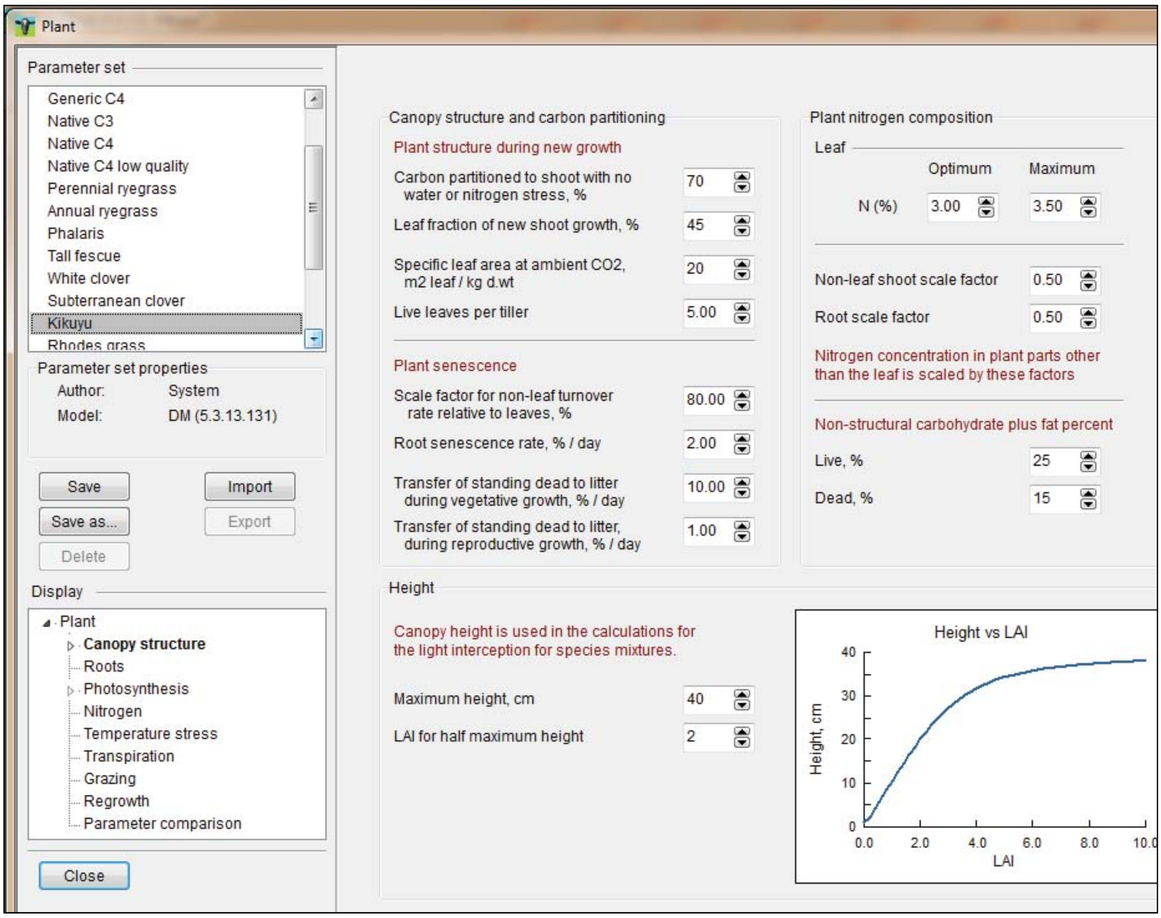


Figure 3.5 Canopy structure input parameter set (DairyMod http://imj.com.au/dairymod/)

b. Roots (Figure 3.6)

This parameter set includes:

- Root distribution
  - Root depth
  - Root depth for 50% distribution

c. Photosynthesis (Figure 3.7)

This parameter set includes:

  - Plant response to defoliation

The only parameter to change here is the **Effective Minimum LAI**:

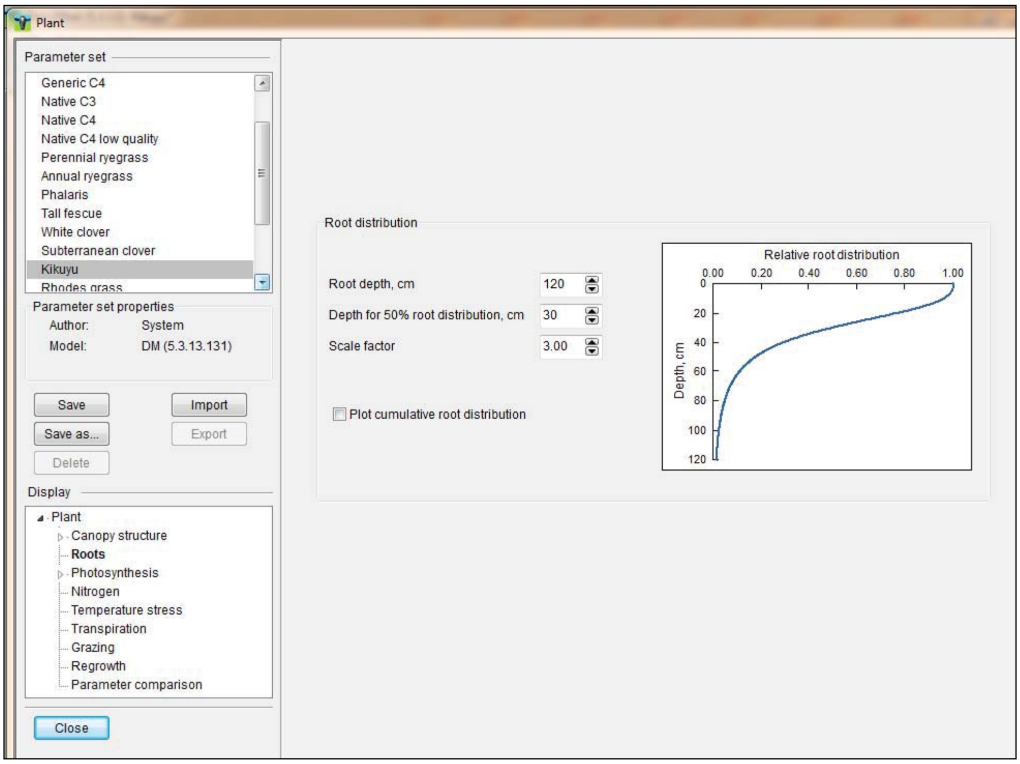


Figure 3.6 Root input parameter set (DairyMod http://imj.com.au/dairymod/)

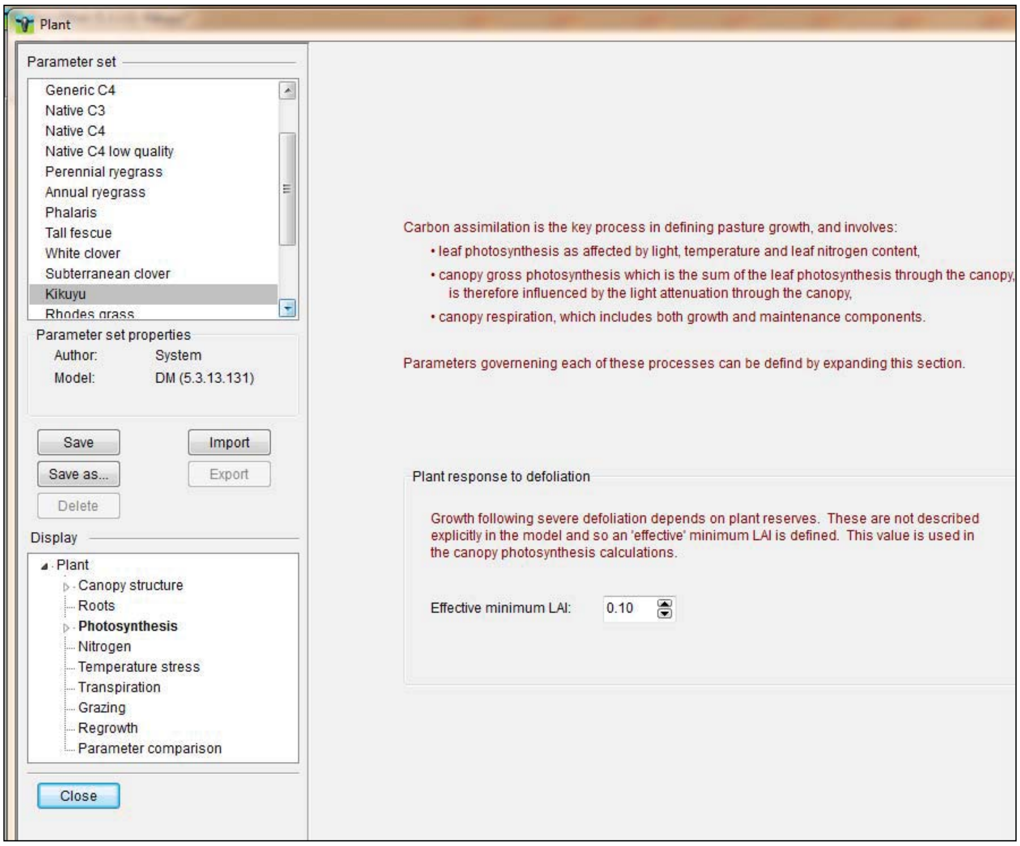


Figure 3.7 Photosynthesis input parameter set (DairyMod http://imj.com.au/dairymod/)

d. Nitrogen (Figure 3.8)

This parameter set includes:

- Nitrogen uptake
- Potential nitrogen remobilization

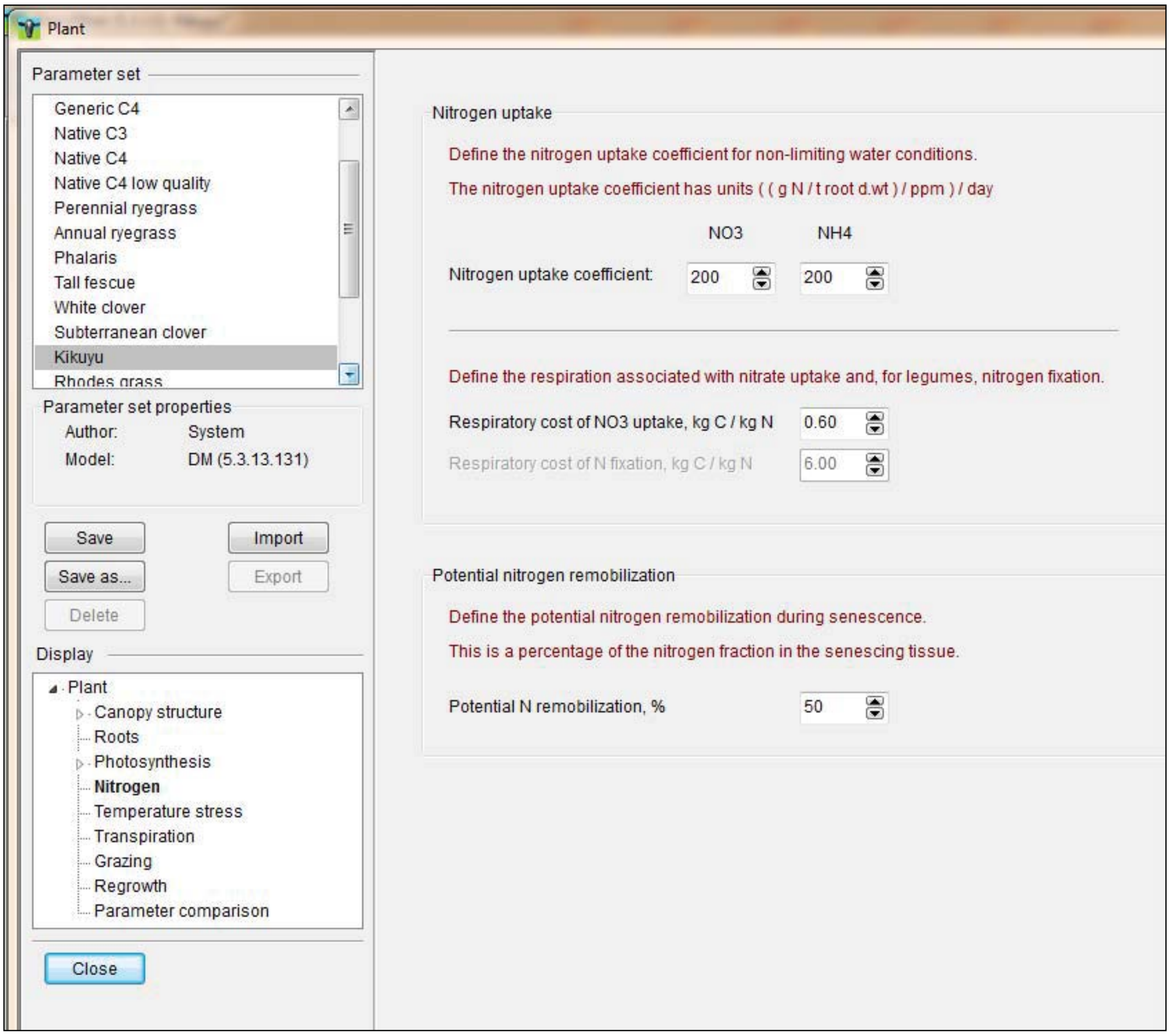


Figure 3.8 Nitrogen input parameter set (DairyMod http://imj.com.au/dairymod/)

e. Temperature Stress (Figure 3.9)

This parameter set includes:

- Low temperature stress
- High temperature stress

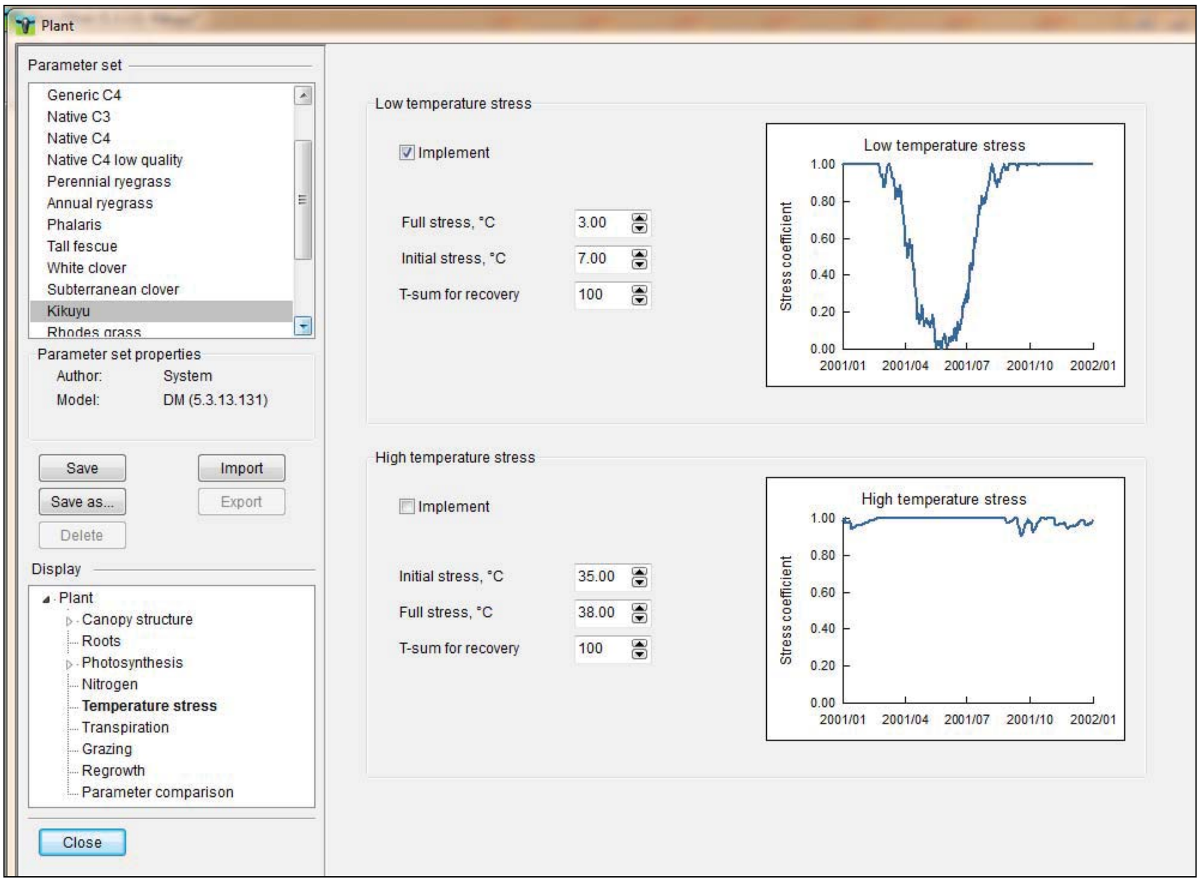


Figure 3.9 Temperature stress input parameter set (DairyMod http://imj.com.au/dairymod/)

f. *Transpiration* (Figure 3.10)

The parameter set addresses the generic function for the reduction in transpiration in response to soil water content. The function is applied to each soil layer for the particular soil water content.

g. *Grazing* (Figure 3.11)

This parameter set includes:

- Digestibility
- Grazing

This parameter set provides the opportunity to change the digestibility parameters of the pasture as it has been analysed of both the living material as well as the dead material. The other important factor to change includes the leaf to stem ration which affects the grazing value of the pasture.

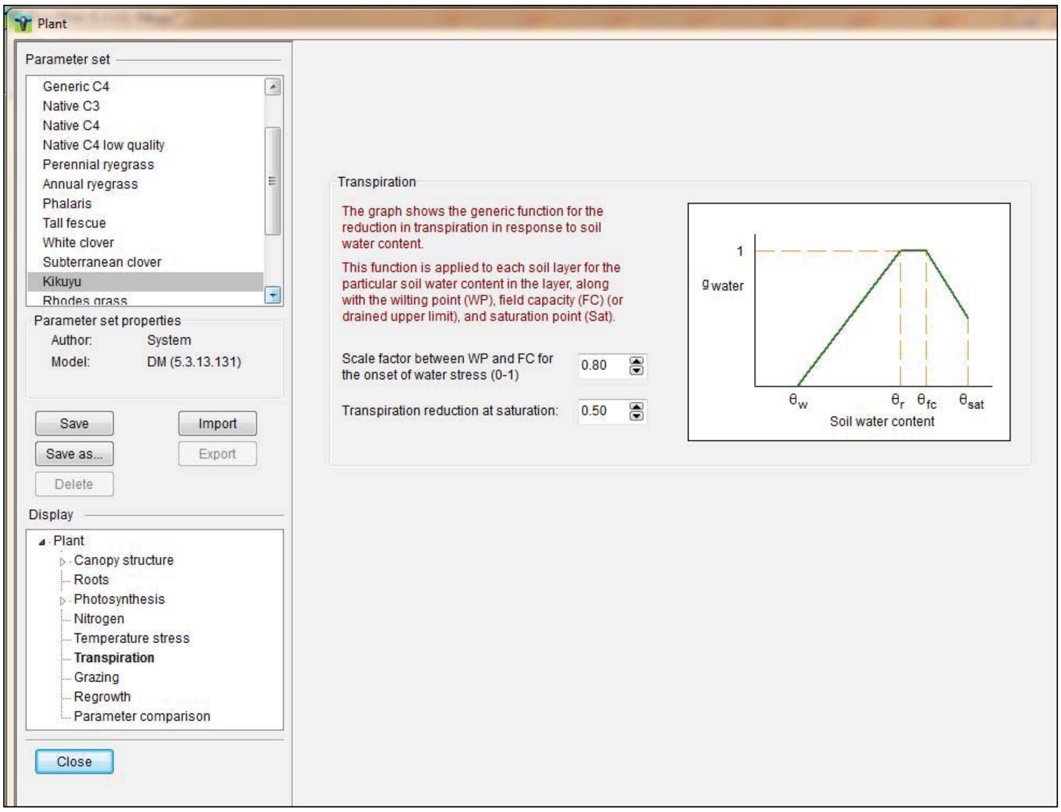


Figure 3.10 Transpiration input parameter set (DairyMod http://imj.com.au/dairymod/)

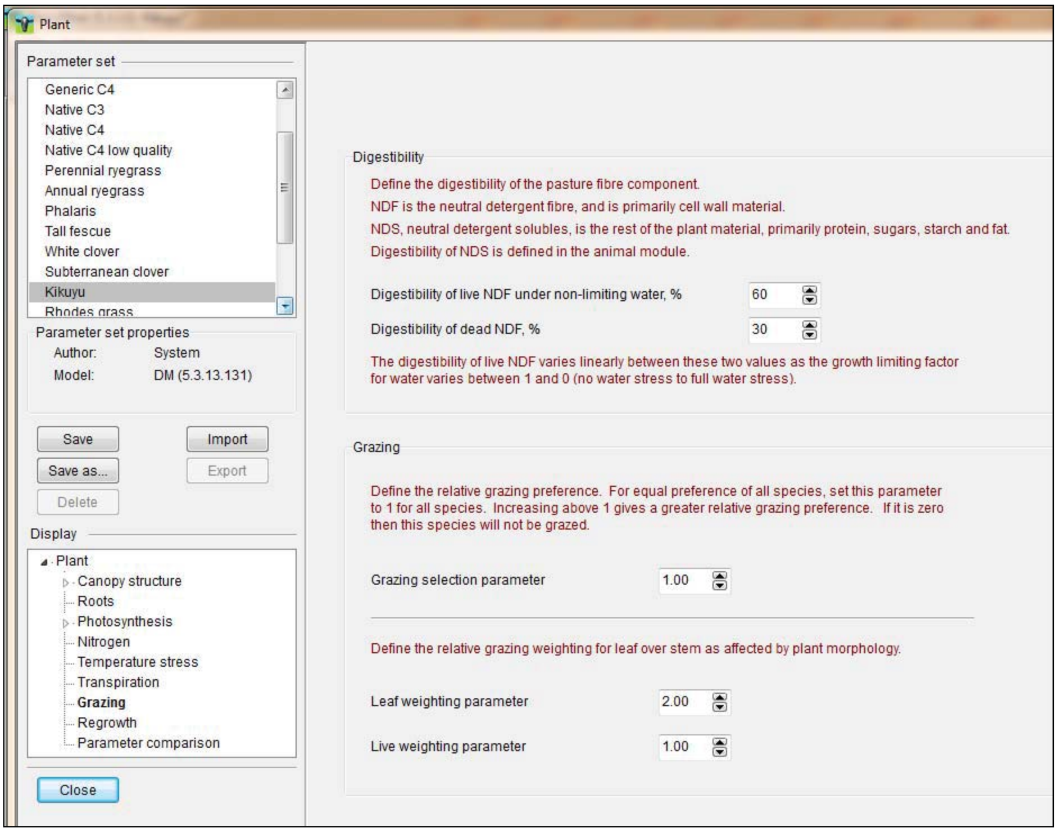


Figure 3.11 Grazing input parameter set (DairyMod http://imj.com.au/dairymod/)

h. Regrowth (Figure 3.12)

This parameter set includes:

- Regrowth characteristics
- Regrowth starting residual
- Climate

This parameter set provides the opportunity to change the initial dry weights of pasture in conjunction with the regrowth duration. All this date is integrated with the baseline climatic data of the growing pasture.

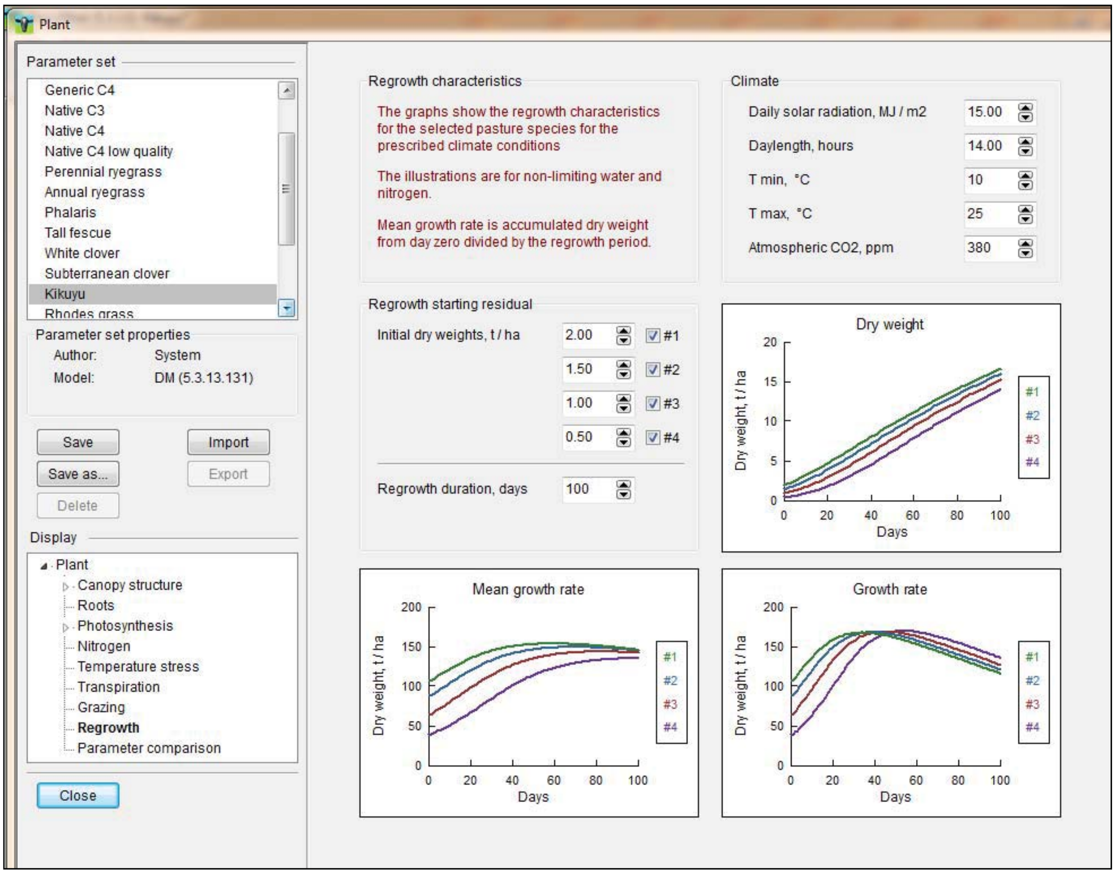


Figure 3.12 Regrowth input parameter set (DairyMod http://imj.com.au/dairymod/)

3.2 Crop

This part of the model makes provision for a winter or spring rotational crop. For the purpose of this study it has no relevance at this stage. It could however be an option when pastures are entirely removed and reseeded with a winter annual, as is the practice for the western Cape region with their overseeding practices.

3.2.1 Soil Water

Soil water is a major factor that drives these systems. The new soil water parameter sets are created by changing all the individual parameters of each factor that influences the soil water properties (**Figure 3.13**). These include:

- Soil physical parameters
- Runoff
- Evaporation
- Leaching

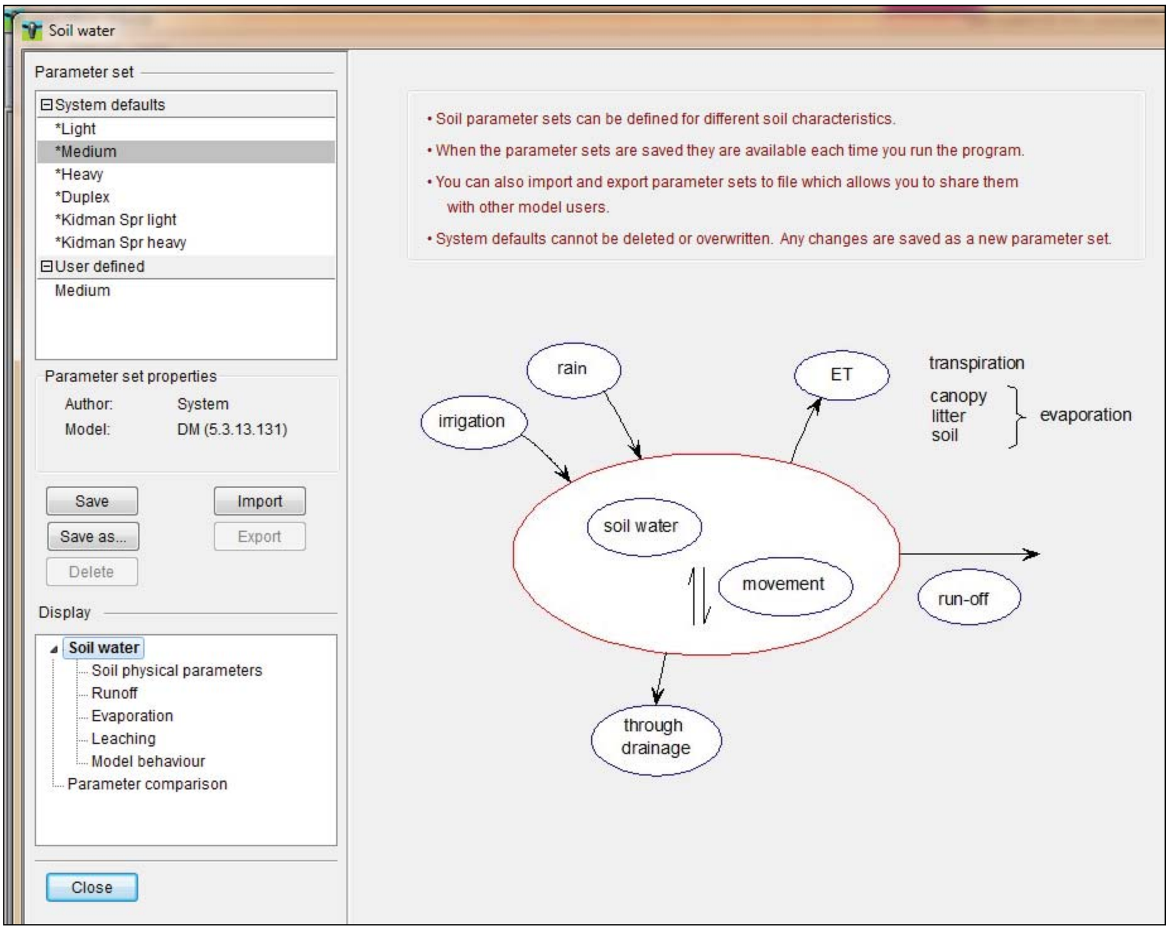


Figure 3.13 Soil water parameter sets for different soil characteristics

(DairyMod http://imj.com.au/dairymod/)

a. Soil Physical properties (Figure 3.14)

This parameter set includes:

- Profile depths and characteristics
- Initial soil water content

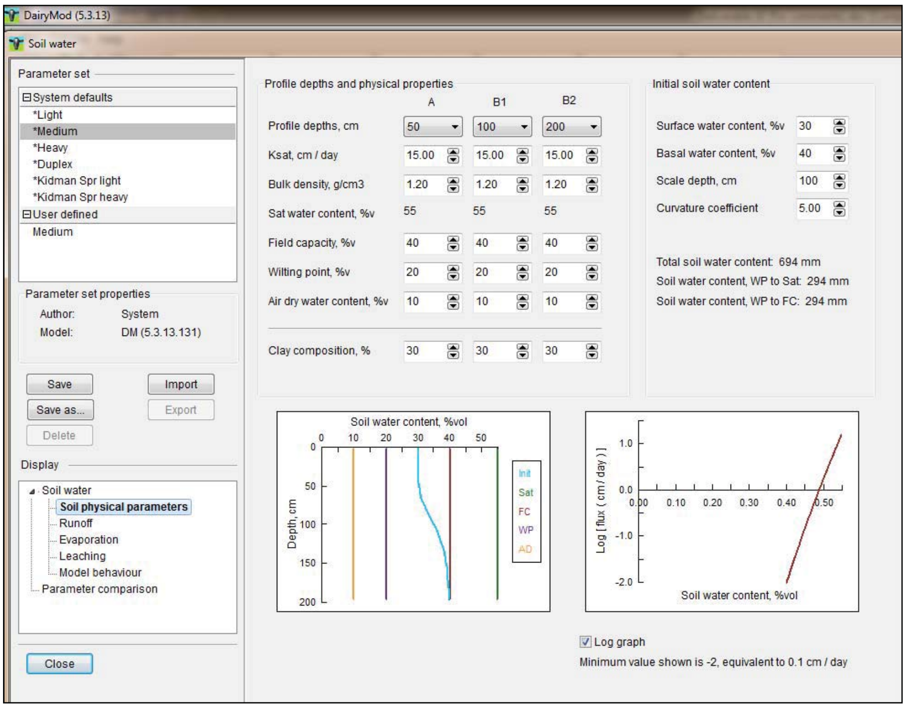


Figure 3.14 Soil physical properties input parameter set (DairyMod http://imj.com.au/dairymod/)

b. Runoff

This parameter set includes:

- Runoff characteristics (Figure 3.15)

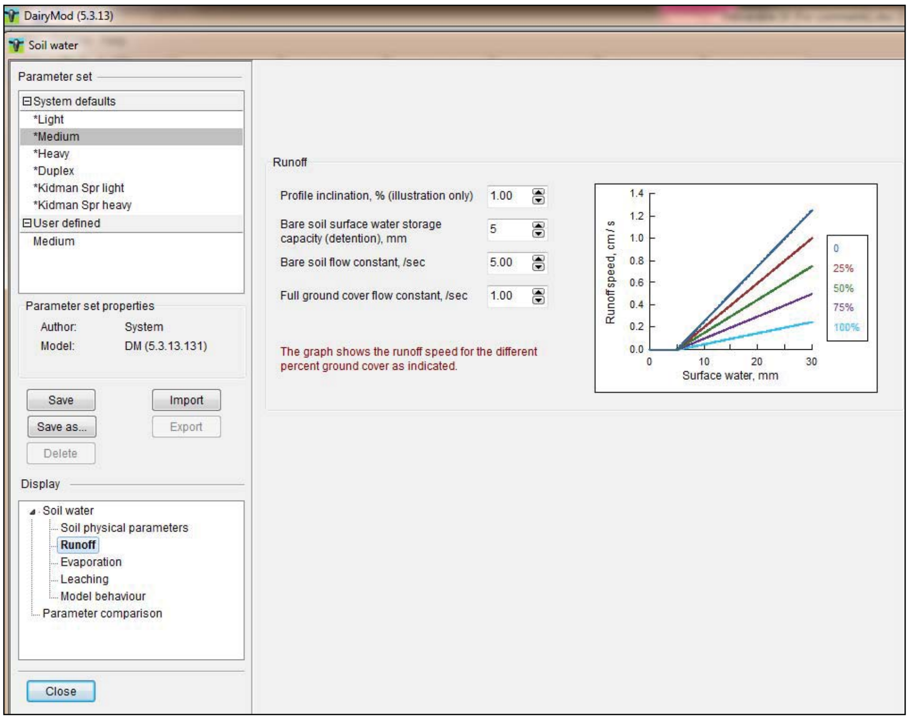


Figure 3.15 Runoff input parameter set (DairyMod http://imj.com.au/dairymod/)

c. *Evaporation parameters* (Figure 3.16)

This parameter set includes:

- Soil evaporation
- Litter
- Canopy and litter water interception

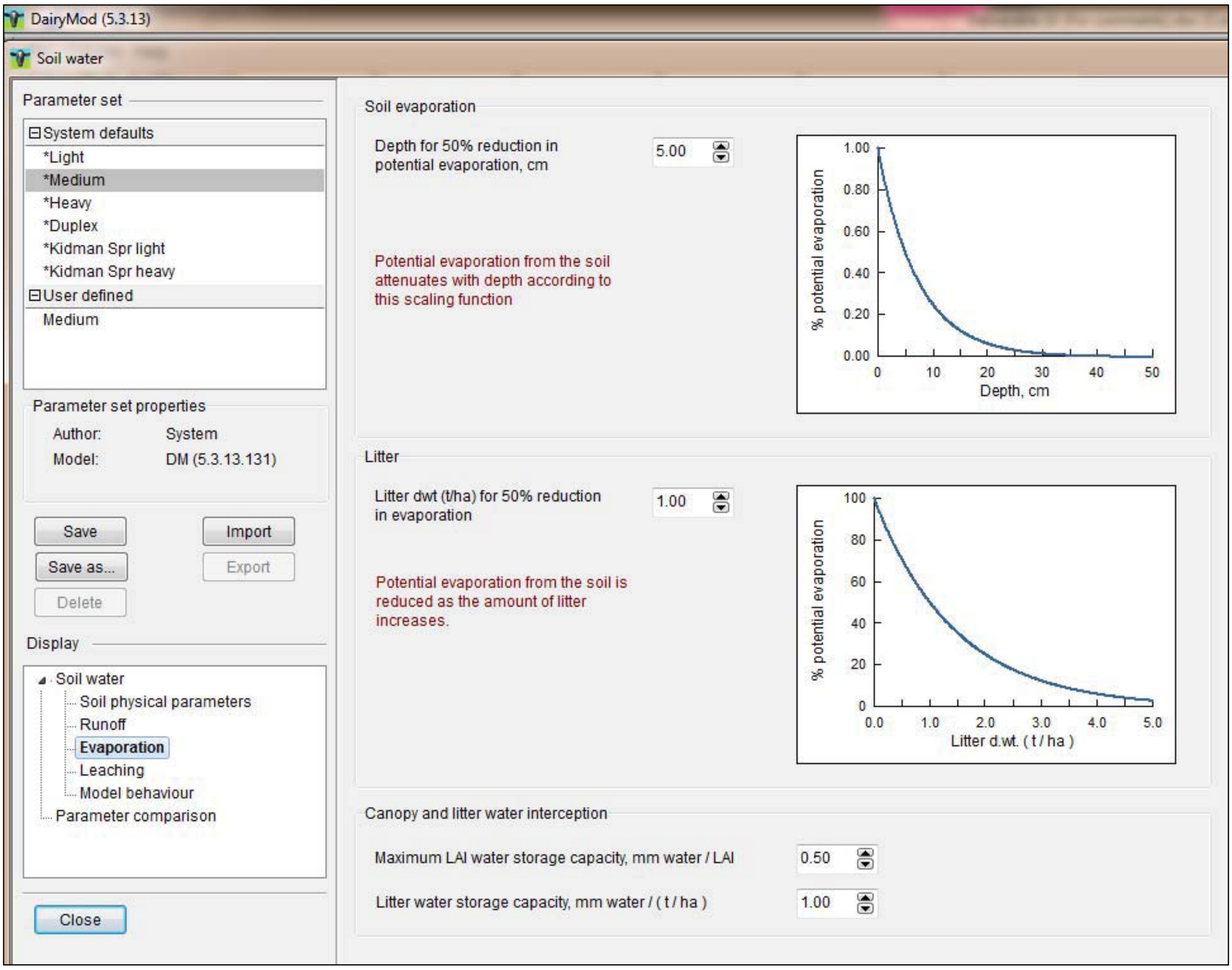
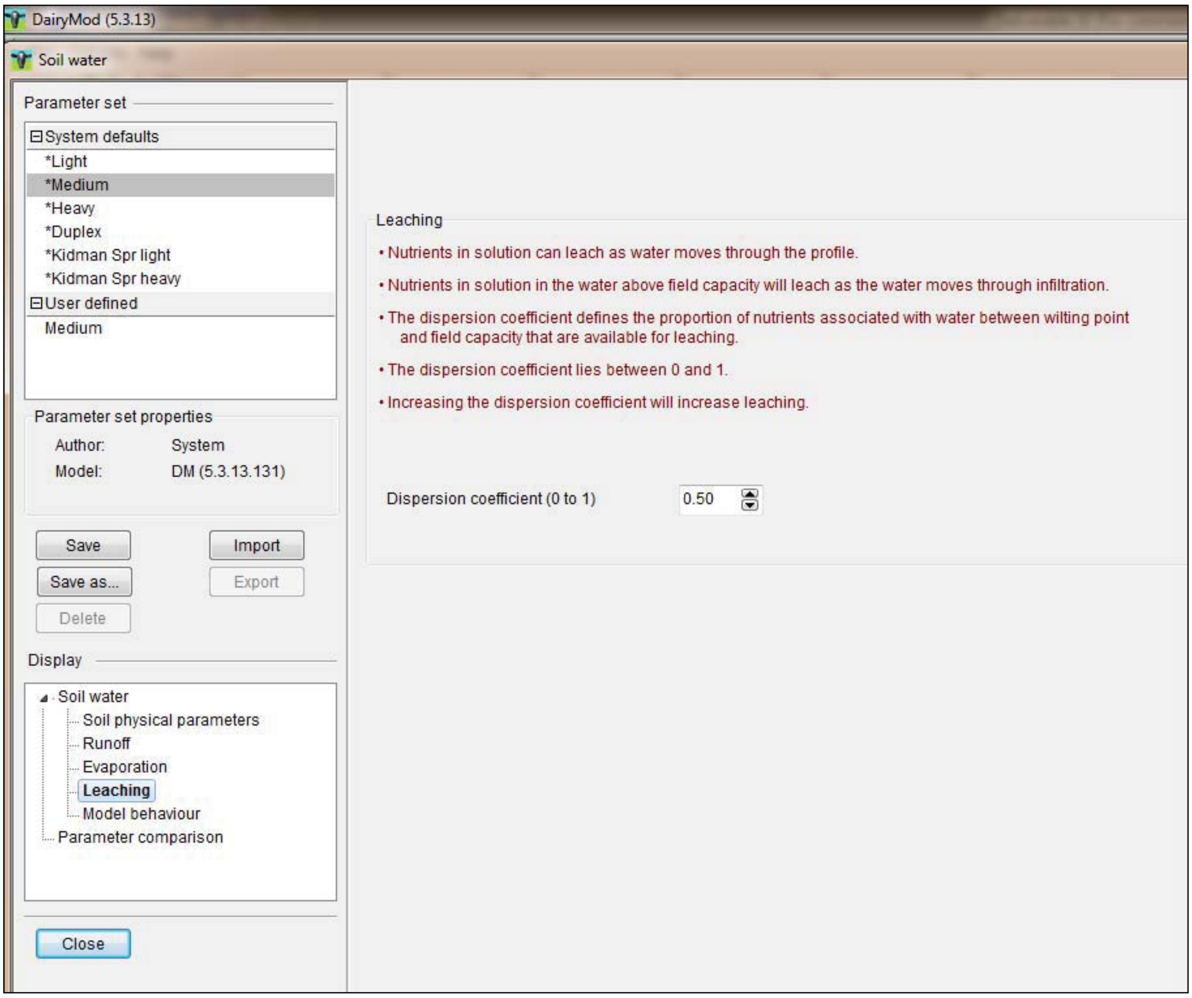


Figure 3.16 Evaporation input parameter set (DairyMod http://imj.com.au/dairymod/)

d. Leaching (Figure 3.17)

This parameter set only concentrates on the dispersion coefficient. The rationale is that the higher the dispersion coefficient the higher the leaching fraction.



•

Figure 3.17 Evaporation input parameter set (DairyMod http://imj.com.au/dairymod/)

3.3 Soil

The new soil parameter sets are created by changing all the individual parameters of each factor that influences the soil water properties (**Figure 3.18**). These include:

- Initialization
- Organic matter dynamics
- Inorganic nutrient dynamics
- Inputs
- Water and Temperature

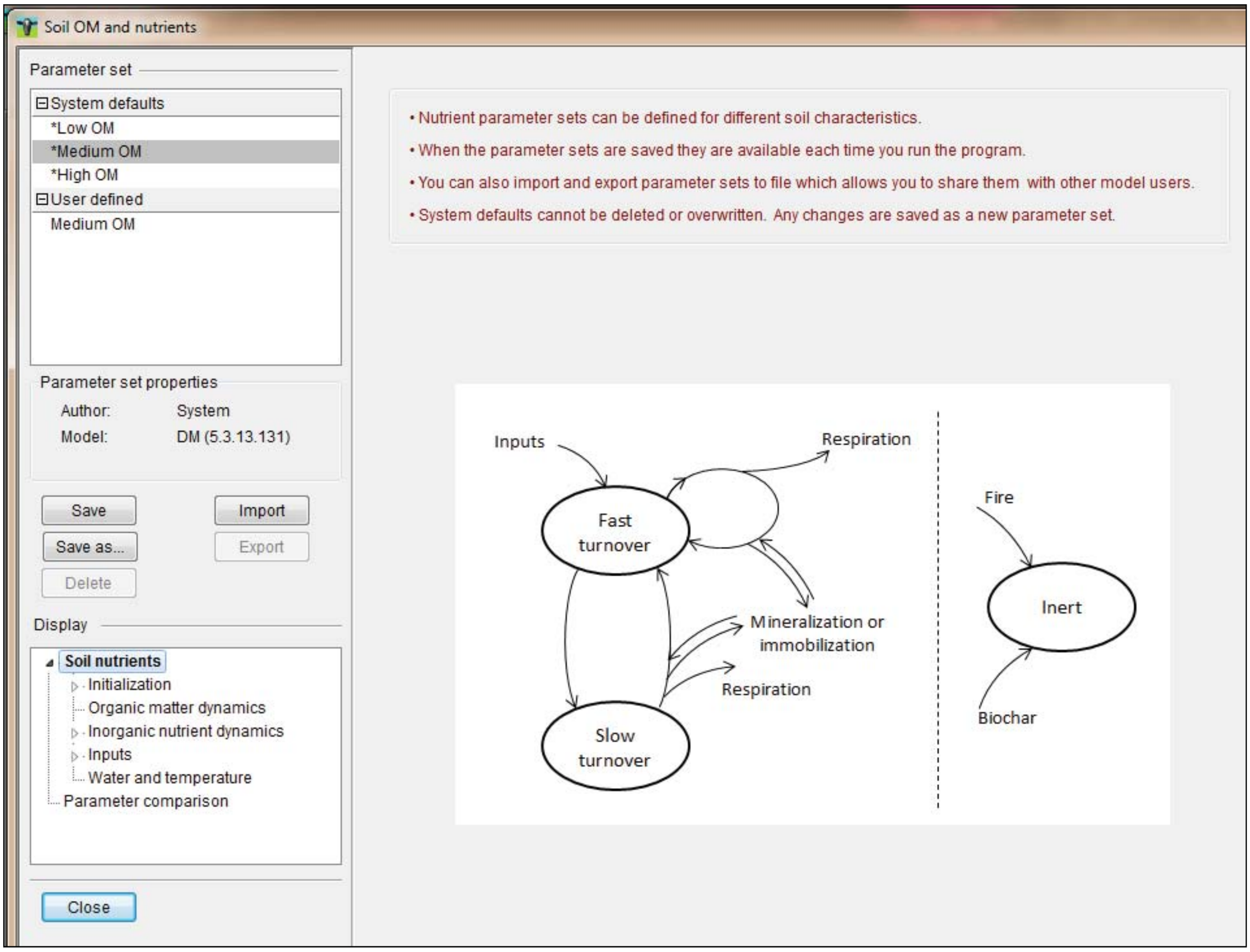


Figure 3.18 Soil parameter sets as affected by different soil characteristics (DairyMod http://imj.com.au/dairymod/)

a. Initialization (Figure 3.19)

This parameter set includes:

- Bulk density for illustration
- Clay fraction for illustration

b. Organic matter dynamics (Figure 3.20)

This parameter set includes:

- Organic matter dynamics parameters
- Display options of daily input and decay rate factors

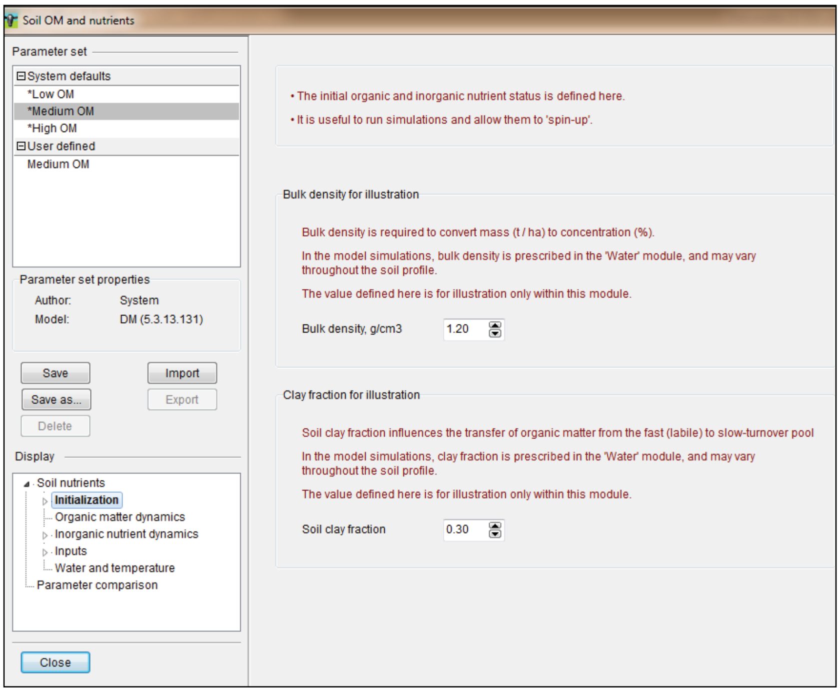


Figure 3.19 Initialization input parameter set (DairyMod http://imj.com.au/dairymod/)

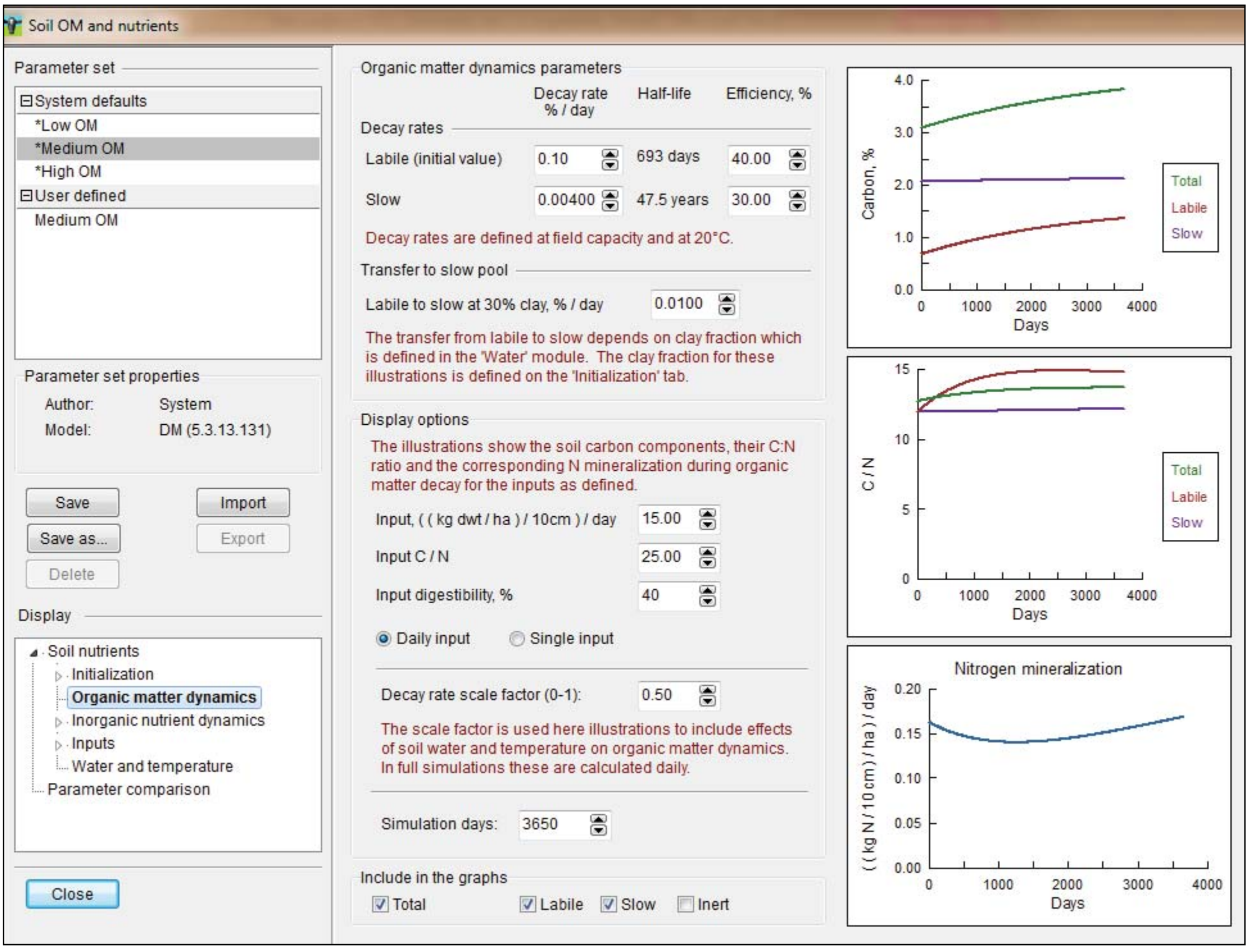


Figure 3.20 Organic matter input parameter set (DairyMod http://imj.com.au/dairymod/)

c. Inorganic nutrient dynamics

This parameter set does not provide an option at the moment to key in inputs. Since inorganic nutrient dynamics involves many processes of mineralization, or immobilization of organic matter, nitrification of ammonium as well as denitrification.

d. Nutrient inputs

This is normally maintained by fertilizer inputs, animal dung and urine as well as small amounts of atmospheric inputs and senescence of plant roots. The fertilizer component is addressesed in the management module.

e. Water and temperature (Figure 3.20)

This parameter set includes:

- Soil water effect
- Temperature effect

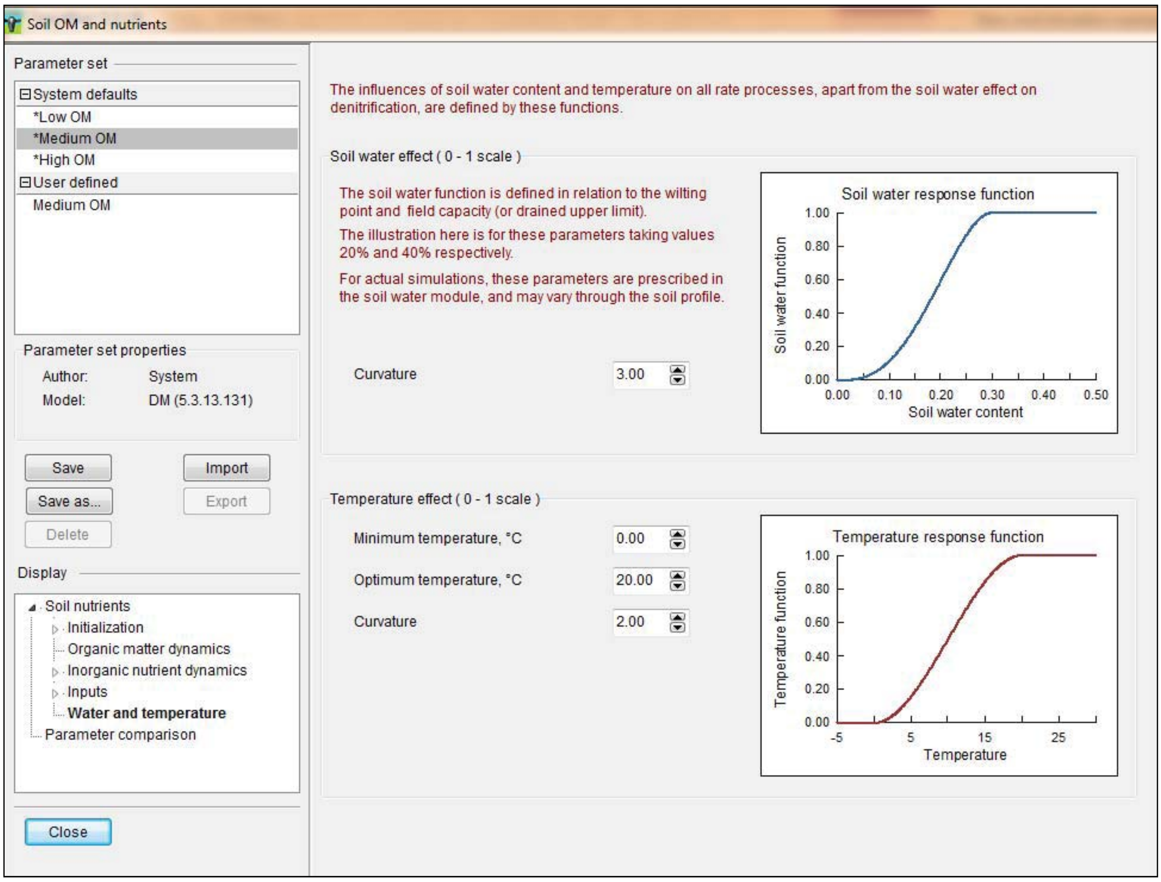


Figure 3.21 Water and temperature input parameter set (DairyMod http://imj.com.au/dairymod/)

3.4 Climate data

Dairy Mod has the function to import local weather data representing a particular region for which the simulation is to be run for (Figure 22). The model makes it easy to upload data from an excel spread sheet. It also provides the function to identify the different climatic input parameters in the spread sheet by selecting the parameter aligned in the programme dropdown menu.

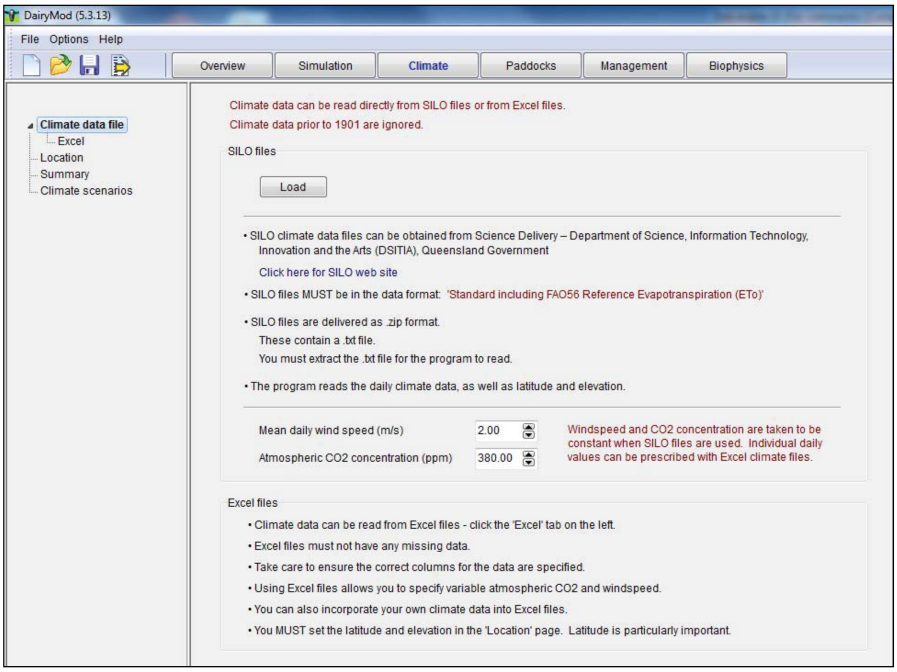


Figure 3.22 Climate file upload function (DairyMod http://imj.com.au/dairymod/)

This section also takes into account the global location (Figure 3.23) where the weather data is captured, and allows the user to change latitude and elevation, etc.

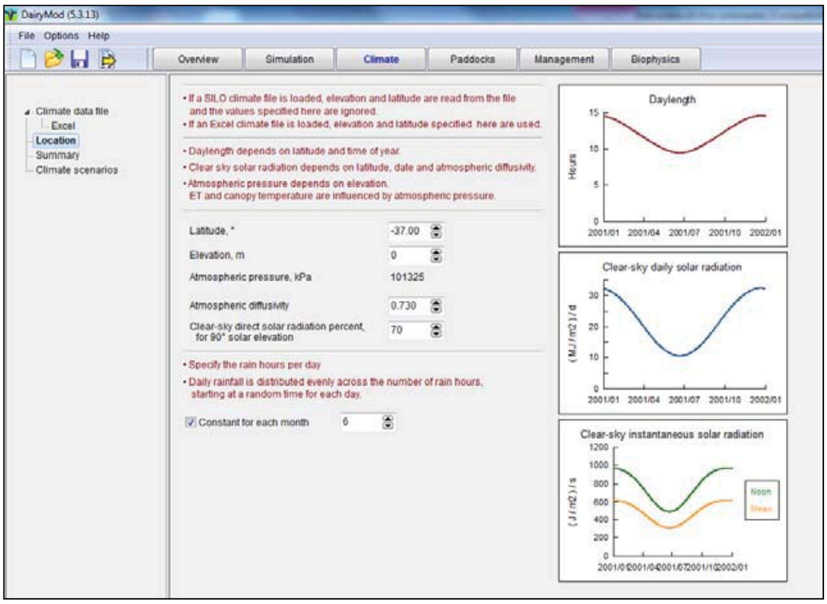


Figure 3.23 Global location parameters (DairyMod http://imj.com.au/dairymod/)

3.5 Management

Dairy Mod provides the option of changing various management factors such as:

- Livestock
- nutrient removal
- nitrogen fertilizer (Figure 3.24)
- Irrigation
- nitrification inhibition
- Fire

a. Nitrogen fertilizer

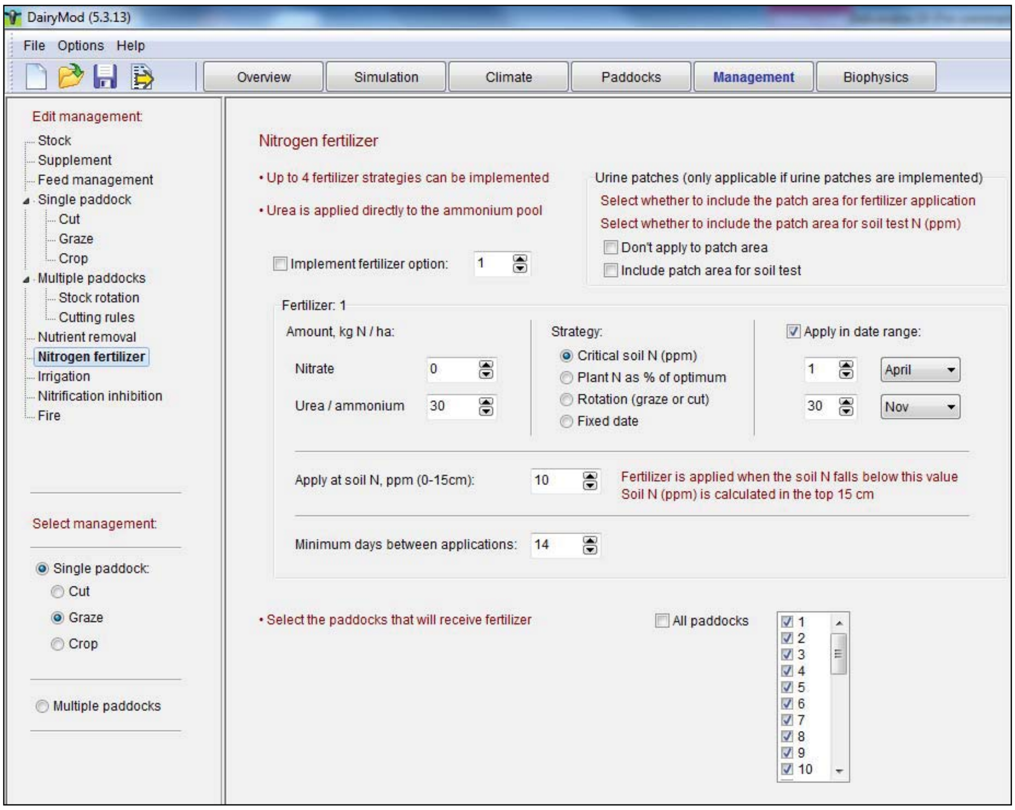


Figure 3.24 Nitrogen fertilizer input parameter set (DairyMod http://imj.com.au/dairymod/)

b. Paddock management

The option to simulate single paddock (Figure 3.25) or multiple paddocks (Figure 3.26) in the model exists too. This can further be linked to the defoliation function of cutting or grazing. With regards to grazing the stocking rate can be adjusted to simulate various particular scenarios.

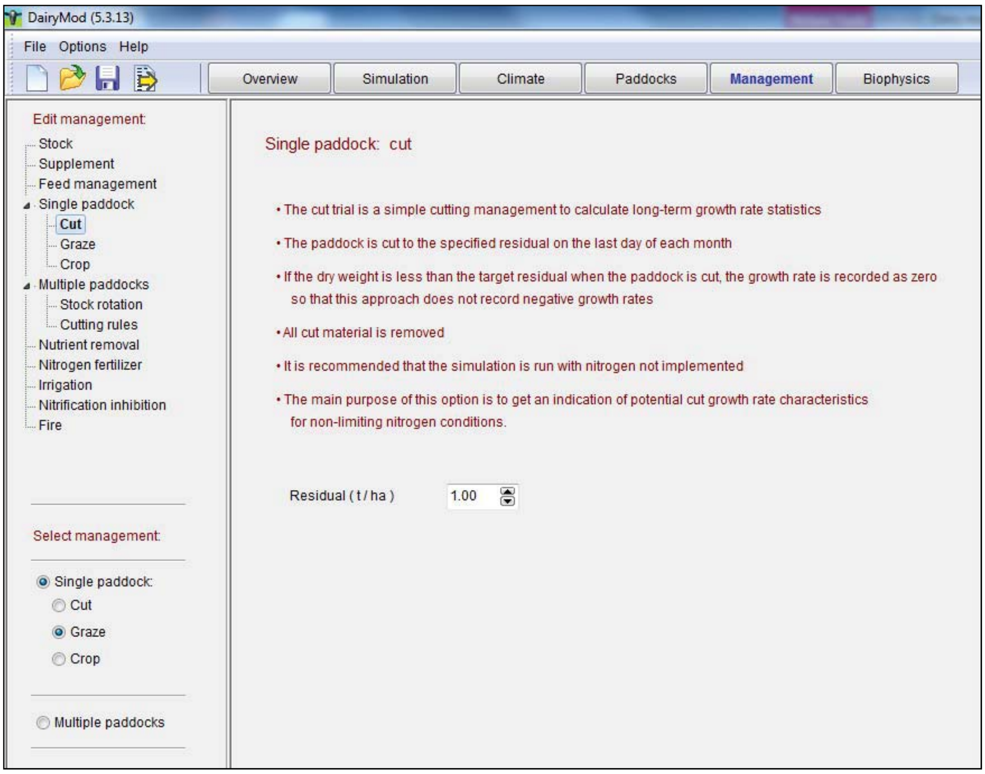


Figure 3.25 Single paddock input parameter set (DairyMod http://imj.com.au/dairymod/)

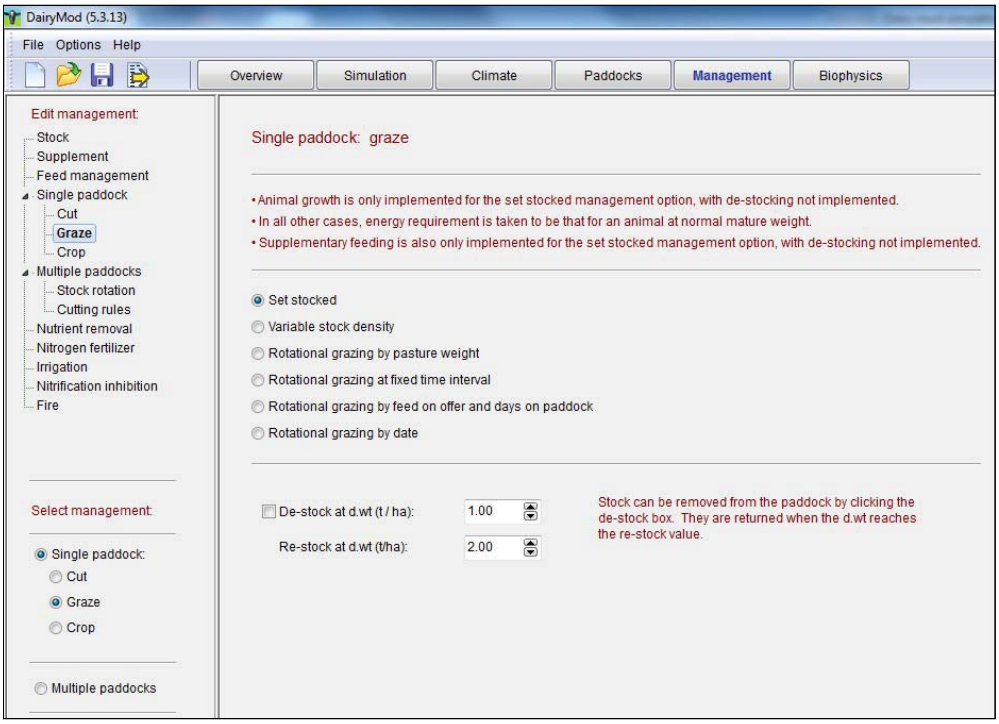


Figure 3.26 Multiple paddock input parameter set (DairyMod http://imj.com.au/dairymod/)

c. Irrigation

The irrigation input parameters (Figure allows the simulations to include the farmers own irrigation system.

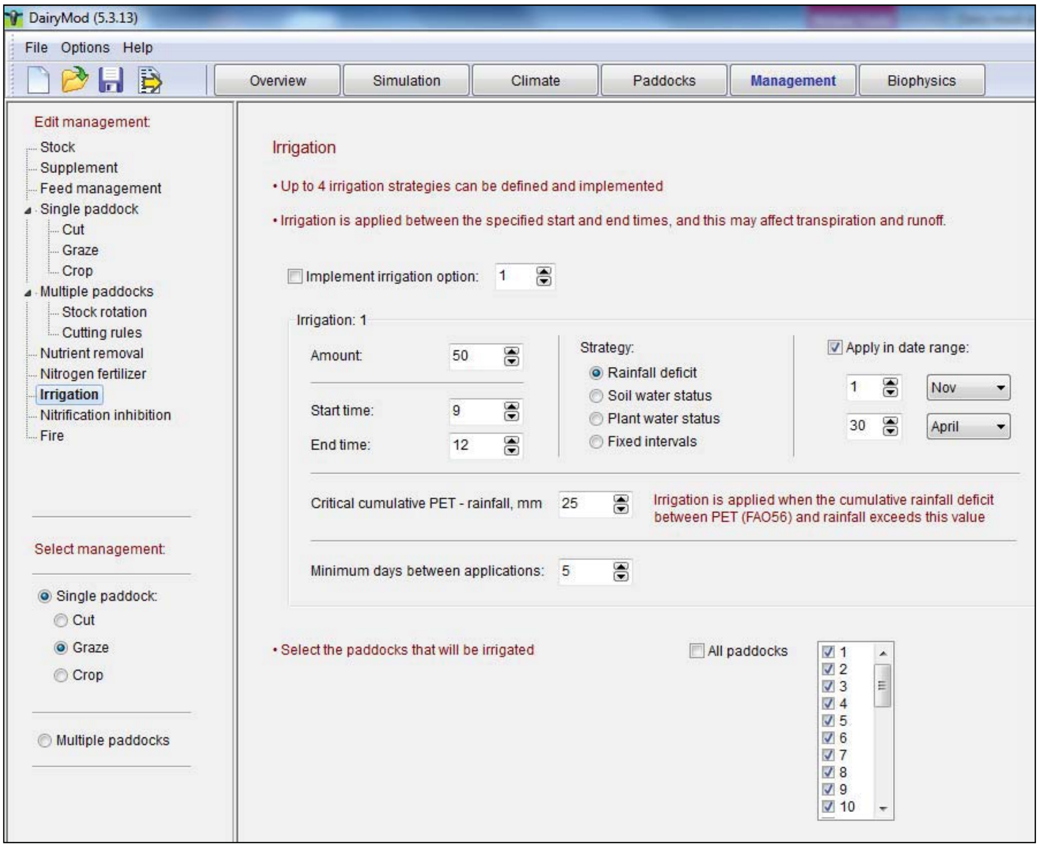


Figure 3.27 Irrigation input parameter set (DairyMod http://imj.com.au/dairymod/)

3.6 Paddocks

This component of the model provides the function of selecting the following input parameters (Figure 3.28):

- Different pasture species used in either the single paddock or multiple paddock grazing or cutting system. Various species defaults occur, and the option exists to alter the data according to local data collected for better representation of a particular farming system.
- Soil hydraulic properties
- Soil organic matter and nutrients

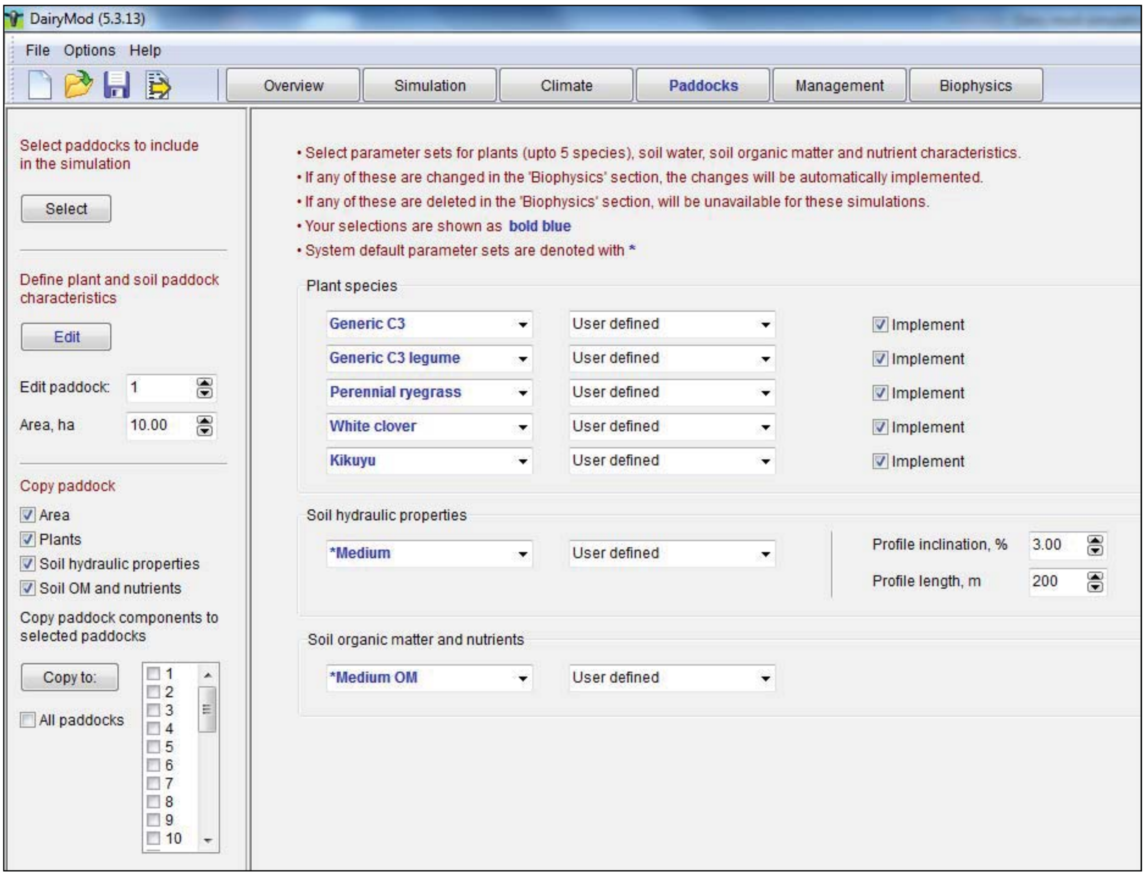


Figure 3.28 Plant species parameter set (DairyMod http://imj.com.au/dairymod/)

CHAPTER 4: 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 (ET_o) 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.

4.1 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 4 are discussed briefly.

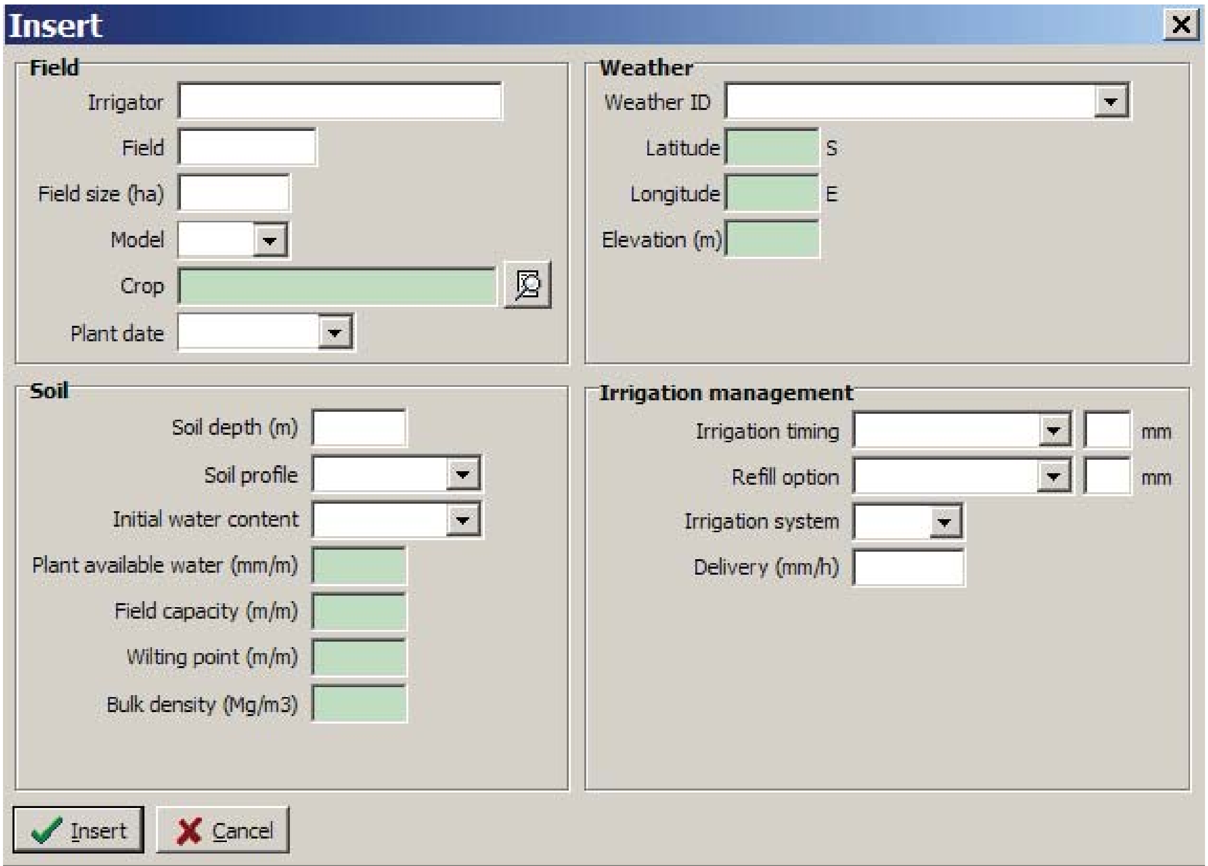


Figure 4.1 Input screen of the SWB irrigator version model

4.1.1 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 simulates growth and water use for lucerne and does not simulate growth and water use for mixed pastures.

4.1.2 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.

4.1.3 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).

4.1.4 Irrigation management

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

4.1.4.1 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 (e.g. 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).

4.1.4.2 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.

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

4.1.4.4 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%)

4.2 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 5).

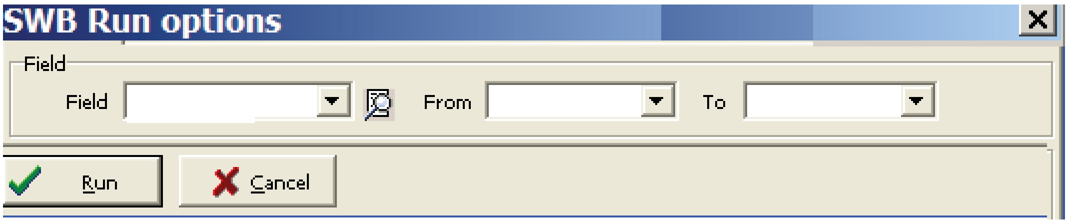


Figure 4.2 SWB run options screen of the irrigator version

4.2 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

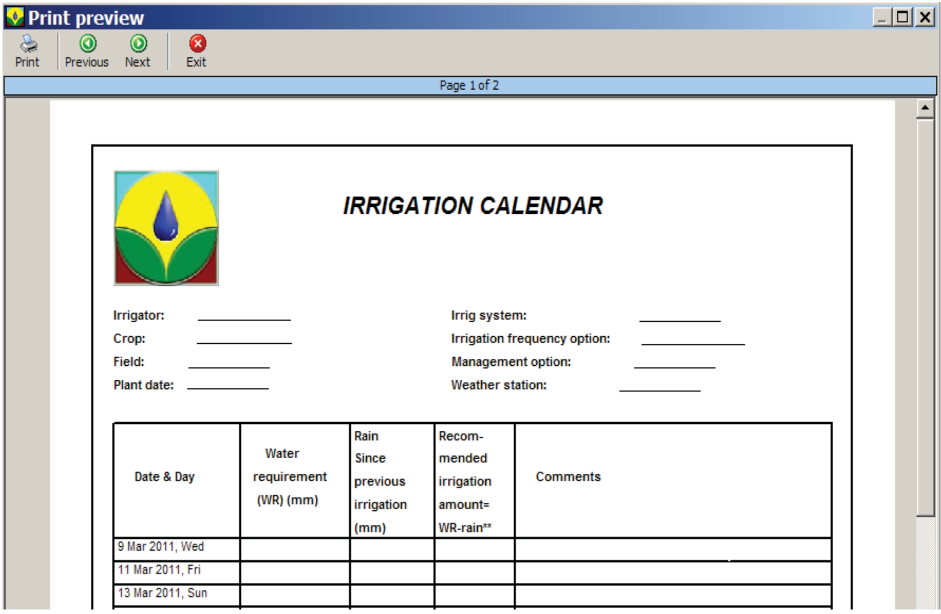


Figure 4.3 Irrigation calendar recommendation output

CHAPTER 5: EXAMPLES OF IRRIGATION REQUIREMENTS FOR LUCERNE and MIXED PASTURE GROWING AREAS

5.1 Production areas

Major lucerne production areas were identified and used in the study and data from these areas were collected and used in the model simulation (Figure 5.1).

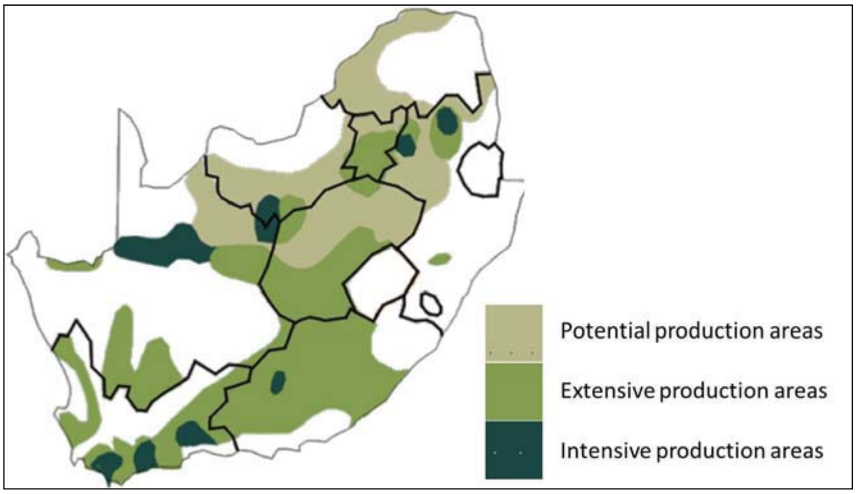


Figure 5.1 The areas where lucerne is planted and the intensity of lucerne production as represented by the different colours (Van Oudshoorn et al., 2001 as cited by Nel, 2012)

During the study, data was collected from different regions were mixed pastures are used.

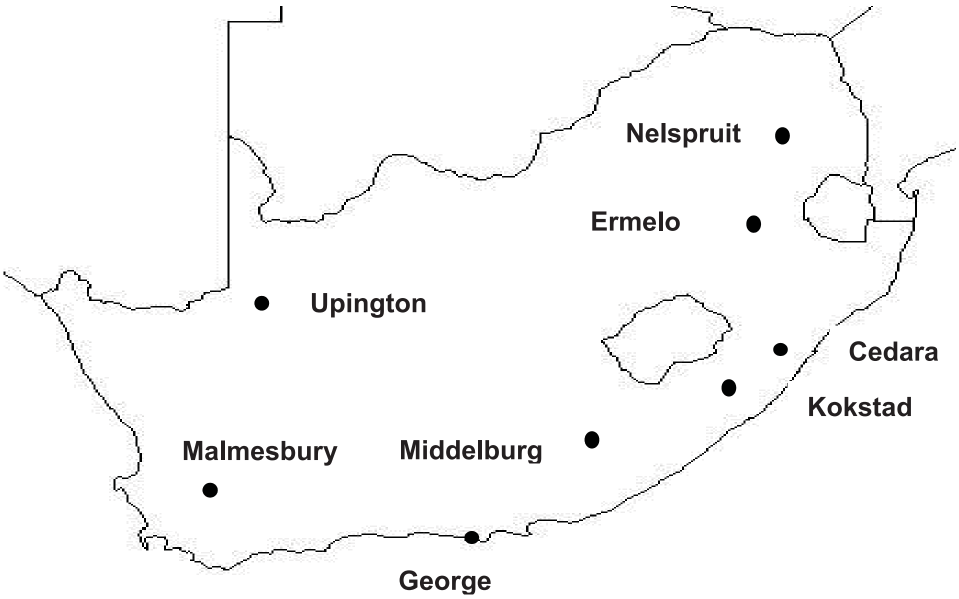


Figure 5.2 Main mixed pasture growing areas of South Africa used in the study

The sites show seasonal variations in rainfall and reference evapotranspiration (ET_o) (Figure 9). Long-term (50 years) rainfall and ET_o for the two major milk producing areas of South Africa. ET_o was calculated according to FAO 56 (Allen et al., 1998) from weather data (including minimum and maximum temperatures).

According to Green (1985), water use ranges between 1200-2100 mm per year depending on weather conditions were reported (Table 5.1). Water use is lowest in the Southern Cape and KwaZulu-Natal while is highest in the Northern Cape this is probably due to higher vapour pressure deficit in the drier parts of the country (Northern Cape and North West). As expected irrigation requirements were dependent on the water use and effective rainfall of a specific region. Similar to water use the irrigation requirements were higher for drier parts of South Africa.

Table 5.1 Water use, irrigation requirement (25 mm per irrigation event) and effective rainfall of lucerne pasture at different regions of South Africa (Green, 1983)

Site	Water use	Irrigation	Effective rainfall	Location
Northern Cape				
Alexander bay	1802	1740	62	28',34'S 16',32'E
Rietfontein Gordonia	2402	2261	141	26',44'S 20', 2' E
Kakamas	2425	2331	94	28',47'S 20', 37' E
P.K. Le Roux dam	2352	2159	193	29',59'S 24', 44' E
Upington	2337	2187	150	28',24'S 21', 16' E
Douglas dam	2125	1908	217	26',28'S 29',56' E
Vioolsdrif	2091	2054	37	28',47'S 17',41'E
Okiep	2090	1977	113	29',36'S 17',52'E
Boegoeberg dam	2048	1719	329	28',10'S 28', 18' E
Sakrivier	2044	1999	45	30',51'S 20',26'E
Western/ Southern Cape				
Lutzville	1846	1717	129	31',36'S 18',26'E
Keisiesvallei – Montague	1442	1274	168	33',42'S 20',0'E
Calvinia	1087	911	176	31',28'S 19'46'E
Citrusdal	2049	1824	225	32',34'S 18',59'E
Rentia – Klawer	1507	1360	147	31',51'S 18',38'E
Robertson	1215	1034	181	31',51'S 18',38'E
Oudtshoorn	1523	1359	164	33',38'S 22',15'E
Kammanassiedam	1759	1599	160	33',39'S 22',24'E
Paul Sauerdam	1106	635	471	33',45'S 24',35'E
Kromriver dam – Humansdorp	1187	831	356	34',0'S 24',30'E

Site	Water use	Irrigation	Effective rainfall	Location
Eastern Cape				
ADDO	1293	1059	234	33',34'S 25',42'E
Aliwal Noord	1373	949	424	30',41'S 26',43'E
Cradock	1710	1486	224	32',10'S 25',37'E
Queenstown	1101	795	306	31',53'S 26',53'E
Middelburg – Grootfontein	1650	1439	211	33',58'S 22',25'E
Somerset East	1358	1014	344	32',44'S 25',35'E
Dohne	1376	942	434	32',31'S 27',28'E
Jansenville	1458	1279	179	32',56'S 24',40'E
Katrivier dam	1468	1140	328	32',34'S 26',46'E
Beaufort West	2008	1907	101	32',18'S 22',40'E
KwaZulu-Natal/Eastern Highveld				
Estcourt	1204	962	242	29',1'S 29',52'E
Makatini	1597	1254	343	27',24'S 32',11'E
Charters creek	1275	811	464	28',12'S 32',25'E
Lydenburg	1238	804	434	25',6'S 30', 28' E
North west				
Vredendal	1503	1401	102	31',40'S 18',29'E
Armoedsvlakte	1698	1373	325	26',57'S 24', 38' E
Barberspan	1759	1176	583	26',34'S 25', 35' E
Smart Syndicate – Britstown	1979	1860	119	30',37'S 23',18'E
Mafeking	1966	1616	350	25',51'S 25', 38' E
Kimberley	1857	1586	271	28',48'S 24', 46' E
Potchefstroom	1297	886	411	26',44'S 27', 5' E
Prieska	1579	1391	188	29',40'S 22', 45' E
Kuruman	1567	1285	282	27',28'S 23', 26' E
Free State				
Balkfontein	1608	1208	400	27',24'S 26', 30' E
Bethlehem	1328	918	410	28',10'S 28', 18' E
Bloemfontein	1500	1165	335	28',57'S 26', 20' E
Fauresmith	1625	1337	288	29',46'S 25', 19' E

Site	Water use	Irrigation	Effective rainfall	Location
Kalkfontein dam	1406	1176	230	29',30'S 25', 13' E
Gauteng/Northern part				
Marnitz	1793	1564	229	23',10'S 28', 23' E
Pietersburg	1711	1456	255	23',52'S 29', 27' E
Potgietersrus	1355	1006	349	24',11'S 29', 1' E
Roodeplaat	1621	1232	389	25',35'S 28', 21' E
Marico Bosveld	1651	1269	382	25',28'S 26', 24' E
Kroondal	1327	888	439	25',43'S 27', 18' E
Loskopdam – Groblersdal	1551	899	652	0',2'S 52', 52' E
Vaalharts	1483	1228	255	27',57'S 24', 50' E
Towoomba	1153	804	349	24',54'S 28', 20' E
Vaalwater	1324	980	344	24',17'S 28', 6' E
Zebediela	1480	1115	365	24',19'S 29', 19' E

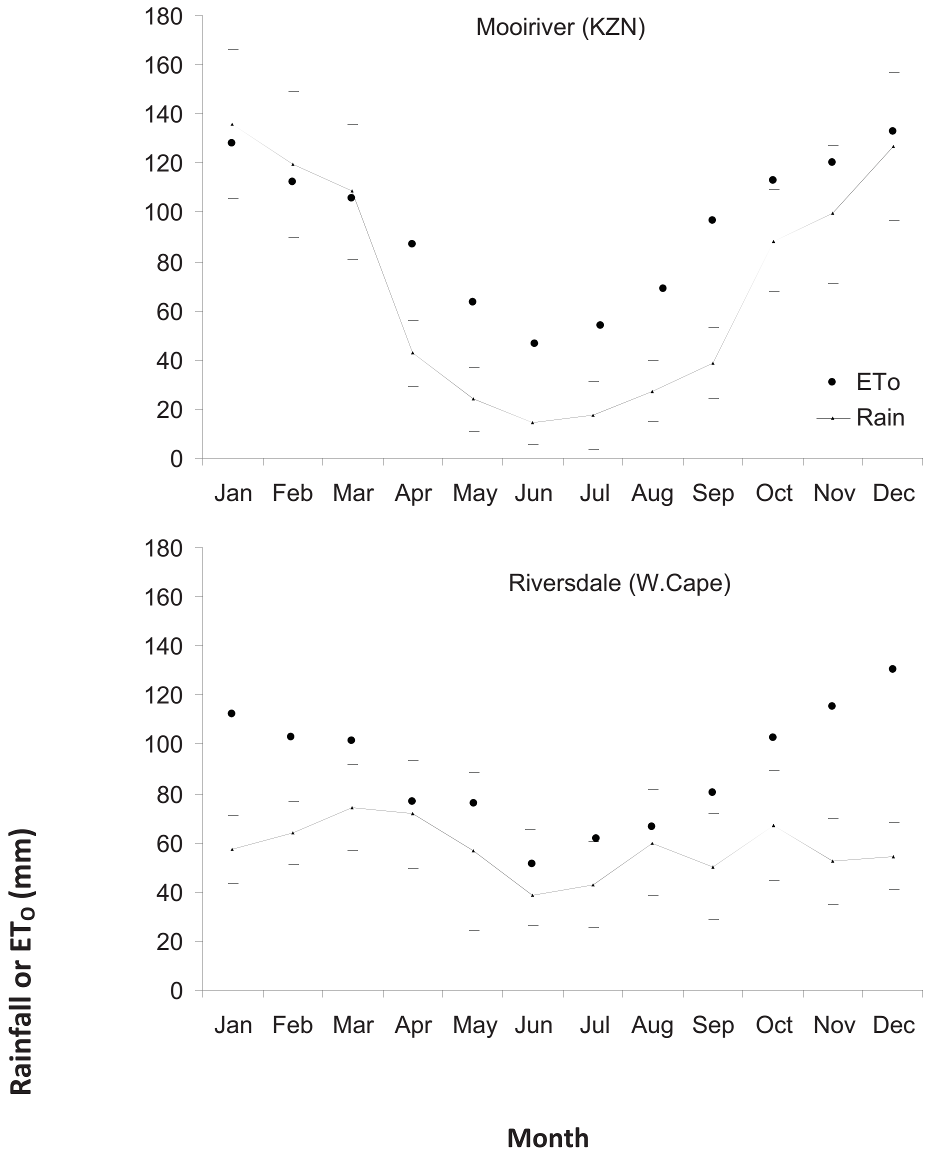


Figure 5.3 Monthly long-term means (1950-2000) of reference evapotranspiration (ET_o) and precipitation in two common grass/legume pastures growing areas

5.2 Estimated pasture crop water requirements – Mono specific pastures (ON STATION)

5.2.1 Kikuyu

Table 5.2 Monthly Crop coefficients (K_c) and crop water requirements for mono specific and mixed pasture crops

	MRCH	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
ET_o (mm.day^{-1})	3.4	3.2	2.8	2.3	2.5	2.7	3.7	4.3	5.8
Calculated Water Use (ET_c) (mm.day^{-1})	2.5	2.2	1.8	---	---	---	1.5	2.7	4.4
Calculated Water Use (ET_c) (mm.week^{-1})	17.6	15.7	12.6	---	---	---	10.2	18.8	30.5
Crop coefficient (K_c)	**0.8**	**0.7**	**0.7**	**---**	**---**	**---**	**0.4**	**0.6**	**0.8**

The data presented for monospecific pastures illustrates the different water requirements per week, which relates to the physiological growth stage (maturity) of the pasture at a specific period after defoliation. It is evident that less water needs to be applied to a pasture in the first two weeks after defoliation. In this time the evaporation factor is at its highest since there is a small canopy present to cover the soil surface. Once the pasture canopy develops more water is available for pasture growth. It is also interesting to note that some pasture species require less water once the pasture stand goes into a reproductive phase.

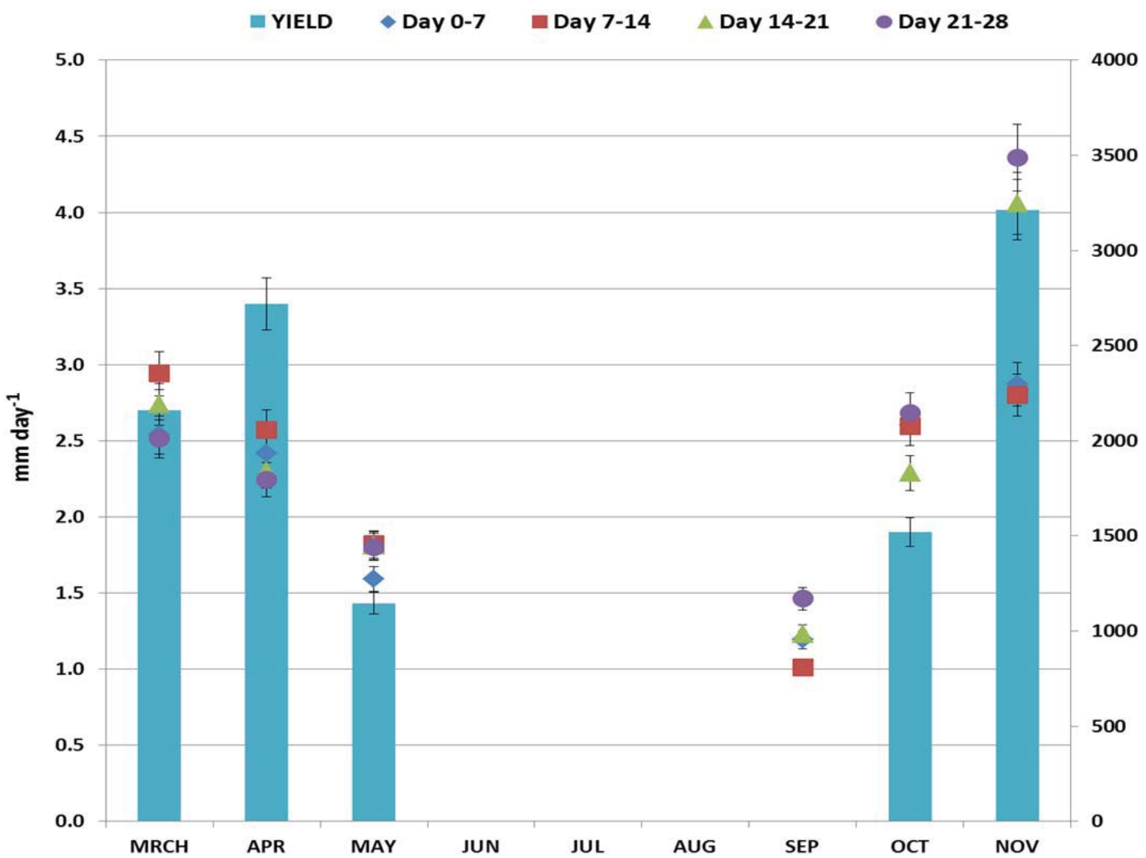


Figure 5.4 Relationship between kikuyu yield (kg DM.ha^{-1}) and weekly mean crop water requirements (mm.day^{-1}) for fixed monthly harvest cycles for the growing season March to November on the Hatfield Experimental farm

5.2.2 Tall fescue

Table 5.3 Monthly Crop coefficients (K_c) and crop water requirements for mono specific and mixed pasture crops

	MRCH	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
ET_o (mm.day^{-1})	3.5	3.2	2.8	2.3	2.5	2.7	3.7	4.3	5.8
Calculated Water Use (ET_c) (mm.day^{-1})	2.1	2.6	2.6	2.2	1.2	1.9	2.6	3.0	5.3
Calculated Water Use (ET_c) (mm.week^{-1})	14.5	18.3	18.2	15.2	8.7	13.2	17.9	21.3	37.2
Crop coefficient (K_c)	**0.6**	**0.8**	**0.9**	**1.0**	**0.5**	**0.7**	**0.7**	**0.7**	**0.9**

It was interesting to observe that the perennial tufted and temperate tall fescue species had a relatively uniform water use from after the day of defoliation to the day of next defoliation. It was however evident that in the extreme warmer months (November), the pasture required more water once the canopy had developed at 21 days and went into bloom quicker than normal. The following week the plant used a significant amount of water to sustain the canopy developed.

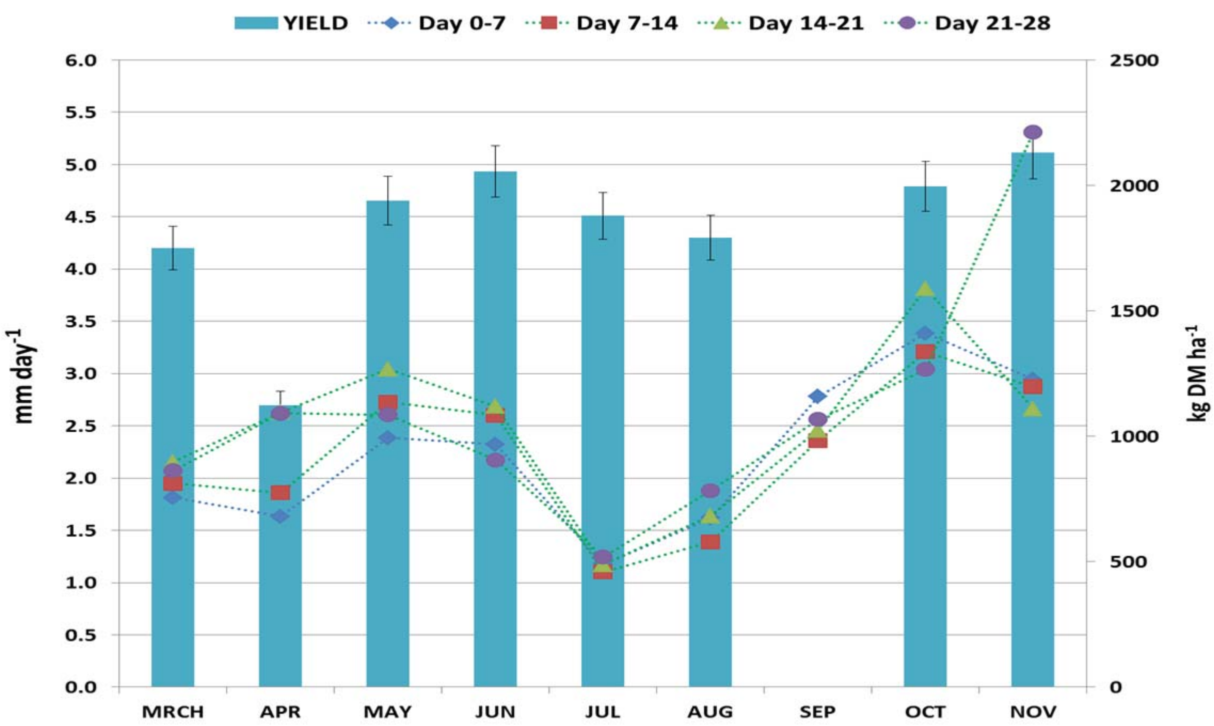


Figure 5.5 Relationship between Tall fescue yield (kg DM.ha^{-1}) and weekly mean crop water requirements (mm.day^{-1}) for fixed monthly harvest cycles for the growing season March to November on the Hatfield Experimental farm

5.2.3 Lucerne

Table 5.4 Monthly Crop coefficients (K_c) and crop water requirements for lucerne (area without frost)

	MRCH	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
ET_o (mm.day^{-1})	4.0	2.7	2.3	1.9	2.5	2.7	3.7	4.3	5.8
Calculated Water Use (ET_c) (mm.day^{-1})	2.8	3.3	2.2	1.5	2.7	1.9	2.6	3.1	5.6
Calculated Water Use (ET_c) (mm.week^{-1})	19.8	23.3	15.5	10.4	18.6	13.2	17.9	21.9	39.2
Crop coefficient (K_c)	**0.7**	**1.2**	**1.0**	**0.8**	**1.1**	**0.7**	**0.7**	**0.7**	**1.0**

Similarly to tall fescue, lucerne enters into a reproductive phase quicker and experiences an increased water requirement in the last week of the harvest cycle in the extremely hot months. This increased water requirement is to sustain the canopy in the climatic conditions with a high evaporative demand.

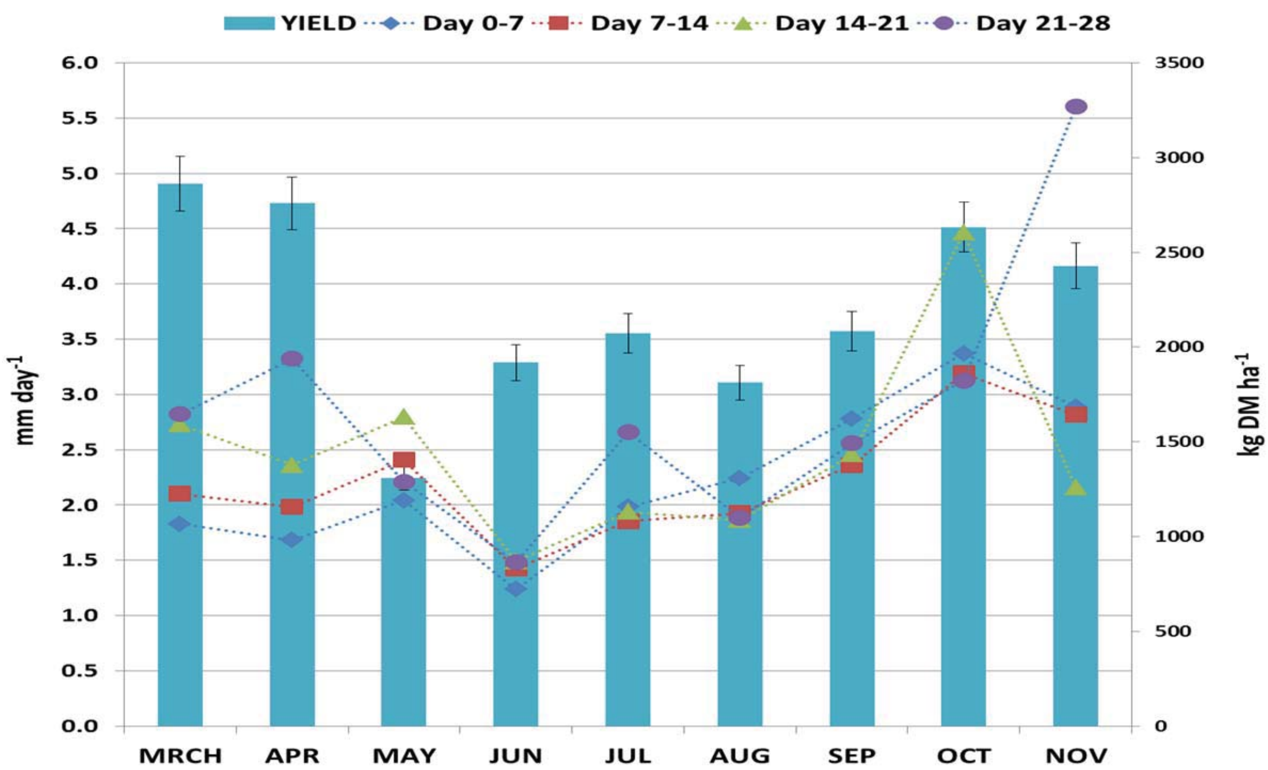


Figure 5.6 Relationship between Lucerne yield (kg DM.ha^{-1}) and weekly mean crop water requirements (mm.day^{-1}) for fixed monthly harvest cycles for the growing season March to November on the Hatfield Experimental farm

5.2.4 White clover

Table 5.5 Monthly Crop coefficients (K_c) and crop water requirements for white clover pasture crop

	MRCH	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
ET_o (mm.day^{-1})	3.4	3.2	2.8	2.3	2.5	2.7	3.7	4.3	5.8
Calculated Water Use (ET_c) (mm.day^{-1})	2.2	4.3	3.9	2.1	1.6	2.9	2.7	3.3	5.1
Calculated Water Use (ET_c) (mm.week^{-1})	15.2	30.0	27.4	15.0	11.3	20.0	19.2	23.3	35.4
Crop coefficient (K_c)	**0.7**	**1.3**	**1.4**	**1.0**	**0.7**	**1.1**	**0.8**	**0.8**	**0.9**

White clover growth presented a similar response to climatic conditions as other temperate species. Interestingly, white clover required more water in the actively growing months i.e. April, May and October. Similarly white clover had a more uniform water use during different weeks in the harvest cycle in the winter growing months.

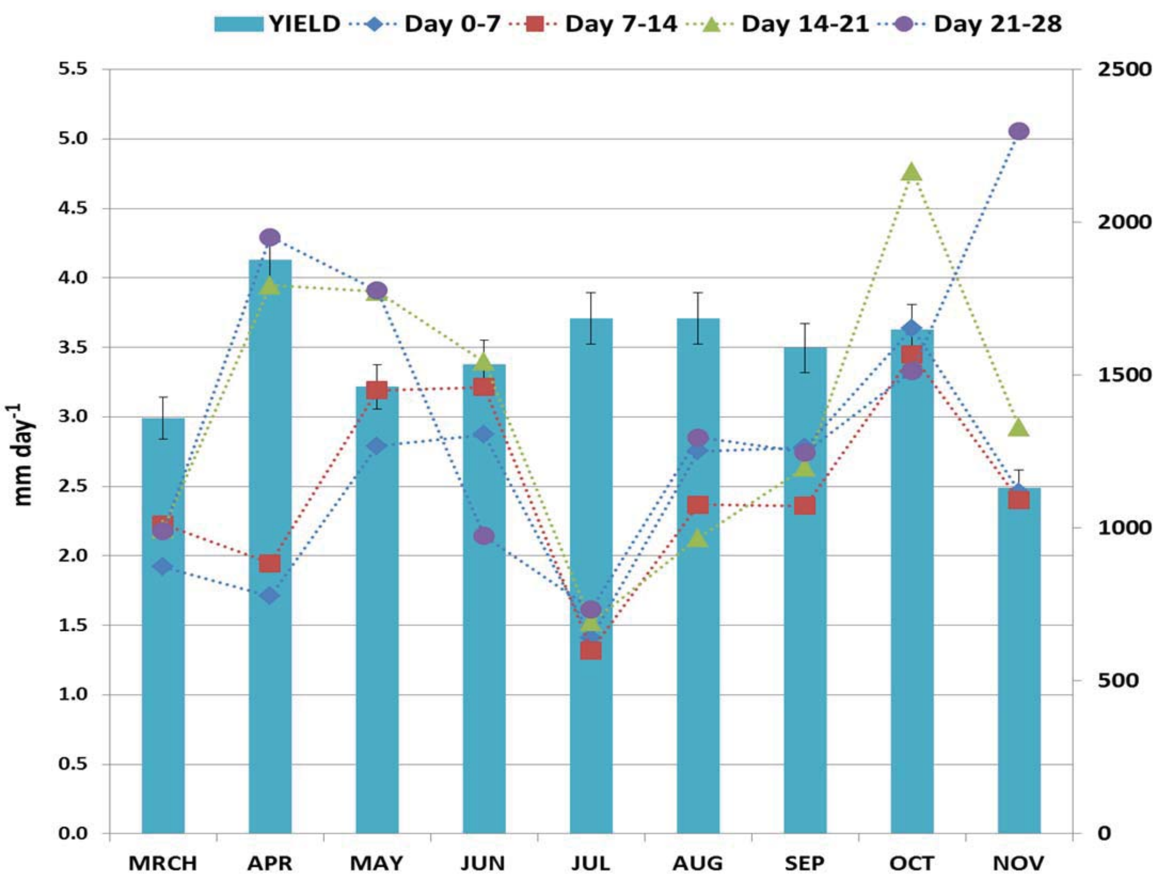


Figure 5.7 Relationship between White clover yield (kg DM.ha^{-1}) and weekly mean crop water requirements (mm.day^{-1}) for fixed monthly harvest cycles for the growing season March to November on the Hatfield Experimental farm

5.3 Estimated pasture crop water requirements – Mixed pastures (ON STATION)

The data presented for the mixed pastures clearly highlights the value of combined species from a water use perspective. It must be remembered that mixed pastures can mean the following: a) a perennial subtropical pasture oversown with an annual/perennial temperate species providing growth in both summer and winter months or b) two temperate species, either grass-grass or grass-legume mixtures with slow to no growth in summer months.

5.3.1 Kikuyu – Lucerne pasture

Table 5.6 Monthly Crop coefficients (K_c) and crop water requirements for mixed kikuyu/lucerne pasture crops

	MRCH	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
ET_o (mm.day^{-1})	3.4	3.7	3.3	2.7	2.5	3.4	3.7	5.3	7.4
Calculated Water Use (ET_c) (mm.day^{-1})	2.3	3.3	2.6	2.3	1.6	2.2	2.4	3.7	5.9
Calculated Water Use (ET_c) (mm.week^{-1})	16.4	23.2	18.2	15.8	11.3	15.3	16.6	25.9	41.4
Crop coefficient (K_c)	**0.7**	**0.9**	**0.8**	**0.9**	**0.7**	**0.7**	**0.7**	**0.7**	**0.8**

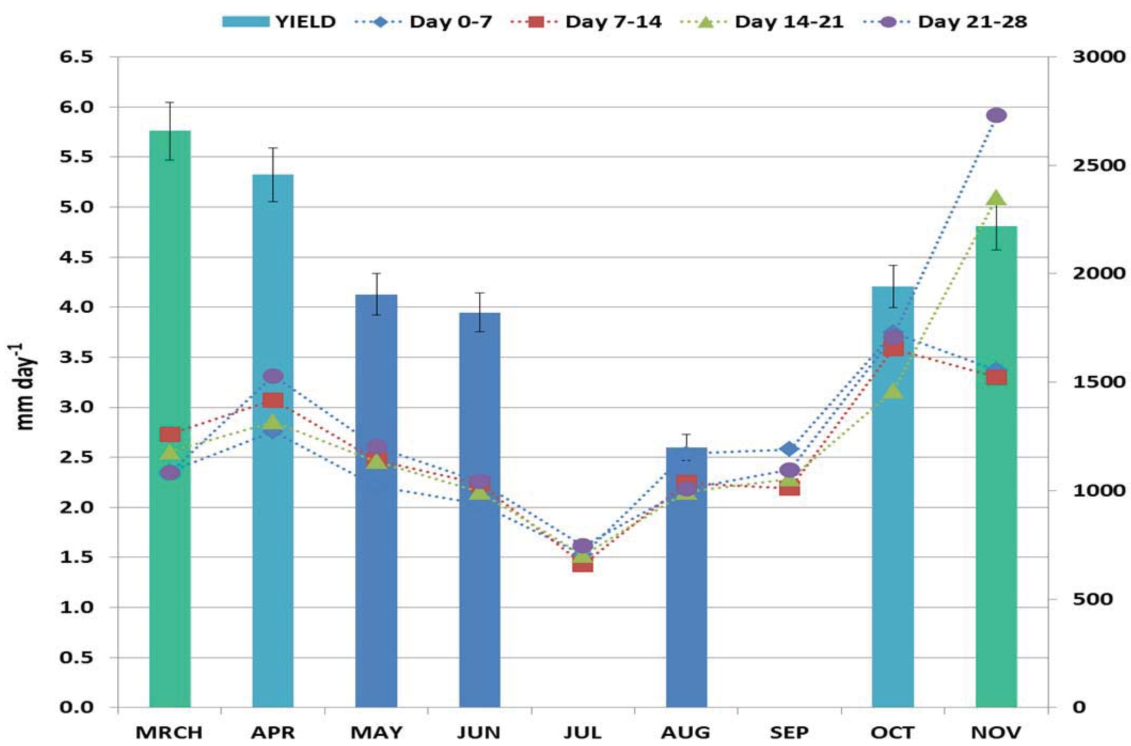


Figure 5.8 Relationship between mixed kikuyu/lucerne yield (kg DM.ha^{-1}) and weekly mean crop water requirements (mm.day^{-1}) for fixed monthly harvest cycles for the growing season March to November on the Hatfield Experimental farm

It is always important to take note of the vigour of the individual species in the mixture, since certain individual species become more dominant than others, as influenced by either preferential climatic conditions or management intensity. The water requirement of a mixed pasture will depend on the dominant component of the mixture in that species specific growth season. This holds true for the subtropical/temperate species mixture, and very similar water use trends are noticeable for the different species in the mixture as seen for the monospecific pastures.

5.3.2 Tall fescue – White clover

Table 5.7 Monthly Crop coefficients (K_c) and crop water requirements for tall fescue/white clover mixed pasture crops

	MRCH	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
ET_o (mm.day^{-1})	3.4	3.2	2.8	2.3	2.5	2.7	3.7	4.3	5.8
Calculated Water Use (ET_c) (mm.day^{-1})	2.0	3.4	3.3	2.2	1.6	2.0	2.6	3.2	5.3
Calculated Water Use (ET_c) (mm.week^{-1})	14.1	23.5	23.3	15.2	11.3	14.1	17.9	22.7	37.2
Crop coefficient (K_c)	**0.6**	**1.1**	**1.2**	**1.0**	**0.7**	**0.8**	**0.7**	**0.8**	**0.9**

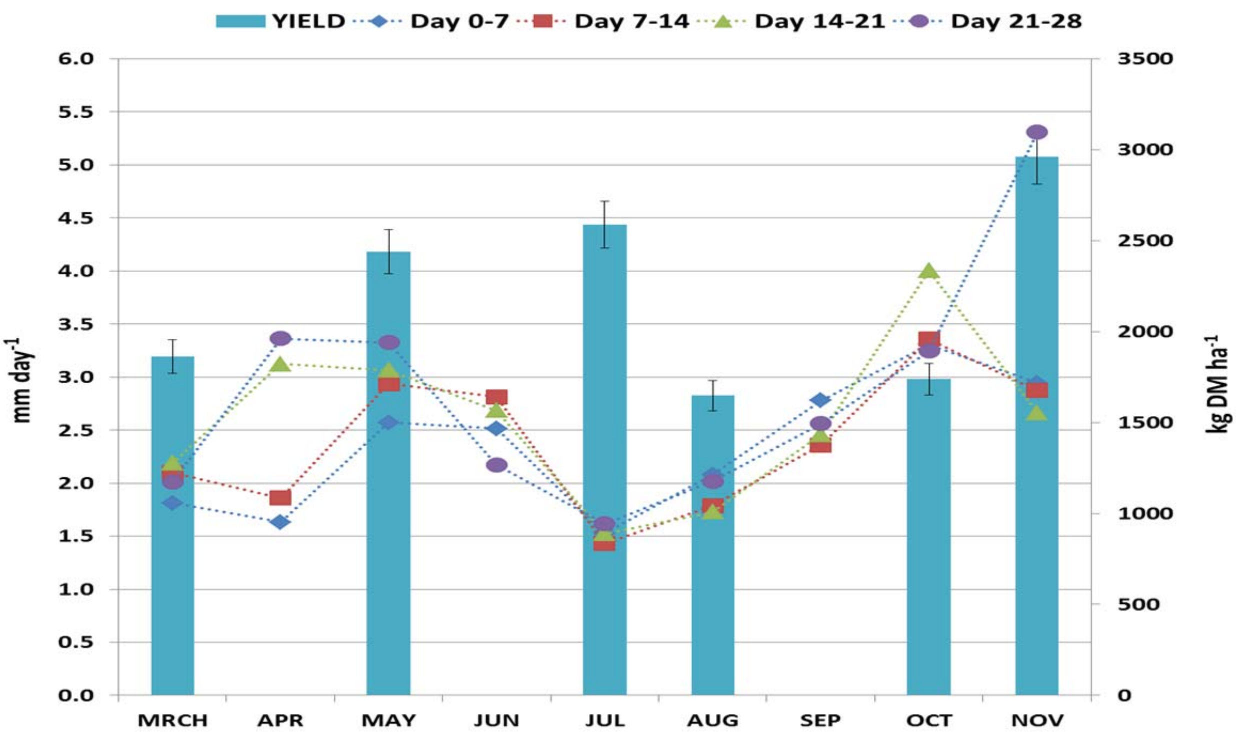


Figure 5.9 Relationship between mixed tall fescue/white clover pasture yield (kg DM.ha^{-1}) and weekly mean crop water requirements (mm.day^{-1}) for fixed monthly harvest cycles for the growing season March to November on the Hatfield Experimental farm

The tall fescue/white clover mixture presented a different scenario, illustrating improved water use and water use efficiency than the individual components. The data does however indicate that in some months there is either a lower yield or slightly higher/lower protein value than the monospecific pastures. It was also important to observe that the white clover species became dominant in the mixture and is a function of the species growth habit (strongly rhizomatous and stoloniferous) and becomes extremely vigorous due to intensive defoliation practices, i.e. mechanical harvesting.

5.3.2 Tall fescue – Lucerne

Table 5.8 Monthly Crop coefficients (K_c) and crop water requirements for tall fescue/lucerne mixed pasture crops

	MRCH	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
ET_o (mm.day^{-1})	3.8	3.2	2.8	2.3	2.5	2.7	3.7	4.3	5.8
Calculated Water Use (ET_c) (mm.day^{-1})	2.4	2.9	2.6	2.0	2.0	2.0	2.4	2.9	5.1
Calculated Water Use (ET_c) (mm.week^{-1})	17.1	20.2	18.4	14.2	13.9	14.1	16.6	20.6	35.8
Crop coefficient (K_c)	**0.7**	**0.9**	**1.0**	**0.9**	**0.8**	**0.8**	**0.7**	**0.7**	**0.9**

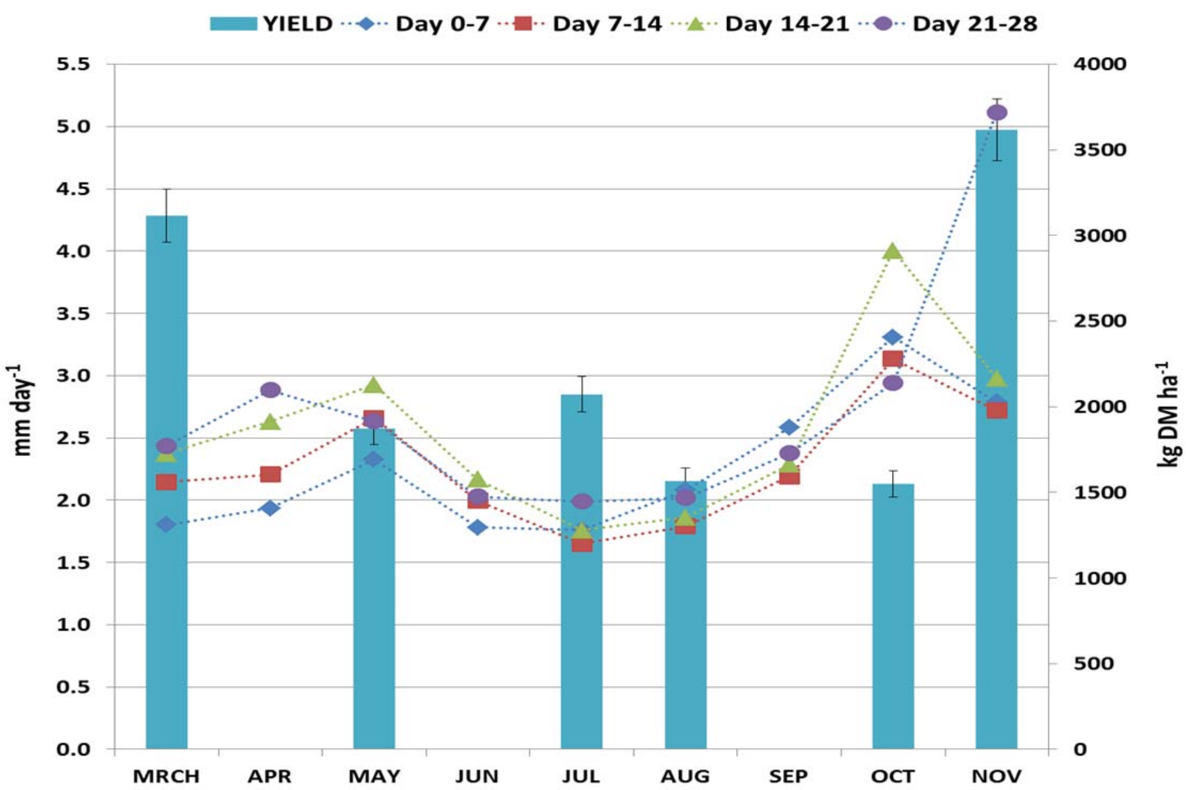


Figure 5.10 Relationship between mixed tall fescue/lucerne pasture yield (kg DM.ha^{-1}) and weekly mean crop water requirements (mm.day^{-1}) for fixed monthly harvest cycles for the growing season March to November on the Hatfield Experimental farm

This mixture presented a more balanced response to climatic conditions and management, but did however become less efficient in the warmer summer months. The water use requirements of this mixture were reflective of the growing seasons. Interestingly, the data for this mixture illustrated that the temperate species will enter into the reproductive phase quicker in the harvest cycle than in their actual growing season, and this results in the mixed pasture using more water to sustain the canopy cover in these months.

5.4 Estimated pasture crop water requirements – ON FARM

5.4.1 Lucerne (North West Province)

Table 5.9 Crop growth parameters for lucerne production areas with frost

	JAN	FEB	MRCH	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
ET_o (mm.day^{-1})	6.4	5.9	4.7	4.1	3	3.1	3.2	4	5.3	6.4	6.7	6.5
Crop coefficient (K_c)	0.85	0.85	0.9	0.8	0.6	0.5	0.5	0.6	0.7	0.85	0.9	0.95
Calculated Water Use (ET_c) (mm.day^{-1})	5.4	5.0	4.2	3.3	1.8	1.6	1.6	2.4	3.7	5.4	6.0	6.2

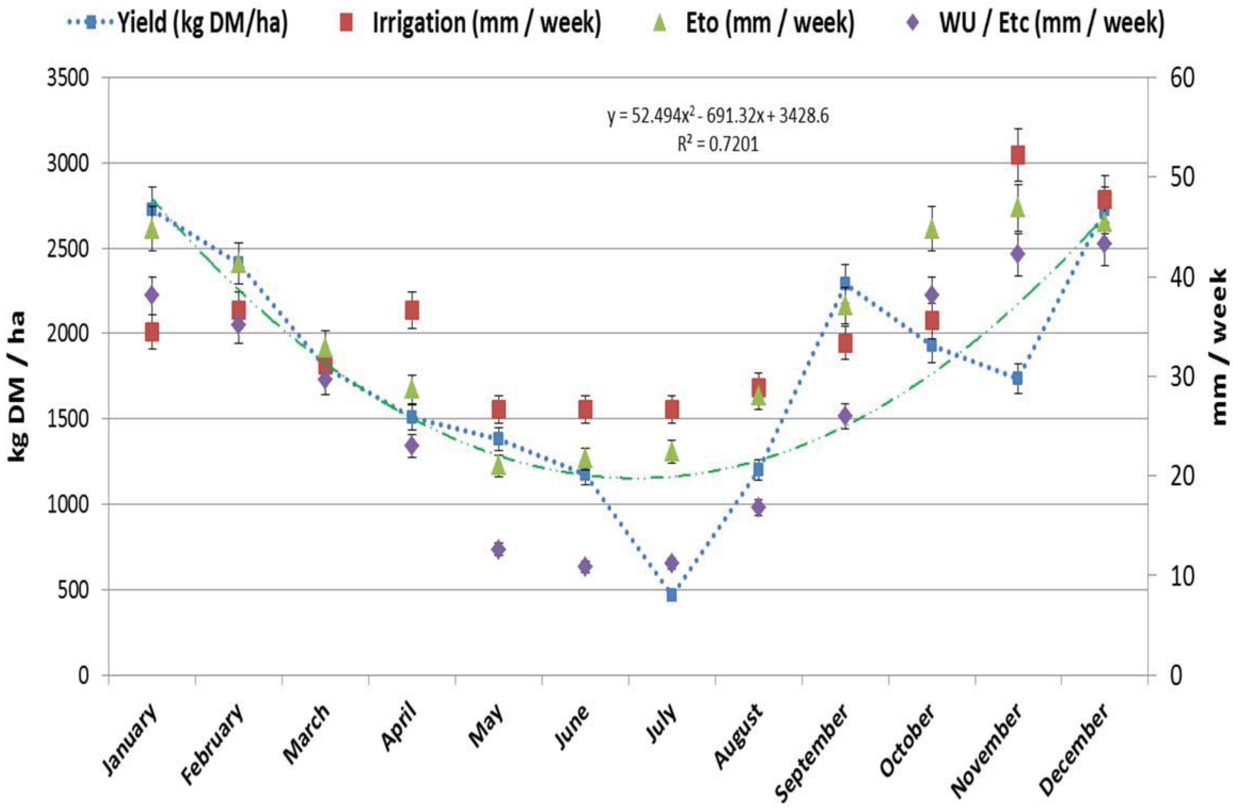


Figure 5.11 Relationship between measured dry matter yield (kg DM.ha^{-1}) and pasture crop water requirements (mm.week^{-1}) and precipitation (mm.month^{-1}) received over 2013-2015 growing season

5.4.2 Mixed kikuyu/ryegrass pasture (Grazed)

Table 5.10 Crop growth parameters for mixed kikuyu/ryegrass pastures

	JAN	FEB	MRCH	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
ET_o (mm.day^{-1})	4.3	4.1	3.5	3	2.4	2	2.2	3	3.4	3.7	4.1	4.3
Crop coefficient (K_c)	0.7	0.7	0.6	0.6	0.65	0.55	0.5	1	0.75	0.75	0.7	0.7
Calculated Water Use (ET_c) (mm.day^{-1})	3	2.9	2.1	1.8	1.6	1.1	1.1	3.0	2.6	2.8	2.9	3.0

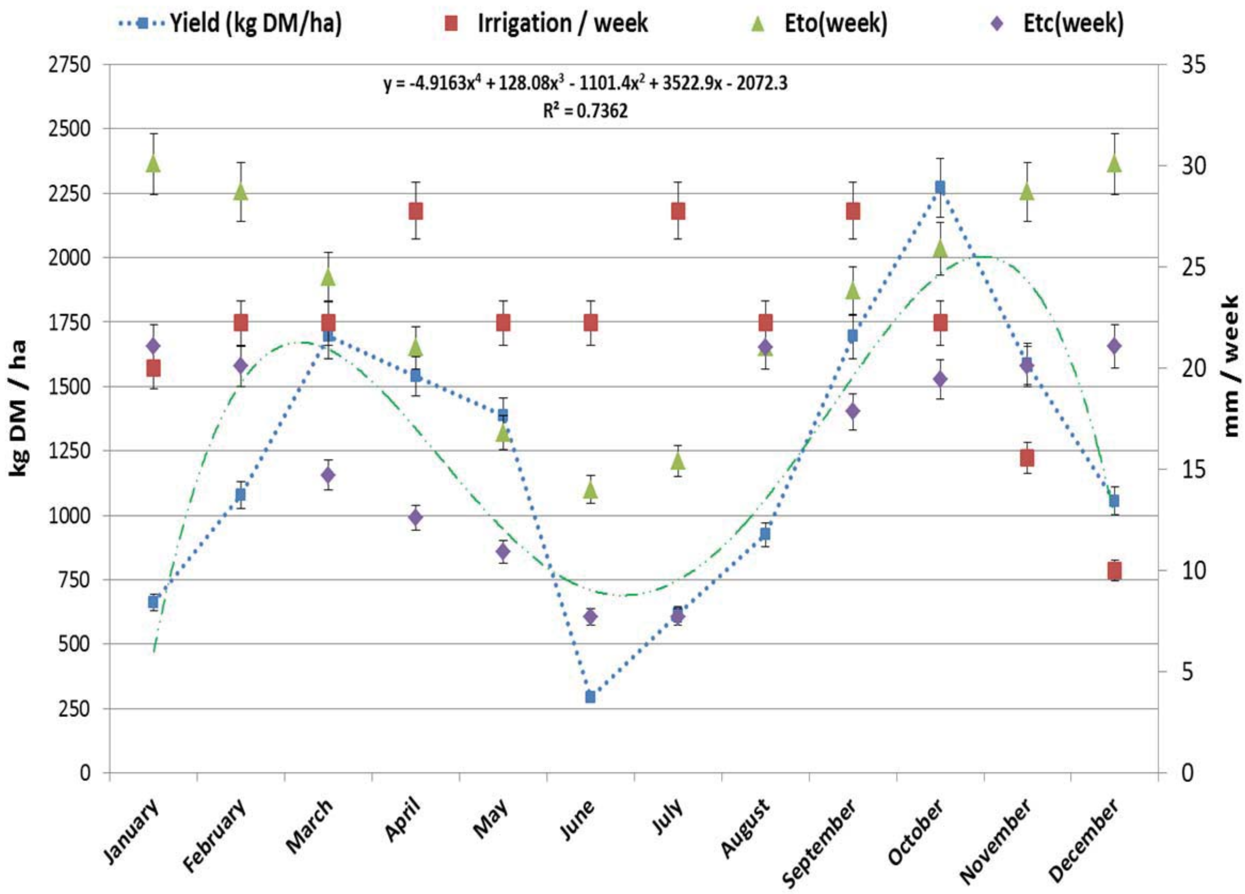


Figure 5.12 Relationship between measured dry matter yield (kg DM.ha^{-1}) and pasture crop water requirements (mm.week^{-1}) and precipitation (mm.month^{-1}) received over 2013-2015 growing season

5.5 Estimated water requirements

Using calculated crop coefficients which are defined as the ratio of ET determined from researched pastures and their soil surfaces to reference ET as defined by weather data, can help establish pasture irrigation requirements (Allen et al., 1998).

$$ET_c = K_c\, ET_o$$

Where:

ET_c *crop evapotranspiration [mm* d^{-1}*]*
K_c *crop coefficient [dimensionless]*
ET_o *reference crop evapotranspiration [mm* d^{-1}*]*

Table 5.11 Calculated crop coefficients of various pasture species and their mixtures full canopy)
* *Unknown*

Pasture	Monthly crop coefficients (K_c)											
	JAN	FEB	MRCH	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
ON-STATION (2 year research period)												
Lucerne (without frost)	*	*	0.7	1.2	1.0	0.8	1.1	0.7	0.7	0.7	1.0	*
White Clover	*	*	0.7	1.3	1.4	1.0	0.7	1.1	0.8	0.8	0.9	*
Tall fescue	*	*	0.6	0.8	0.9	1.0	0.5	0.7	0.7	0.7	0.9	*
Kikuyu	*	*	0.8	0.7	0.7	0.0	0.0	0.0	0.4	0.6	0.8	*
Kikuyu/Lucerne	*	*	0.7	0.9	0.8	0.9	0.7	0.7	0.7	0.7	0.8	*
Tall fescue/White clover	*	*	0.6	1.1	1.2	1.0	0.7	0.8	0.7	0.8	0.9	*
Tall fescue/Lucerne	*	*	0.7	0.9	1.0	0.9	0.8	0.8	0.7	0.7	0.9	*
ON-FARM (2 year monitoring period + model simulations)												
Lucerne (with frost)	0.85	0.85	0.9	0.8	0.6	0.5	0.5	0.6	0.7	0.85	0.9	0.95
Kikuyu/ryegrass	0.7	0.7	0.6	0.6	0.65	0.55	0.5	1.0	0.75	0.75	0.7	0.7

Research has provided the following general guidelines to irrigate various pastures.

Table 5.12 Estimated water requirements of various pasture species and mixtures thereof (full canopy)

Pastures	Autumn	Winter	Spring	Summer
		($mm.week^{-1}$)		
Subtropical (Warm season) pastures – ON STATION				
Kikuyu (*Pennisetum clandestinum*)	17.0	12.0 #	20.0	30.0
Temperate (Cool season) pastures – ON STATION				
Tall fescue *(Festuca arundinacea)*	16.0	14.0	17.5	30.0 *
Lucerne *(Medicago sativa)*	21.0	15.0	15.5	30.5 *
White clover *(Trifolium repens)*	23.0	18.0	19.5	29.0 *
Subtropical (Warm season) grass – Temperate (Cool season) legume mixed pasture – ON STATION				
Kikuyu/Lucerne	20.0	15.0	19.0	34.0
Temperate (Cool season) grass – Temperate (Cool season) legume mixed pasture – ON STATION				
Tall fescue/Lucerne	18.5	15.5	17.0	28.0
Tall fescue/White clover	19.0	16.5	18.0	30.0
Temperate (Cool season) pastures – ON FARM				
Lucerne (Hay crop)	28.0	12.5	32.0	44.0
Subtropical (Warm season) grass – Temperate (Cool season) grass mixed pasture – ON FARM				
Kikuyu/Perennial ryegrass (Grazing)	14.6	9.5	21.0	29.5

** High evaporative loss (Dormant season)*
 # Risk of increased drainage (Dormant season)

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Significant data is being obtained from farmers and their own monitoring programmes. This data is being captured and incorporated into a database which helps validate the models that are being tested rather than developed. This research study has been able to incorporate lucerne crop parameters and has been providing some good simulations. The mixed pasture crops however has been the challenge. With the changing mixture components, each season there is a more prominent species in the mixture. These challenges has led the research team to concentrate on the canopy cover of the mixture rather than the individual components in the mixture themselves. These mixed crops have therefore been a challenge for SWB.

DairyMod however, is a model that makes provision for such mixed crops, and has the option to distinguish between the mixed pasture components, allocating the more dominant species to the mixture. Where SWB cannot take the impact of grazing of pastures on water use etc. into account, DairyMod has that function.

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 models 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 lucerne and common grass/legume pastures as example. The model is available on the web and can be downloaded free of charge. The water (irrigation) requirements of mixed and monospecific pastures can be determined by the following the following recommendations:

Step 1: Determine the pasture components (which species) of the mixture and their expected growth cycles according to production system (grazing intensity or harvesting period)

Step 2: Derive/use available crop coefficients (K_c)

Step 3: Determine and use the areas ET_o together with crop coefficients to calculate ET_c

Step 4: Obtain RPM readings (Calibration important)

Step 5: Measure the canopy cover (PAR and LAI) – if possible

Step 6: Run DairyMod or SWB (generate irrigation calendars) with available resource parameters including ET_o

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.

TRUTER WF., FESSEHAZION M., and ANNANDALE JG. 2012. Review of available knowledge on irrigation system, water management, water requirements and pasture management of selected pastures. Deliverable 1. WRC PROJECT K 5/2173/4 Water Utilization in Agriculture. 131 pages.

TRUTER WF., BOTHA PR., DANNHAUSER CS., MAASDORP BV., MILES N., SMITH A., SNYMAN HA., TAINTON NM. 2015. Southern African pasture and forage science entering the 21st century: past to present. African Journal of Range & Forage Science 2015, 32(2): 73-89

9781431208395