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Using adaptive management and modelling to improve nitrogen and water use efficiency in crop production: A case study using annual ryegrass

by

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**Submitted in partial fulfilment of the requirements for the degree PhD (Agronomy) in the faculty of Natural and Agricultural Sciences
University of Pretoria
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LIST OF ACRONYMS AND ABBREVIATIONS

ADF	Acid detergent fibre
asl	Above sea level
ANOVA	Analyses of variance
CEC	Cation exchange capacity
CL	Critical level
CP	Crude protein
CP_{max}	Maximum crude protein
CP_{min}	Minimum crude protein
CP_{opt}	Optimum crude protein
D	Index of agreement
DAP	Days after planting
Dr	Deep drainage
DWAF	Department of Water Affairs and Forestry
ETo	Reference evapotranspiration
FAO	Food and Agriculture organization
FC100	Common scientific practice
FC80	Irrigated 80% of FC100 - deficit irrigation
FC60	Irrigated 60% of FC100 - deficit irrigation
G	Soil heat flux
GDD	Growing degree day
Gen-cal	General irrigation guideline
H	Sensible heat flux
I	Irrigation
IUE	Irrigation use efficiency
LAI	Leaf area index
LSD	Least significant difference
MAE	Mean absolute error of measured values
ME	Metabolisable energy
MIUE	Marginal irrigation use efficiency
N_c	Critical nitrogen concentration
NDF	Neutral detergent fibre
NEWSWB	New Soil Water Balance
NNI	Nitrogen nutrition index
NUE	Fertiliser nitrogen use efficiency

N_{MB}	Nitrogen mass balance
N_{init}	Initial soil inorganic nitrogen
N_{min}	Mineralisable nitrogen
NPN	Non-protein nitrogen
NTP	non-true protein
N_{fer}	Nitrogen input from fertiliser
N_{up}	Above ground crop nitrogen uptake
N_{soil}	Adaptive nitrogen
N_{water}	Adaptive water
P	Precipitation
R	Runoff
r^2	Coefficient of determination
Rn	Net irradiance
RR20	Leaving 20 mm deficit
SOM	Soil organic matter
VPD	Vapour pressure deficit
Site-cal	Site specific calendar
SWBPro	Soil Water Balance irrigator/consultant version
SWB-Sci	Soil Water Balance scientific version
TDR	Time domain reflectometer
NSC	Total non-structural carbohydrates
TP	True protein
T	Sonic temperature
WFD	Wetting front detector
WUE	Water use efficiency
WK25	Common farmers practice of 25 mm
ΔQ	Soil water storage
ε	Wind direction
u	Horizontal wind velocity
v	Vertical wind velocity
w	Vertical wind velocity
z	Rooting depth
θ	Soil water content

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DECLARATION

I, Melake Kessete Fessehazion, hereby declare that this dissertation for the degree PhD (Agronomy) at the University of Pretoria is my own work and has never been submitted by myself at any other University. The research work reported is the result of my own investigation, except where acknowledged.

MK Fessehazion

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Abstract

Poor management of nitrogen (N) fertilisers and water in agro-ecosystems reduces yield, quality and N-use efficiency, and leads to pollution. The objective of this study was to improve irrigation and N management for planted pastures through adaptive management with simple tools and modelling. Field experiments were conducted in 2007 and 2008 at Cedara (KwaZulu Natal) and Hatfield (Gauteng) using annual ryegrass as a case study under a range of N and irrigation application strategies. Collected data sets were also used to calibrate and validate the SWB-Pro (simple) and SWB-Sci (detailed) model versions. After validation, the model was used to develop irrigation calendars and strategies, and estimate irrigation requirements for annual ryegrass.

The highest forage yields were produced when N application rates ranged between 30 to 60 kg N ha^{-1} for each growth cycle, except for the first 2-3 growth cycles when there was high soil N carryover from the previous season. The current farmers' recommendation (fixed N application rate of 50 kg ha^{-1} per growth cycle) maximised biomass but reduced pasture quality. Adaptive strategies based on nitrate concentration in wetting front detectors at different depths, reduced fertiliser N application by 28–32% and reduced potentially leachable residual soil N, while improving forage quality without yield reduction. The rate 30-40 kg N ha^{-1} per growth cycle provided a compromise between forage yield and quality.

The SWB model performed well in simulating ryegrass growth, leaf area index, forage yield, root zone soil water deficit, daily evapotranspiration, biomass N uptake and soil nitrate. Site specific and monthly variable irrigation calendars were developed using the SWB-Pro model, for four major milk producing areas of South Africa. The simpler monthly irrigation calendars can be used in the absence of irrigation monitoring tools or more accurate site specific

calendars. The SWB-Pro model requires relatively few and simple inputs. However, irrigation monitoring/scheduling with the aid of real time modelling or measurements is better than calendars developed using the SWB-Pro model with long-term historical weather data.

The SWB-Sci model showed ways of improving water use efficiency using ‘room for rain’ and ‘mildly deficit irrigation’ approaches in high rainfall areas. Scenario modelling demonstrated that the best management strategy of achieving maximum yield together with low N leaching is by integrating N and water management. This integrated management can be based on the wetness of the soil and nitrate concentration in the deep root zone using wetting front detectors. The model can be used to generate monitoring protocols such as depth of wetting front detector placement and selecting N thresholds to be used for adaptive management.

Setting approximate thresholds for wetting depth and nitrate concentration is a first step in implementing an adaptive management strategy. However, the challenge is to find monitoring tools which allow effective implementation of the strategy. In this study, the wetting front detector proved to be a robust, on-farm water and nitrate monitoring tool which is relatively simple and cost effective. Should it become widely adopted, farmers are expected to improve these thresholds as more experience is gained. The SWB model could also be used to evaluate alternative thresholds for adaptive N and water management.