MODELLING THE SOIL WATER BALANCE TO IMPROVE IRRIGATION MANAGEMENT OF TRADITIONAL IRRIGATION SCHEMES IN ETHIOPIA

By

Geremew Eticha Birdo

Submitted in partial fulfilment of the requirements for the degree

Doctor of Philosophy

in Agronomy

Department of Plant Production and Soil Science, Faculty of Natural and Agricultural Sciences

University of Pretoria

Pretoria

November 2008

Supervisor: **Dr. J.M. Steyn**

Co-supervisor: **Prof. J.G. Annandale**

DECLARATION

I, Geremew Eticha Birdo declare that this dissertation, submitted for the degree of Doctor of Philosophy in ***Irrigation Agronomy*** at the University of Pretoria, is my own work and has not been previously submitted by me for a degree at any other university.

Geremew Eticha Birdo

Date: January 2008

Place: Pretoria, Republic of South Africa

DEDICATION

"This work is dedicated to

my mother, harmee Likkitu Hundarraa,

who aspires to see me obtaining an education at the highest level."

PREFACE

This work was conducted in the Department of Plant Production and Soil Science at University of Pretoria, South Africa. The project involved two field experiments in Ethiopia and another two field experiments in South Africa. The aim of this work was to monitor and evaluate traditional irrigation schemes in Ethiopia in order to improve the country's productivity.

One of the works executed in Ethiopia was a survey conducted on traditional irrigation schemes to take stock of farmers' water management (amounts and intervals), major technical and social constrains hindering higher productivity, and to recommend possibilities for improvement. The result of this survey indicates the amount of water and intervals that farmers traditionally practice, as well as other technical and social constraints for future improvement.

The second activity in Ethiopia was to compare two traditional irrigation scheduling methods with two other, more scientific, methods under the furrow system, using standard crop cultivars. This activity helped the researcher to compare the performance of traditional water management to that of the scientific method, and identify the critical areas for further improvement or look for sound technologies that could replace the traditional practice.

The two activities performed in South Africa involved the use of detailed scientific methods to evaluate yield and quality performance of crops, crop growth stages for water stress, and calibrate and validate the mechanistic Soil Water Balance (SWB) model for large scale application, which could be a major tool to bring tradition and science together.

This thesis is compiled from chapters (articles) that were already published, accepted or submitted for publication and a few other publications in process. The dissertation is prepared in accordance to the guidelines set up for authors for the publication of manuscripts in the South African Journal of Plant and Soil.

1. Geremew, E.B., Steyn, J.M. & Annandale, J.G. 2007. Evaluation of growth performance and dry matter partitioning of four processing potato (*Solanum tuberosum*) cultivars. *New Zealand Journal of Crop and Horticultural Science,* 35, 385-393.

2. Geremew, E.B., Steyn, J.M., Annandale, J.G. & Steyn, P.J. 2007. Evaluation of tuber processing quality of four potato cultivars. (Re-submitted for publication in the *South African Journal of Plant & Soil,* after incorporating the reviewer's comments).

3. Geremew, E.B., Steyn, J.M. & Annandale, J.G. 2007. Comparison between traditional and scientific irrigation scheduling practices for furrow-irrigated potatoes (*Solanum tuberosum*) in Ethiopia. (Accepted for publication in the *South African Journal of Plant & Soil*).

4. Geremew, E.B., Steyn, J.M. & Annandale, J.G. 2007. Growth and yield response of onions (*Allium cepa*) to water stress at different growth stages. (Prepared for submission in the *South African Journal of Plant & Soil*).

5. Geremew, E.B., Steyn, J.M. & Annandale, J.G. 2007. The SWB model calibration and validation of onions water-stressed at different growth stages. (Prepared for submission in the *South African Journal of Plant & Soil*).

6. Geremew, E.B., Steyn, J.M. & Annandale, J.G. 2007. Traditional water management practices: merits and de-merits. A case study at Godino traditional irrigation scheme, Ethiopia. (Prepared for publication in the *Ethiopian Journal of Agricultural Science*).

In addition, the researcher expects to produce not less than four more articles from the remaining body of the thesis, in the area of soil water characteristics and model calibration and validation, for publication in various journals.

ACKNOWLEDGEMENTS

I would like to express my sincere thanks and gratitude to my supervisors, Dr JM Steyn and Prof. JG Annandale, who provided me with immeasurable support, guidance and critical comments throughout my study period. My gratitude goes to Dr Steyn for his financial support from a project of his, while my scholarship came to a halt untimely.

Oromiya Agricultural Research Institute (OARI) sponsored the study through the funding of a World Bank loan to the Ethiopian Research Capacity Building. I gratefully acknowledge this institution for the facilitation of my research.

I am also grateful to the International Water Management Institute (IWMI) at Pretoria for partial financial support for the survey work at Godino, through the APPIA project of East Africa, Ethiopia.

My special thanks go to my colleagues in the Department, Eyob Habte, who acquainted me with the field and laboratory research equipments and Yaekob Beletse, Tsedal G/Mariam, Yibekal Alemayehu and Thembeka Mpaiseng for their professional support during the development of the thesis.

The staff of the Department of Plant Production and Soil Science, including the farm workers who were so pleasant towards me – I am indebted to them.

I am grateful to Mr G/Medhin W/Giorgis, who supplied me with sprouted potato seed, Mr Aliye Hussen and the then Deputy Director General of EARO, Dr Abera Dheressa, who facilitated logistics and supported me with encouraging ideas during the research work at Godino and Bushoftu.

Special thanks go to Mr Nigusu Bekele, who assisted me in the fieldwork, and to Dr Selamyihun Kidane, Dr Solomon and the management of DZARC.

My thanks go to Obbo Dassaaleny Fayissaa and Obbo Geetachoo Bashaargoo, who helped me with the installation and maintenance of research facilities at the Godino irrigation scheme.

Thanks to my friends at Pretoria, Dr Getu Beyene, Dr Abubeker Hassen, Dr Yoseph Beyene, Dr Yoseph Assefa, Dr Solomon Kebede and Mr Temesgen Tadesse, with whom I passed good times.

The hospitality of Mrs Amina Mohammed and the entertainment of baby Hassen Abubeker were marvellous and I owe them my special gratitude.

Finally, yet importantly, I thank my family for their patience during my long stay away from them, especially Obbo Dirribaa Sooressaa, who supported my elderly mother.

ABSTRACT

Traditional irrigation was practiced in Ethiopia since time immemorial. Despite this, water productivity in the sector remained low. A survey on the Godino irrigation scheme revealed that farmers used the same amount of water and intervals, regardless of crop species and growth stage. In an effort to improve the water productivity, two traditional irrigation scheduling methods were compared with two scientific methods, using furrow irrigation. The growth performance and tuber yield of potato (cv. Awash) revealed that irrigation scheduling using a neutron probe significantly outperformed the traditional methods, followed by the SWB model Irrigation Calendar. Since the NP method involves high initial cost and skills, the use of the SWB Calendar is suggested as replacement for the traditional methods.

SWB is a generic crop growth model that requires parameters specific to each crop, to be determined experimentally before it could be used for irrigation scheduling. It also accurately describes deficit irrigation strategies where water supply is limited. Field trials to evaluate four potato cultivars for growth performance and assimilate partitioning, and onions' critical growth stages to water stress were conducted. Crop-specific parameters were also generated. Potato and onion crops are widely grown at the Godino scheme where water scarcity is a major constraint. These crop-specific parameters were used to calibrate and evaluate SWB model simulations. Results revealed that SWB model simulations for Top dry matter (*TDM*), Harvestable dry matter (*HDM*), Leaf area index (*LAI*), soil water deficit (*SWD*) and Fractional interception (*FI*) fitted well with measured data, with a high degree of statistical accuracy.

The response of onions to water stress showed that bulb development (70-110 DATP) and bulb maturity (110-145) stages were most critical to water stress, which resulted in a significant reduction in onion growth and bulb yields. SWB also showed that onion yield was most sensitive to water stress during these two stages.

An irrigation calendar, using the SWB model, was developed for five different schemes in Ethiopia, using long-term weather data and crop-specific parameters for potatoes and onions. The calendars revealed that water depth varied, depending on climate, crop type and growth stage.

Keywords: canopy cover, dry matter partitioning, furrow irrigation, irrigation scheduling, leaf area index, neutron probe, onion bulb yield, potato tubers, Soil Water Balance model, traditional irrigation, water stress

TABLE OF CONTENTS

CHAPTER 10

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

a	Campbell's coefficient of the log-log water retention function
ADL	Allowable depletion level
Alt	Altitude (m)
ARC	Agricultural Research Council
CDM_i	Canopy dry matter daily increment (kg)
cv.	Cultivar
D	Index of agreement of willmott
DAP	Days after planting
DATP	Days after transplant
DM	Dry matter production (kg m^{-2})
DM_i	Daily increment of total dry matter (kg m^{-2})

Dr	Drainage (mm)
DWR	Dry matter water ratio (Pa)
dz	Soil layer thickness (m)
DZARC	Debre-Zeit agricultural research centre
E	Actual evaporation (mm)
e_a	Actual (atmospheric) vapour pressure (kPa)
E_c	Radiation conversion efficiency (kg MJ^{-1})
EMDD	Emergence day degree (d ^oC)
eq(s)	equation(s)
e_s	Saturated vapour pressure (kPa)
ET	Evapotranspiration (mm = kg m^{-2})
ETcrop	Crop evapotranspiration
ETo	(FAO) reference crop evapotranspiration (mm d^{-1})
f	Layer root fraction
FAO	Food and Agriculture Organization of the United Nation (Rome, Italy)
FI	Fractional interception
FI_{PAR}	Fractional interception of photosynthetically active radiation
FLDD	Day degrees at end of vegetative growth (d ^oC)
FL_{solar}	Fractional interception of solar radiation
f_r	Fraction of dry matter partitioned to roots
GDD	Growing day degrees (d ^oC)
H_C	Crop height (m)
H_{Cmax}	Maximum crop height (m)
HDM	Harvestable (tuber) dry matter (kg m^{-2})
I	Irrigation amount (mm)
I_C	Amount of precipitation intercepted by the canopy (mm)
IR	Irrigation requirement
IWMI	International Water Management Institute
IWUE	Irrigation water use efficiency
K	Canopy radiation extinction coefficient
K_{Cb}	Basal crop coefficient
K_{PAR}	Canopy extinction coefficient of photosynthetically active radiation
K_S	Canopy extinction coefficient of total solar radiation
LAD	Leaf area duration

LAI	Leaf area index (m^2 m^{-2})
*LAI*y	Leaf area index of senesced leaves
LDM	Leaf dry matter (kg m^{-2})
LSD	Least significant difference
MAE	Mean absolute error
MTDD	Maturity day degree (d ^{o}C)
NIR	Near infrared radiation (0.73 µm)
OARI	Oromiya Agricultural Research Institute
P	Precipitation (mm)
Pa	Atmospheric pressure for a given altitude (kPa)
PAR	Photosynthetically active radiation (0.4 0.7 µm)
PAW	Plant available water
PART	Stem-leaf partitioning parameter (m^2 kg^{-1})
PE	Potential evaporation (mm)
PET	Potential evapotranspiration (mm)
PT	Potential transpiration (mm)
PWP	Permanent wilting point
R	Runoff (mm)
r^2	Coefficient of determination
RD	Root depth (m)
RDM	Root dry matter (kg m^{-2})
RD_{max}	Maximum root depth (m)
RGR	Root growth rate (m^2 $kg^{-0.5}$)
RH	Relative humidity (%)
RH_{max}	Daily maximum relative humidity (%)
RH_{min}	Daily minimum relative humidity (%)
RMSE	Root mean square error
R_S	Solar radiation (MJ m^{-2} day^{-1} or W m^{-2})
SAR	Sodium adsorption ratio
S.a.	Sinno anno (no date)
SDM	Stem dry matter (kg m^{-2})
SG	Specific gravity
SI	Stress index
SLA	Specific leaf area (m^{-2} kg^{-1})

SWB	Soil Water Balance
SWD	Soil water deficit (mm = kg m^{-2})
T	Actual transpiration (mm = kg m^{-2})
T_a	Air temperature T_a= T_d (^oC)
T_b	Base temperature (^oC)
$T_{cut\text{-}off}$	Cut-off temperature (^oC)
TDM	Top dry matter (kg m^{-2})
TDMstart	Top dry matter at emergence (kg m^{-2})
TFI	Tuber form index
T_o	Standard air temperature at sea level (293 ^oK)
TransDD	Day degrees of transition period from vegetative to reproductive growth stage (d ^oC)
T_W	Wet bulb air temperature (^oC)
U	Wind speed (m s^{-1})
*U**	Dimensionless root uptake rate
U_2	Wind speed measured at 2 m height (m s^{-1})
VPD	Vapour pressure deficit (Pa)
WC	Water content
WFD	Wetting front detector
WUE	Water use efficiency (kg ha^{-1} mm^{-1})
Y	Yield (kg ha^{-1})
Z	Soil depth (m)
α	Adiabatic lapse rate (K m^{-1})
γ	Psychrometer constant (kPa $^oC^{-1}$)
ΔS	Change in soil water storage (mm)
Δt	Duration (day)
θ	Volumetric soil water content (m^3 m^{-3})
θ_{fc}	Volumetric soil water content at field capacity (m^3 m^{-3})
θ_{pwp}	Volumetric soil water content at permanent wilting point (m^3 m^{-3})
θ_{sat}	Volumetric water content at saturation (m^3 m^{-3})
ρ_b	Bulk density (Mg m^{-3})
ρ_w	Water density (Mg m^{-3})
σ	Stefan-Boltzmann constant (5.6697×10^{-8} W m^{-2} K^{-4})

Ψ_{avg}	Root weighted average soil matric potential (J kg^{-1})
Ψ_{fc}	Soil matric potential at field capacity (J kg^{-1})
Ψ_{lm}	Leaf water potential at maximum transpiration (J kg^{-1})
Ψ_{m}	Soil matric potential (J kg^{-1})
Ψ_{pwp}	Soil matric potential at permanent wilting point (J kg^{-1})
Ψ_{x}	Xylem water potential (J kg^{-1})