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

By

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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 Likitu 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.


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.
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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
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<tr>
<td>a</td>
<td>Campbell's coefficient of the log-log water retention function</td>
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<td>ADL</td>
<td>Allowable depletion level</td>
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<tr>
<td>Alt</td>
<td>Altitude (m)</td>
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<td>ARC</td>
<td>Agricultural Research Council</td>
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<tr>
<td>CDmi</td>
<td>Canopy dry matter daily increment (kg)</td>
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<td>cv.</td>
<td>Cultivar</td>
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<td>D</td>
<td>Index of agreement of willmott</td>
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<td>DAP</td>
<td>Days after planting</td>
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<td>DATP</td>
<td>Days after transplant</td>
</tr>
<tr>
<td>DM</td>
<td>Dry matter production (kg m⁻²)</td>
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<tr>
<td>DMi</td>
<td>Daily increment of total dry matter (kg m⁻²)</td>
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</table>
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 °C)
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 °C)
FL_{solar}  Fractional interception of solar radiation
f_r  Fraction of dry matter partitioned to roots
GDD  Growing day degrees (d °C)
H_C  Crop height (m)
H_{C_{max}}  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
IWMRI  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
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<th>Symbol</th>
<th>Term</th>
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<td>LAI</td>
<td>Leaf area index (m² m⁻²)</td>
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<td>LAIy</td>
<td>Leaf area index of senesced leaves</td>
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<tr>
<td>LDM</td>
<td>Leaf dry matter (kg m⁻²)</td>
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<tr>
<td>LSD</td>
<td>Least significant difference</td>
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<td>MAE</td>
<td>Mean absolute error</td>
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<td>MTDD</td>
<td>Maturity day degree (d °C)</td>
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<td>NIR</td>
<td>Near infrared radiation (0.73 µm)</td>
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<td>OARI</td>
<td>Oromiya Agricultural Research Institute</td>
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<td>P</td>
<td>Precipitation (mm)</td>
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<td>Pa</td>
<td>Atmospheric pressure for a given altitude (kPa)</td>
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<td>PAR</td>
<td>Photosynthetically active radiation (0.4 0.7 µm)</td>
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<td>PAW</td>
<td>Plant available water</td>
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<td>PART</td>
<td>Stem-leaf partitioning parameter (m² kg⁻¹)</td>
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<td>Potential evaporation (mm)</td>
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<td>Root growth rate (m² kg⁻⁰.⁵)</td>
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<td>RH</td>
<td>Relative humidity (%)</td>
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<td>RHmin</td>
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<td>RMSE</td>
<td>Root mean square error</td>
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<td>Rs</td>
<td>Solar radiation (MJ m⁻² day⁻¹ or W m⁻²)</td>
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<td>SAR</td>
<td>Sodium adsorption ratio</td>
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<td>S.a.</td>
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<td>SDM</td>
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<td>SI</td>
<td>Stress index</td>
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<td>SLA</td>
<td>Specific leaf area (m² kg⁻¹)</td>
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<tr>
<td>SWB</td>
<td>Soil Water Balance</td>
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<td>SWD</td>
<td>Soil water deficit (mm = kg m(^{-2}))</td>
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<td>T</td>
<td>Actual transpiration (mm = kg m(^{-2}))</td>
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<td>Air temperature (T_a = T_d) (°C)</td>
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<td>Tb</td>
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<td>TDM</td>
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<td>WFD</td>
<td>Wetting front detector</td>
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<td>Y</td>
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<td>γ</td>
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<td>ΔS</td>
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<td>ρ(_b)</td>
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<td>ρ(_w)</td>
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<td>σ</td>
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<td>Symbol</td>
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<tr>
<td>$\Psi_{avg}$</td>
<td>Root weighted average soil matric potential (J kg$^{-1}$)</td>
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<td>$\Psi_x$</td>
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