Multi-Temporal Remote Sensing for Estimation of Plant Available Water-holding Capacity of soil

A thesis submitted to the University of Adelaide in fulfillment of the requirement for the degree of Doctor of Philosophy

Sofanit Girma Araya

B.Sc. in Geology, Addis Ababa University, Ethiopia
M.Sc. in Geoinformatics, University of Twente, The Netherlands

School of Biological Sciences

The University of Adelaide

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Abstract

Soil maps are fundamental for agricultural management. However, mapping soils is a difficult task because of their high spatial variability and the challenge of choosing representative field sites for soil analysis. Globally, soil information is becoming a prioritized agenda, due to the increasing demand for soil information for quantitative ecological, environmental and agronomic modelling. Hence, improved digital soil mapping techniques are required to fulfill this demand.

The Plant Available Water-holding Capacity (PAWC) is a key soil property in most agricultural management activities as it determines the maximum water that can be readily extracted by plants. Globally, there is an increasing demand for spatially explicit soil PAWC data for understanding the potential consequences of climate change and development of adaptation strategies. The coarse resolution of current PAWC information limits the spatial detail of future predictions and decision support.

Plant growth in water-limited Mediterranean climates is predominantly controlled by soil water availability. In rain-fed cropping systems, differences in PAWC can explain a large proportion of the spatial and temporal crop yield variability. The overall aim of this research was to develop a methodology to estimate spatial pattern of PAWC at a high spatial resolution using satellite-based remote sensing techniques. The underlying hypothesis is that the spatio-temporal plant growth patterns contain integrated information about soil properties and plant-soil-water interaction in the profile. The objective was to evaluate if phenological metrics derived from MODIS-NDVI (Moderate Resolution Imaging Spectroradiometer Normalized Difference Vegetation Index) can be used to infer about PAWC. The study was conducted in the South Australian agricultural region, which is one of the major grain producing regions of the country.

Central to facilitating the research was the design and development of a flexible software package (CropPhenology) to extract phenological metrics that are indicators of crop condition at different growth stages. The CropPhenology package was developed in R to be used for analyzing data for all later stages of the project. It is available in the public domain repository GitHub.

Initially, the sensitivity of remote sensing phenological metrics for differences in soil PAWC was assessed in a controlled situation. Phenological metrics for crop grown in soils of contrasting PAWC values under identical agricultural management were compared. The results identified potential phenological metrics to be used as indicators for soil PAWC. The findings support that the soil signal can be extracted from time-series vegetation growth dynamics.

The research further evaluated the efficacy of the phenological metrics for assessment of spatio-temporal crop growth variability for management practices. The association between phenological metrics and management zones were analyzed in a South Australian cropping field. The result shows that phenological metrics have potential to inform about both spatial variability and temporal variability, highlighting a pathway towards alternative approaches for assessing the spatio-temporal variability in cropping fields.

Finally, an approach was developed for spatial PAWC estimation. Multiple linear regression models were developed that analytically associate of the measured soil PAWC values with MODIS-NDVI phenological metrics. The PAWC map shows significant agreement with the landscape-scale soil map of the region with realistic detail of PAWC variability within the soil map units across management units. The evidence from this result indicates the potential of phenological metrics from satellite remote sensing for soil PAWC mapping at unprecedented detail over a broad regional extent. Advances in PAWC mapping as demonstrated in this thesis will improve models assessing future climate change development of adaptation strategies and will narrow the gap in spatial detail between regional decision making and farm-based precision agriculture.

Publications arising from this thesis

Refereed

Araya, S., Ostendorf, B., Lyle, G., Lewis, M. (2013) "Crop phenology based on MODIS satellite imagery as an indicator of plant available water content." In: Proceedings of the 20th International Congress on Modelling and Simulation, Adelaide, South Australia. 1–6 Dec. 2013. The Modelling and Simulation Society of Australia and New Zealand. p 1896–1902. ISBN: 978-0-9872143-3-1. http://www.mssanz.org.au/modsim2013/H15/araya.pdf

Araya, S, Lyle, G., Lewis, M., and Ostendorf, B. (2016) "Phenologic metrics derived from MODIS NDVI as indicators for Plant Available Water-holding Capacity." *Ecological Indicators* 60:1263-72. doi: http://dx.doi.org/10.1016/j.ecolind.2015.09.012.

Araya, S., Ostendorf, B., Lyle, G., and Lewis, M. (2017) "Remote Sensing Derived Phenological Metrics to Assess the Spatio-Temporal Crop Yield Variability." *Advances in Remote Sensing*, 6, (3) 212-228, doi: https://doi.org/10.4236/ars.2017.63016

Araya, S., Ostendorf, B., Lyle, G., and Lewis, M. "CropPhenology: An R package for extracting crop phenology from time-series remotely sensed vegetation index imagery." *Ecological Informatics (Under review)*

Araya, S., Ostendorf, B., Lyle, G., and Lewis, M. "Spatial estimation of Plant Available Water-holding Capacity using phenological indicators" *Ecological Indicators (Under review)*

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My little boy Michael, I am ever grateful to be your mom.

I Love you million times to the moon and back!

Finally, and most importantly

*To **God**, my strength,*

“How awesome are your deeds!”

"I know that you can do all things; no purpose of yours can be thwarted”

x

This thesis is dedicated

To

My ***MOM, Amsale Atle***

Who paid ultimate sacrifices for me to be the person I am today.

And

My ***Husband, Abay Teshome***

Who has been constantly and tirelessly supporting and encouraging me during the challenging time of my study.

This would never been possible without you being next to me.

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Acronyms

AVHRR	Advanced Very High Resolution Radiometer
MODIS	MODerate resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
PAWC	Plant Available Water-holding Capacity
PA	Precision Agriculture
SSCM	Site Specific Crop Management
SA	South Australia
EP	Eyre Peninsula