Spatial assessment of the interactions between subsoil constraints, soil available water capacity, and potential crop yields

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Abstract

The depth-to a constraint determines how much of the soil profile, and the water it contains, can be accessed by plant roots. Spatial information describing the impact of constraints on available water capacity (AWC) and yield is important for farm management, but rarely considered. The interactions between the depth-to three yield-limiting constraints ($pH \geq 9$, $EC1:5 \geq 1$ dS m^{-1}, $ESP \geq 15$ %), AWC, and cotton and wheat yield was mapped across ~80,000 ha in northern NSW. This was done with digital soil mapping, machine learning, pedotransfer functions, and water use efficiency equations at a 30 m resolution. One or more constraints were found across 54 % of the study area in the upper 1.2 m of the soil profile, overall reducing the AWC and potential yield. The simplification of multiple sources of information into a simplified decision-making tool (i.e. map of potential yield loss due to constraints) enables growers and farm mangers to quantify the impact of constraints on soil AWC and yield to better optimise crop yields and economic returns.

Keywords

Soil constraints, digital soil mapping, available water capacity, pedotransfer function.

Introduction

Although Australian agricultural soils often feature many desirable physical and chemical characteristics, over three-quarters of these soils have one-or-more constraints in the surface and/or subsoil (Bot et al. 2000). Soil constraints are chemical or physical properties of the soil that may impede root growth and limit crop yields by reducing the availability of stored soil moisture to plants (van Gool et al. 2005). The depth-to a constraint determines how much of the soil profile, and the water it contains, can be accessed by roots (van Gool et al. 2005). Information describing the depth at which subsoil constraints occur, their interactions with available water capacity (AWC), and how this impacts yield is important for farm management, but rarely considered. Despite increasing access to vast amounts of publicly accessible and farm sourced data including proximal and remote sensing information, soil surveys, and yield monitoring data, much of this information is underutilised by farmers/agronomists.

Most studies that have mapped the spatial distribution of soil constraints are limited by coarse vertical and horizontal spatial resolutions. Coarse depth resolutions in the subsoil (e.g. 0.60 – 1.00 m) make it difficult to accurately determine the depth at which a constraint is reached, and is a particular limitation for studies that map soil constraints according to standard Global Soil Map depth intervals (e.g. Grundy et al. (2015), Leenaars et al. (2018)). Other attempts to capture the vertical distribution of soil constraints down the profile have produced individual maps for different depth increments (e.g. Filippi et al. (2018)), providing growers with an overwhelming volume of information which is difficult to interpret. Also, while the interactions between AWC and yield, and the impact of constraints on yield, are well understood (e.g. Dang et al. 2010), the combined interactions between constraints, AWC, and yield have rarely been considered spatially at the farm and field scale.

The current study builds upon previous research (Filippi et al. 2019; Filippi et al. 2020) to spatially map the depth-to multiple subsoil constraints (pH 9, EC1:5 1 dS m^{-1}, ESP 15 %) and quantify their impact on AWC and potential wheat and cotton yields using pedotransfer functions (PTFs) and water use efficiency (WUE) equations. The study area focused on the alluvial cotton and grain growing valleys of eastern Australia. This study aims to integrate multiple layers of information describing the interactions between constraints, available water, and yield to produce a simplified decision-making tool for the farm and field-scale management of subsoil constraints.

Methods

Soil data from three soil surveys across ~80,000 ha of the Ashley Irrigation Area in northern NSW, including 1651 samples from 244 individual sites, were collated and resampled to 1 cm depth increments using equal-area quadratic smoothing splines (Bishop et al. 1999) to standardise the depth intervals. This soil data, alongside a range of spatial covariates (radiometrics, terrain attributes, satellite imagery) from publicly accessible databases, was used to build a series of Random Forest models to predict the spatial distribution of the depth-to three yield-limiting, agronomically important subsoil constraints; pH 9, EC1:5 dS m^{-1}, ESP 15 %. These thresholds were chosen as they were determined to be the values for each constraint that physically or chemically impede root growth, resulting in negative impacts on crop growth and yield for wheat and cotton (Hazelton and Murphy 2016). These predictions were mapped at a 1 cm vertical resolution down to 120 cm and the accuracy and quality of each model was assessed using leave-one-site-out cross validation (LOSOCV), where whole soil profiles were removed to ensure that soil samples from the same site were not used in both calibration and validation datasets.

The AWC in the top 120 cm of the soil profile was estimated using pedotransfer functions (PTFs) (Padarian Campusano 2014) from modelled soil texture and organic carbon content estimations. The PTFs enable the estimation of soil properties using field capacity and permanent wilting point, estimated from more readily available or more easily measured soil information. The AWC for each 1 cm soil layer was summed down to the depth a constraint was first reached so that the ‘constrained’ AWC excluded soil water beyond the depth-to a constraint. The ‘unconstrained’ ACW map was calculated without considering the presence of constraints so that the AWC for each layer was summed for the full 120 cm of the profile. The total unavailable water due to the presence of constraints was calculated as the difference between the unconstrained and constrained AWC maps.

Potential yield loss due to the presence of constraints was estimated for cotton and wheat using water use efficiency (WUE) equations developed by Roth et al. (2014) and French and Schultz (1984).

Results

There was little similarity in the spatial distributions of each constraint. In the top 120 cm of the soil profile, approximately 1 % of the study area was constrained by a pH of 9, 25 % was constrained by an EC1:5 of 1, and 37 % was constrained by an ESP of 15 % (Figure 1). Across the study area, constraints were reached relatively shallow in the soil profile (Figure 1). Overall, 54 % of the study area was affected by one-or-more constraints in the top 120 cm of the soil profile.

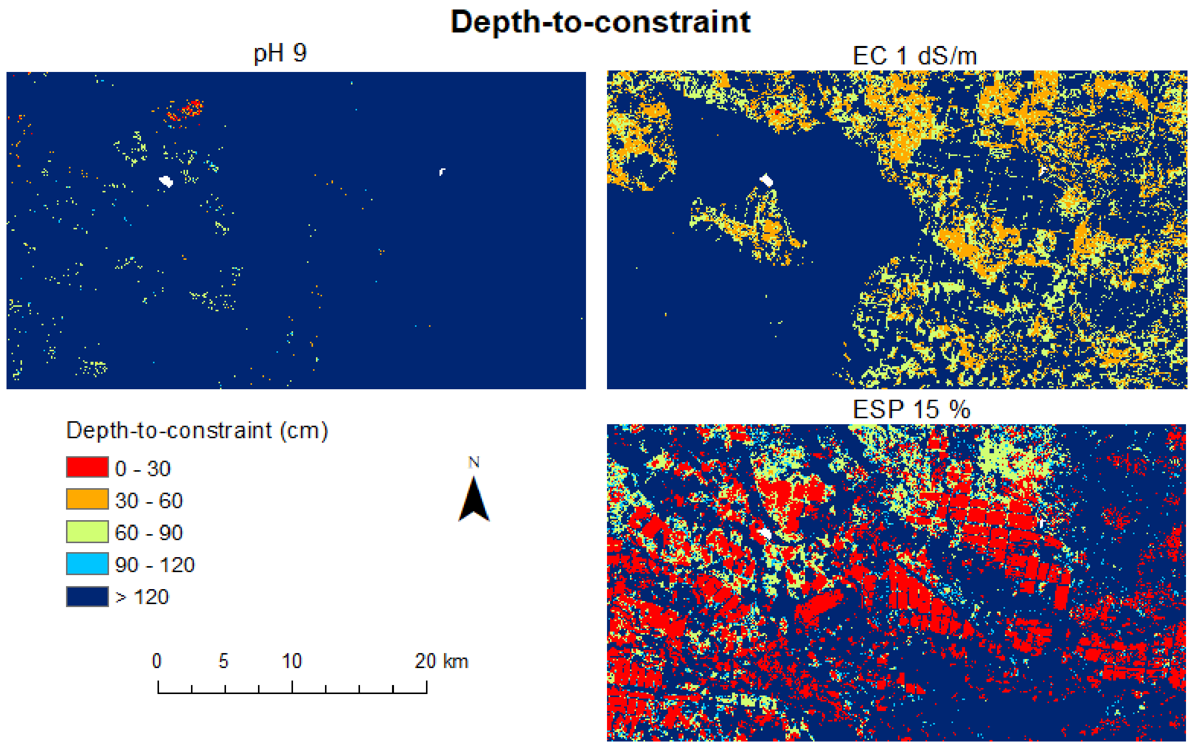

Figure 1. The depth-to three yield-limiting constraints; pH 9, EC$_{1:5}$ 1 dS m^{-1}, ESP 15 %.

The total unavailable water due to the presence of constraints was highly spatially variable, averaging 51 mm across the study area. Overall, more water was unavailable due to constraints in clearly defined fields to the far west and north-east of the study area, as well as a small central region (Figure 2).

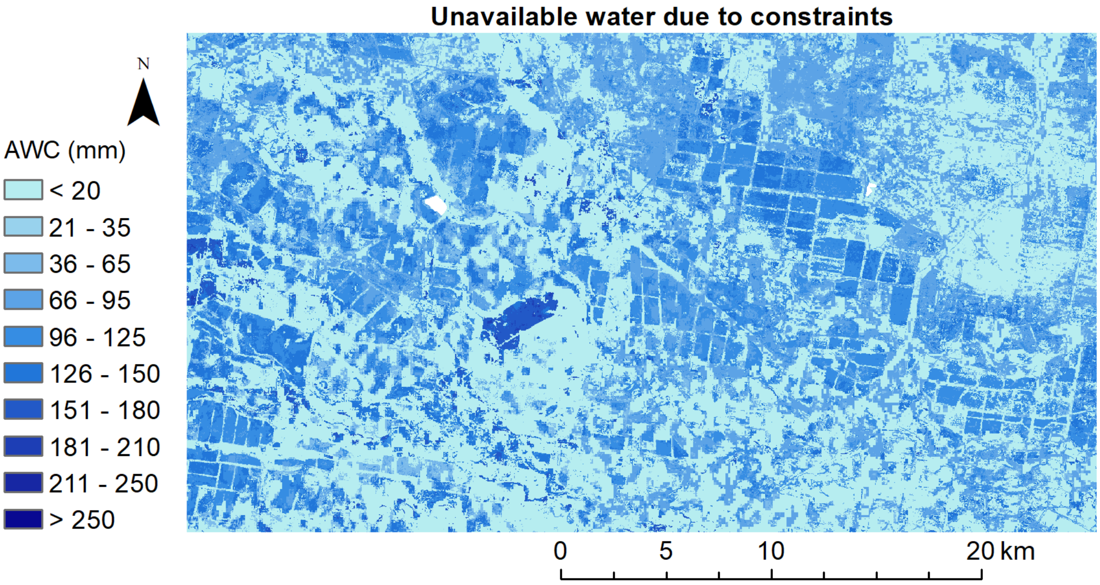

Figure 2. Unavailable water in the top 120 cm of the soil profile due to the presence of all constraints.

Potential yield loss due to the presence of all constraints (i.e. pH 9, EC$_{1:5}$ 1 dS m^{-1}, and ESP 15 %) was highly spatially variable (Figure 3). On average, potential yield loss for wheat was 1.01 tonnes (t) ha^{-1} and exceeded 4.13 t ha^{-1} in some locations, while for cotton, potential losses in lint yield averaged 0.67 bales ha^{-1} with a maximum potential yield loss of 2.73 bales ha^{-1}.

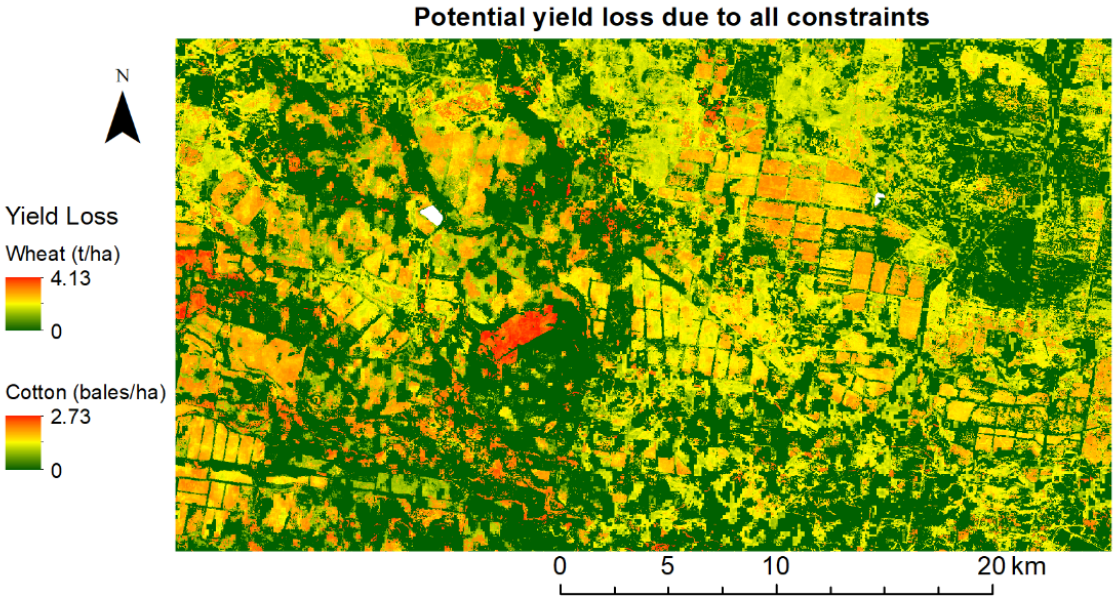

Figure 3. Potential yield loss due to the presence of all constraints.

Conclusion

Conclusion

Over 54 % of the study area was affected by at least one constraint within the top 120 cm of the soil profile, contributing to an average of 51 mm of unavailable water and average potential yield losses of 1.01 t ha^{-1} for wheat and 0.67 bales ha^{-1} for cotton. The workflow developed in this study effectively demonstrates the simplification of multiple sources of readily available information into a single map to assess the impact of constraints on AWC and yield. Subsoil constraints reduce the effective rooting depth of a crop, reducing AWC and potential yield. Understanding the impact of constraints on AWC is important for determining the feasibility of amelioration or management strategies to minimise unnecessary expenditure on resources, particularly if constraints are beyond the reach of a chemical or mechanical ameliorant. This work should be extended by validating potential yield loss estimations with farm-sourced yield data. Future work should consider a more flexible approach in determining threshold values for constraints, considering the interaction between different soil properties. In addition, temporal changes in the soil water balance due to environmental factors such as in-season rainfall should be accounted for in future work.

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