Identifying the relative importance of potential multiple soil constraints to wheat and canola growth rate

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Abstract

A major impediment for grain growers managing multiple soil physicochemical constraints is an inability to account for spatiotemporal variability in their impact on yield so as to select the most appropriate management response. We report progress on developing an approach that identifies the relative importance of multiple soil constraints across three paddocks at a 3D scale in western Victoria. Conditional Random Forest regression modelling was used to analyse the effect of different physicochemical soil attributes on relative crop growth rates assessed using proximal sensing. The relative importance of specific soil constraints was found to vary both across the different paddocks and crop growth stage. Overall, soil attributes influencing water supply (such as field capacity, permanent wilting point, soil texture, extractable boron, soil chloride concentration, electrical conductivity, exchangeable sodium percentage) and nutritional factors (such as nitrate, ammonium, available phosphorus, soil organic matter) were the most important variables influencing wheat and canola growth rate. Our findings point to the potential of this approach to allow growers to identify which soil constraints are most important when selecting different management strategies to enhance productivity.

Key words: Machine learning, *3D modelling, proximal sensing, soil management, sustainability*

Introduction

Multiple soil physicochemical constraints (MSC) substantially limit productivity and reduce farm profit among growers in the southern grain region of Australia. Previous research has identified high spatiotemporal variability (in terms of occurrence and severity) of these soil constraints within paddocks (Armstrong et al. 2009). Given this high spatiotemporal variability, effective management of MSC will require a timely assessment on potential impacts on soil water and nutrient uptake and grain yield to allow farmers to select management responses that maximise profitability. Notwithstanding, most farmers have largely relied on management interventions that target single factors and a blanket response across the paddock. A major reason for this management approach is the inability to account for the spatiotemporal variability of MSC due to the time and expense of grided soil sampling. Recent advances in proximal sensing technologies have allowed more practical and less expensive targeted sampling to identify where and when soil constraints occur within the paddock. For example, EM38 technology using electromagnetic induction can provide surrogate measurements of apparent soil electrical conductivity which reflects soil salinity, clay content and soil water storage (O'Leary et al. 2003). Other technologies include the use of gamma radiometric (for indirect measurement of soil texture and stoniness), ground penetrating radar surveys (for estimating depth to clay and perched water table) and readily available satellite-derived information such as Sentinel-2 crop Normalised Difference Vegetation Index (NDVI). These data can provide reliable and cost-effective diagnosis of potential soil constraint through multivariate analysis of their interrelationship with plant growth and yield. This study examines the relationship between various soil physicochemical properties at a 3D level and growth rate of wheat and canola crops measured with proximal sensing procedures to identify the important factors driving variation in crop growth rate (CGR) and ultimately yield.

Materials and Methods

Site description

This study presents reports from three selected paddocks managed by commercial growers within the medium (350-500 mm) rainfall zone of Victoria. These paddocks located at Nurcoung (Lat. 36^{o}39'11.39" S, Long. 141^{o}40'56.76" E), Nurrabiel (Lat. 36^{o}57'3.76" S, Long. 142^{o}2'51.85" E) and Wallup (Lat. 36^{o}21'15.31" S, Long. 142^{o}2'42.05" E) were carefully selected based on previous soil test reports, observed variability in soil physicochemical properties and the presence of potential soil constraints (e.g. sodicity, salinity, soil strength, high boron, low nutrient, waterlogging, etc.). In 2019, these paddocks were sown to wheat (Nurrabiel & Wallup) and canola (Nurcoung), respectively.

Data collection and processing

Multiple depth electromagnetic induction (EM) and gamma radiometric (GRS) geophysical surveys were conducted pre-sowing (March/April) in 2019 following a single pass of equipped utility task vehicle. GRS data was collected simultaneously with the EM 38 (horizontal and vertical placement) as well as the EM 31 data on 18m or 40 m transects in each paddock. These data were then pre-processed to remove outliers and interpolated across the entire paddock using the *Geostatistical Analyst* extension in ArcGIS (version 10.6). Using the EM survey maps and commercial NDVI satellite imagery, 30 monitoring sites (10 m x 10 m grid area) were carefully selected within in each paddock for soil sampling and plant growth measurements. Bulked soil samples (2-3 cores) were collected in April/May from the 30 monitoring sites in each paddock using a 4 cm diameter hydraulic soil probe. Soil samples were oven-dried at 40°C and analysed for physicochemical properties using standardized laboratory procedures and mid-infrared (MIR) spectrometer. Two biomass cuts (2 rows x 0.5 m) were taken from around each of the 30 monitoring sites at four different growth stages including mid-tillering, booting, anthesis and grain maturity. In addition, NDVI was calculated for each paddock using available cloud-free European Space Agency (ESA) Sentinel-2 level 2A imagery. The NDVI was then used to estimate plant biomass across each of the paddocks and subsequently for modelling CGR at each of the four growth stages. Subsequently, the soil sensing, soil test and CGR data were compiled into the dataset for modelling and statistical analysis.

Modelling

The Conditional Random Forest (CRF) was applied in modelling the relationship between the soil physicochemical properties, soil sensing and CGR data from each of the three paddocks. Overall, 137 explanatory variables (potential constraints) including elevation, soil sensing, and soil data (at five different depth intervals: 0-10, 10-20, 20-40, 40-80, 80-120) from the 30 monitoring sites (n=30) were included in modelling with the CGR at each of the four growth stages used as the corresponding response variable. For brevity, only results of analysis at anthesis growth stage are reported here.

Results and Discussions

Figure 1 shows the relative importance of the various soil attributes and their proxies in relation to crop growth rate across the different paddocks at mid-anthesis (GS65) /end of flowering (GS4.9). Overall, CRF performed relatively well (R^2 ranged from 0.70 to 0.74 while Adjusted R^2 ranged from 0.47 to 0.60) in modelling this relationship across the three paddocks. This raises the question as to what other factors not assessed are potentially affecting crop growth rates in these paddocks and as such our results will be updated as more information becomes available. At Nurcoung, soil chloride (Cl) (10-40cm), plant available water, soil texture (clay and sand fractions), mineral nitrogen (nitrate and ammonium), electrical conductivity (EC) and exchangeable sodium percentage (ESP) are most influential variables in modelling canola growth rate. The dominance of soil attributes influencing water supply to the crop as important variables is expected, considering the prevalence of contrasting soil textures in this paddock and the significance of water to the growth of canola.

Nuttall and Armstrong (2010) had reported the significance of available subsoil moisture at sowing in explaining canola crop yield from similar environment and soil types. The impact of subsoil chloride concentration on yield of crops including canola in similar soil type has been reported (Dang et al. 2008). This is largely due to the role of soil Cl concentration in limiting water extraction by crop roots.

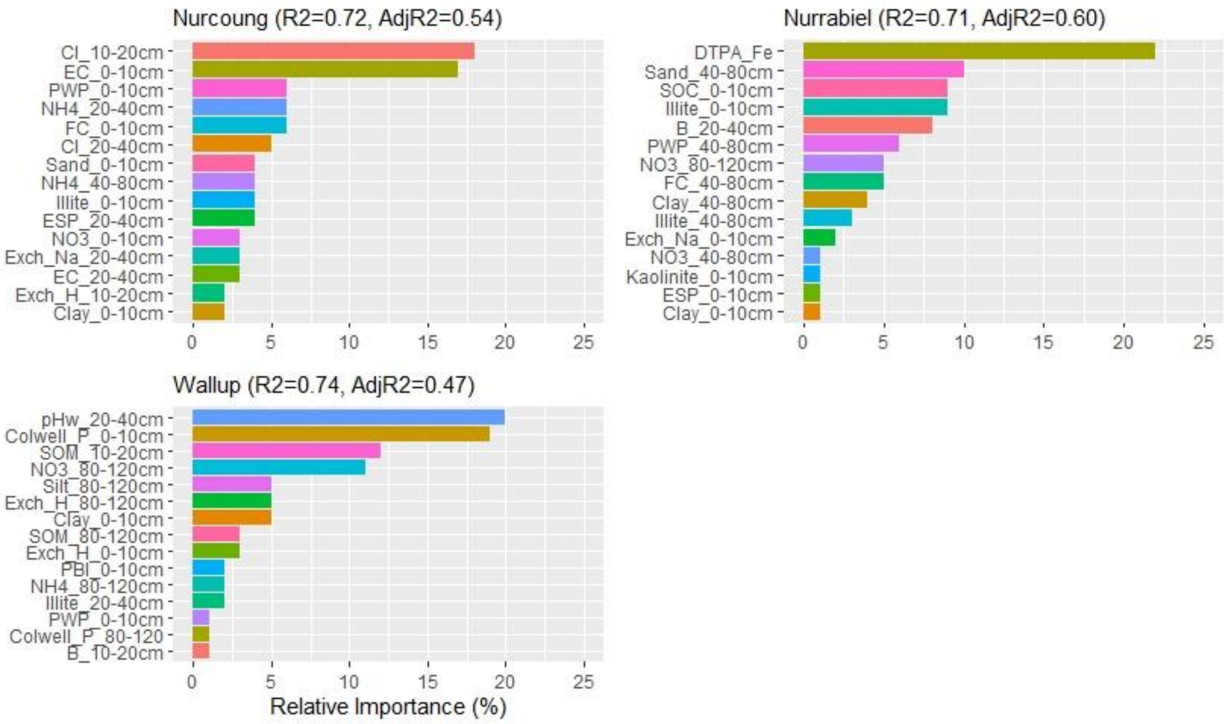

Figure 1. Relative importance of top 15 soil and soil sensing attributes in relation to crop growth rate as determined by CRF. Abbreviations: Cl; soil chloride concentration, DTPA_Fe; DTPA extractable iron concentration, EC; electrical conductivity, PWP; MIR predicted permanent wilting point, FC; MIR predicted field capacity, NH4; ammonium, ESP; exchangeable sodium percentage, NO3; nitrate, Exch_Na; exchangeable sodium, Colwell P; available phosphorus using the Colwell test, B; hot CaCl2 extractable boron; SOC; soil organic carbon, SOM; soil organic matter.

At Nurrabiel, clay minerals (illite and kaolinite), high extractable iron, subsoil texture (clay and sand fractions), hot $CaCl_2$ extractable Boron (B), available soil water, nitrates and surface ESP were the most important variables in predicting wheat growth rate at anthesis. Like Nurcoung, this paddock varies markedly in soil texture trends, with the northern half dominated by duplex soils (sand over clay) while the southern half is predominantly cracking clays with highly alkaline subsoils. High levels of extractable B are often associated with alkaline soils in low-medium rainfall areas of south eastern Australian and has been attributed to reduced yield in similar cereal crop such as barley previously (Cartwright et al 1986). High B in association with sodicity (ESP) can also limit water extraction by crops (Nuttall and Armstrong, 2010). In addition, soil texture controls soil water availability and storage which are critical for sustaining wheat yield (Nuttall and Armstrong, 2006).

At Wallup, which is predominantly a Calcarosol soil, subsoil pH, surface and subsoil Colwell phosphorus (P), subsoil pre-sowing mineral nitrogen (N), soil texture (silt and clay fractions) and soil organic matter dominates the important factors in modelling wheat growth rate. The influence of subsoil pH on wheat growth rate in this paddock is obvious considering the high subsoil pH compared to other paddocks, especially at Nurrabiel where wheat was equally grown. High pH significantly impacts P 3 availability to crops especially in calcareous soils due to fixation by calcium carbonate. P and N are important nutritional factors limiting growth rate of cereals and therefore their pre-sowing values are critical indicators of potential deficiency in the soil.

Conclusion

Our study has demonstrated the potential of this approach to identify which of the multiple potential soil constraints are most important when selecting different management strategies to enhance productivity. Overall, results indicated the importance of soil properties controlling water and nutrient availability to the growth rate of crops across the different paddocks. Future work will examine data for the 2020 and 2021 growing seasons as well modelling relationships using dense datasets from calibration of the soil and plant sensing data (covering the entire paddock) to identify spatial variability of soil constraints. Also, another work is currently evaluating the use of different amelioration strategies to mitigate the impact of identified multiple soil constraints on grain crop production.

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