Understanding the drivers of within-field grain protein content variability with spatial data layers

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Abstract

Wheat grain protein content (GPC) is a key determinant of the prices that grain growers receive, yet there is often signification variation within- and between-fields. There is an opportunity to make use of the plethora of publicly-available information and data being collected on-farm to capture, describe and quantitatively assess variability in grain production systems. This includes understanding the drivers of variability in GPC and yield, and their combined relationship within fields. Correlations between GPC and yield were mapped within 46 fields across four seasons (2020 – 2023) for nine farms in Western Australia and northern New South Wales, Australia, using a 150 m moving window. The relationship between these yield-protein correlations, total applied nitrogen and electromagnetic (EM) surveys (as a proxy for variation in soil moisture and clay content/texture) were then explored to understand potential drivers of variability. Overall, higher rates of total applied nitrogen corresponded to more negative yield-protein relationships, while relationships were less clear with soil moisture but in some fields may have reflected the "dilution effect" of higher yields resulting in decreased protein concentrations under non-water-limiting conditions. Future work will consider a greater number of spatial data layers, fields, farms, and seasons across Australia to better understand the nature and drivers of variability in GPC. Understanding the drivers of variation will enable growers to adjust management to optimise both yield and quality, resulting in positive outcomes for on-farm economics, productivity, and environmental sustainability.

Keywords

Precision agriculture, grain protein sensor, yield monitor data, moving window correlation

Introduction

Wheat grain protein content (GPC) is a key determinant of the prices that grain growers receive. Like grain yield, there is often significant variation in GPC within- and between-fields. The GPC is determined by complex interactions between genetic, environmental and management factors, including variety, soil nitrogen (N) and applied as fertiliser, and soil moisture (Whelan and Taylor 2013). Accurately measuring and mapping GPC within a field, across a farm, and over multiple seasons, can be useful to better understand the nature and drivers of variability in GPC, manage the quality of marketed grain, and better understand, evaluate, and improve N nutrition decisions (Whelan and Taylor 2013).

Today, more data than ever before is being collected on-farms and by the industry. Harvester-mounted grain protein sensors have been available for more than 20 years (e.g. CropScan), and in 2023, John Deere commercially released the HarvestLab 3000™ Grain Sensing system in Australia for real-time, on-the-go measurement of protein, starch, and oil values for wheat, barley, and canola. Despite growing interest in measuring and mapping GPC, and utilising grain protein maps for improved decision-making such as site-specific N fertilization strategies (e.g. Scott 2022), the uptake of these sensors has been relatively slow and GPC maps are not available for every field, farm, or season. To overcome these knowledge gaps, Tilse *et al.* (2024) used a combination of existing, readily-available on-farm (e.g. yield, cropping history, sowing and harvest dates) and publicly-available data layers (e.g. digital elevation model, radiometric surveys, remotely-sensed vegetation indices) to model and map GPC within ~ 80 broadacre fields of dryland winter wheat across two large collections of farms in Western Australia (WA), and northern New South Wales (NNSW). Existing on-farm and publicly-available data layers could be used to predict GPC on unseen fields with a Lin's Concordance Correlation Coefficient (LCCC) of 0.59 (where a LCCC of 1 is a perfect fit).

While an inverse relationship between wheat grain yield and protein content is generally expected, this is not always the case within fields (Whelan *et al.* 2009). Tilse *et al.* (2024) observed that within NNSW fields from 2020 - 2023, the relationship between yield and protein varied both spatially and season-to-season. In some fields, there was considerable variation in GPC despite yields appearing to be relatively consistent across the same area (Figure 1). Further investigation revealed historical field boundaries where smaller fields had been aggregated to one large field ~ 10 years prior. It is not clear what may be driving these patterns of variability, but anecdotal evidence suggests that these issues are occurring more on the heavier clay soils of NNSW compared to the sandier textured soils in WA.

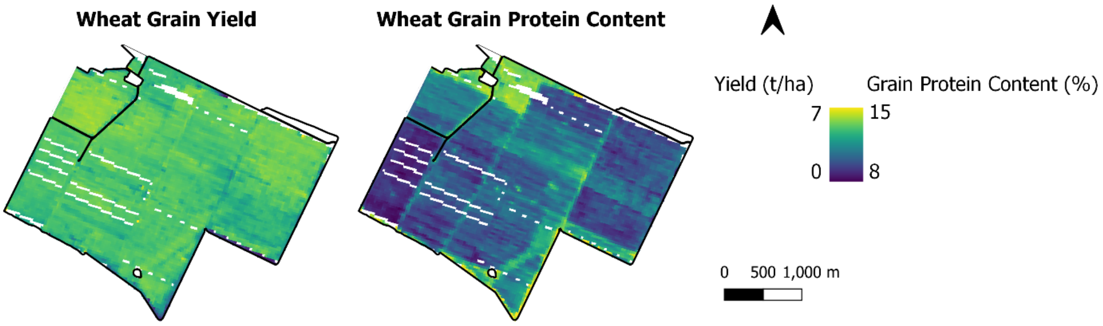

Figure 1. Observed wheat grain yield (tonnes per hectare, t/ha) and protein content (%) across a field in northern New South Wales.

Today, more data than ever before is being collected on-farms and by the industry (e.g. yield data, soil and electromagnetic (EM) surveys), and there is an enormous amount of public data (e.g. remote sensing imagery) now available and free to access. While the type and coverage of different data layers will vary between fields and farms, there is an opportunity to use the plethora of data available to capture, describe, and quantitatively assess variability in grain production systems, including understanding drivers of variability in both GPC and yield. Understanding the drivers of this variation will enable growers to adjust management to optimise both yield and quality. For example, in production systems where strong premiums/discounts apply, maximising yield potential while targeting a uniform protein content depending on the market/variety may be optimal. Alternatively, growers may choose to vary inputs to optimise profitability and agronomic response (Whelan and Taylor 2013). Improving our understanding of the drivers of variability in yield and GPC and their relationship can have positive outcomes for on-farm economics, production efficiencies, and environmental sustainability. This study builds upon previous work by Tilse *et al*. (2024) and others (e.g. Whelan *et al*. 2009) to investigate the relationship between wheat grain yield and protein content within fields, and considers a range of readily-available on-farm and publicly-available data layers to better understand the nature and drivers of this relationship.

Methods

Study area and available data

Wheat grain yield and protein data were collected onboard harvesters equipped with John Deere's HarvestLab 3000^{TM} grain sensing system for 170 fields from 4 seasons (2020, 2021, 2022, 2023) across WA and NNSW, Australia. Here, we present the use of a subset of this wheat grain yield and protein data from 46 fields across 4 seasons (2020, 2021, 2022, 2023), representing a total of 63 unique 'FieldYears' of grain yield and protein data, from two large collections of broadacre, dryland farms in WA and NNSW. All fields had both yield and protein data available, which was collected at the same location. Covariate data layers were then gathered for each field, including total applied N and soil EM surveys. Total applied N was calculated based on variable-rate fertiliser (e.g. Urea) maps for each field.

Moving window correlations and covariate relationships

Local correlations between wheat grain yield and GPC content in a 150 m moving window were mapped across a 30 m grid within each field to investigate their relationship. All covariates (total applied N, EM) were then extracted across the same 30 m grid. All correlations were aggregated into broader categories (i.e. -1 to -0.75, -0.75 to -0.50, -0.50 to -0.25, -0.25 to 0, 0 to 0.25, 0.25 to 0.50, 0.50 to 0.75, and 0.75 to 1) and the relationship between yield-protein correlations and each covariate were then assessed within fields. A positive yield-protein relationship represents a general trend where yield and protein increase (or decrease) together, whereas a negative relationship represents a general trend whereas yield increases, protein tends to decrease, and vice versa.

Results and discussion

When the relationship between yield and protein was quantified using a 150 m moving window within each field, the relationship between wheat grain yield and GPC was variable in both strength and direction and all fields showed that this relationship had a strong spatial structure. An example field is provided in Figure 2. Within fields, negative correlations dominated and more than half the FieldYears in both WA and NNSW had negative yield-protein relationships that covered at least 50 % of the within-field area (Figure 3).

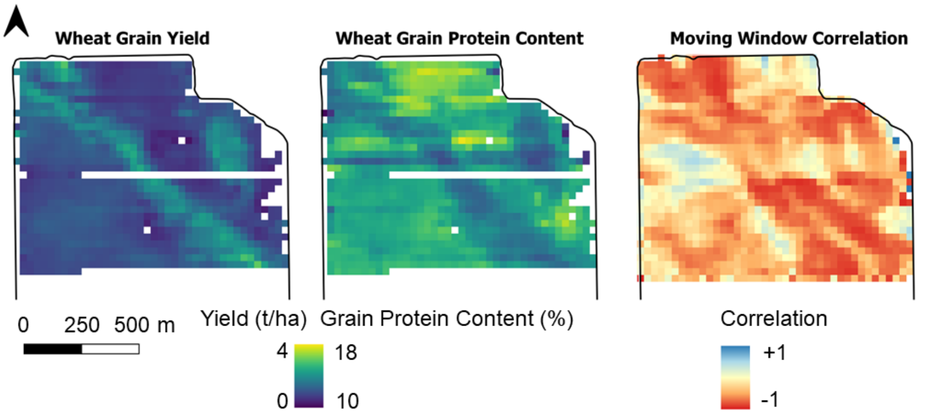

Figure 2. Observed wheat grain yield (tonnes per hectare, t/ha), protein content (%), and 150 m moving window correlations for an example field in Western Australia.

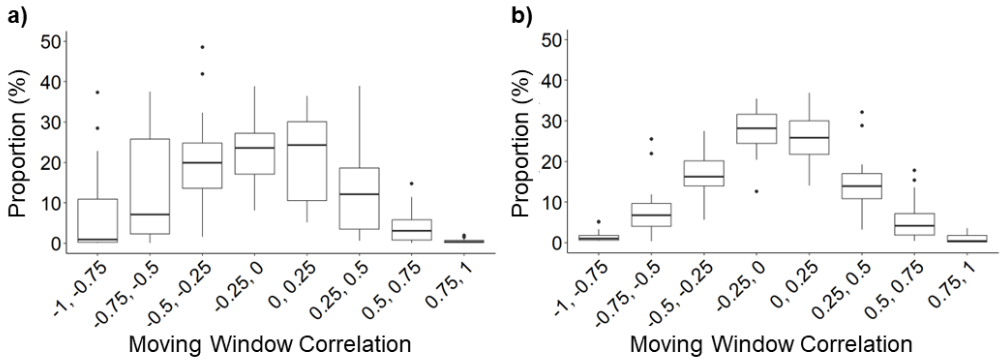

Figure 3. Proportion of each field area covered by yield-protein moving window correlation categories for all FieldYears in Western Australia (a) and northern New South Wales (b).

In almost all fields where variable-rate N was applied (WA only), higher total applied N values corresponded to a more negative yield-protein relationship. An example field is shown in Figure 4 a, which is the same field presented in Figure 2. While the nature of this negative relationship is not clear, as it can represent either a high yield/low protein or low yield/high protein scenario at a particular location, we speculate that this may be associated with the consistent relationship that exists between cereal grain yield and protein concentration according to N supply (Russell 1963). With increasing N supply, wheat grain yield and protein concentrations increase up to a certain point, after which yields plateau (or decrease at very high N levels) while protein concentration continues to increase (Holford *et al*. 1992; Scott 2022).

Electromagnetic induction surveys measure the bulk apparent electrical conductivity (EC_a) of the soil, which is influenced by a range of soil properties including soil clay content (texture), soil moisture, and salinity. While soil tests are a more direct measure, not all growers have soil tests/maps available and EM surveys are a useful proxy for representing variability. Based on prior knowledge and soil surveys of the farm conducted as part of the Grains Research and Development Corporation (GRDC) project "3D Plant Available Water Capacity (PAWC) and constraint mapping" (UOS2206-009RTX; Wang 2024), EC_a values were used to capture variability in soil texture and were used as a proxy for the soils water holding capacity (WHC), where higher soil EC_a values may represent higher clay content and thus, higher soil WHC. Within-fields, the relationship between yield-protein correlations and EC_a values was mixed. In some fields, higher EC_a values corresponded to a more negative yield-protein relationship; an example of this relationship is presented in Figure 4b. We speculate that this likely represents a typical inverse relationship between yield and protein due to the grain protein "dilution effect", where under non-limiting soil moisture conditions, as the amount of carbohydrates in the grain (yield) increases, the protein concentration decreases (Simmonds 1995). Within other fields, higher EC_a values corresponded to a positive yield-protein relationship, suggesting that at a higher soil water holding capacity, both yield and protein were high (or low). However, overall there was considerable variability in the yield-protein relationship and interactions with covariate data layers between the NNSW and WA growing regions, and between seasons.

Future work will examine the drivers of yield, protein, and their relationship within and between fields, farms, and seasons over a greater number of fields and farming regions across Australia and consider a range of both on-farm (e.g. maps of soil constraints, Wang 2024) and publicly-accessible data layers (e.g. remote sensing imagery) to describe and understand this variability. Further work also aims to quantify the degree of variability in both wheat grain yield and protein, and consider site-specific management options once the drivers of variability have been assessed.

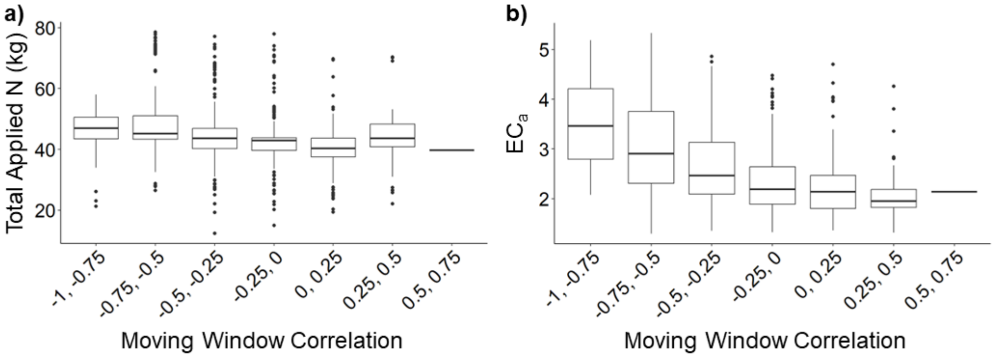

Figure 4. Interactions between yield-protein moving window correlations within an example field in Western Australia (WA) and total applied nitrogen (N, kg, a); and apparent electrical conductivity (EC_a, b).

Conclusion

There is the opportunity to make use of the plethora of publicly-available information and data being collected on-farms to capture, describe, and quantitatively assess variability in grain production systems. When the relationship between wheat grain yield and protein was calculated within fields using a 150 m moving window, correlations were predominately negative in both WA and NNSW. However, there are distinct differences between each growing region (rainfall seasonality, soil type and texture) which may contribute to differences in the yield-protein relationship spatially and between seasons. As total applied N rates increased, the relationship between yield and protein became more negative. In some fields, a high soil EC_a, indicating a high soil water holding capacity, corresponded to a negative relationship between yield and protein which is speculated to be due to the grain protein "dilution effect" where higher yields result in decreased protein concentrations under non-water-limiting conditions. In other fields, a high soil EC_a corresponded to positive yield-protein relationship. Future work will consider a greater number of data layers, fields, farms, and seasons across Australia to better understand the nature and drivers of variability in GPC. Understanding the drivers of variation will enable growers to adjust management to optimise both yield and quality, resulting in positive outcomes for on-farm economics, productivity, and environmental sustainability.

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