Data-driven insights for cotton farming in the northern territory: An exploratory analysis

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Abstract
This study is part of a project being implemented with the focus on understanding the factors affecting cotton yield and sustainability in the Northern Territory. Data was gathered during the 2023 season from the Douglas Daly and Katherine regions, including 2 research farms and 3 commercial properties. An extensive data preparation was undertaken, including consolidation, cleaning and transformation to ensure robust analysis. Exploratory Data Analysis (EDA) revealed consistent yields across Douglas Daly sites, with one outlier property requiring further investigation. Correlation analysis showed a moderate relationship between soil parameters (nitrogen and phosphorus levels) and cotton yield, with cover crop biomass having a significant effect. Our results indicate a widespread nitrogen deficiency and suboptimal phosphorus levels, although conductivity, salinity, and pH levels were generally acceptable, with some variations in soil acidity and cation concentrations. This study highlights the complex factors influencing cotton yield and provides a foundation for future research aimed at optimizing crop production in the territory and similar regions while supporting the goals of sustainable agriculture.

Keywords
Cotton, relationship, yield, soil, cover crop.

Introduction
Cotton is one of Australia's most significant summer crops, consistently yielding well above global averages and producing some of the highest-quality fibre (AcresofOpportunity 2022). With over 1.1 million tons of cotton exported, Australia ranks as the third-largest exporter of cotton lint worldwide (FAO 2022). Most Australian cotton is irrigated, but climate change and prolonged droughts have sparked renewed interest in growing dryland cotton in northern Australia. Recent investments in research and development, the establishment of a local cotton gin at Katherine, and proximity to Asian markets are expected to further bolster the growth of a profitable cotton industry in northern Australia and specifically the Northern Territory (NT) (Rhebergen and Yeates 2023).

However, growers and investors in the NT need scientifically validated recommendations for dryland cotton growing practices so that they can confidently adopt them. It is crucial to address knowledge gaps regarding various factors that impact the cotton industry's development in the territory. Since the reintroduction of cotton to the NT in 2018, growers have faced several challenges that must be resolved to mitigate production risks, enhance whole-farm sustainability, and ensure long-term profitability. These challenges include crop establishment, limited crop rotation and cover crops options, nutrition management, and pest and disease monitoring and management (NTDITT 2023-2026). This study aims to investigate the effect of these factors on cotton yields in the region.

Methods
Two replicated cotton trials were conducted at Katherine Research Station (KRS) and Douglas Daly Research Farm (DDRF). Additionally, three observational sites were selected on commercial growers' properties within the Douglas Daly region. To maintain anonymity, these sites are coded from site 1 to site 5 and the two fields of site 5 as A and B. A Randomized Complete Block Design (RCBD) was implemented at KRS and DDRF, while the different trial locations on the three growers' fields in the Douglas region were considered replicates. Data from the 2022-23 season was sourced from the trial sites and the three commercial properties.

Data included sites' latitude and longitude, soil chemical and physical properties, cover crops and their biomass, planting date and density, quantity and application method of fertiliser, dates of phenological stages, morphological and growth rate of cotton plants and yield. Soil sampling was done at pre-planting and after harvesting at 0 – 15, 15 – 30 and 30 – 60 cm in each paddock from several locations to make composite samples. Soil samples were analysed by CSBP Limited, an accredited laboratory in Western Australia. The mean values of the parameters spanning the whole soil depth was used for reporting purposes in this study.

Data was subjected to re-processing and cleansing by using filters to rectify inconsistencies or incorrect measurements. Various data elements were transformed to render the dataset suitable for analysis.

A heatmap was used to visualize matrix-like data by employing colour as an aesthetic element to understand linear relationships among various variables (Gu 2022). The colour intensity in the heatmap corresponds to the Pearson correlation coefficients, visually indicating the degree of linear association between pairs of variables and enabling quick recognition of inter-variable relationships. Red indicates a positive relationship, while blue indicates a negative correlation between two variables.

Results

An examination of the yield from trials in the Douglas Daly region (sites 2-5) indicated that they were generally comparable across sites t, with averages at each site ranging from 3,054 kg ha^{-1} to 3,766 kg ha^{-1}. Low yields were recorded at site 5A of approximately 800 kg ha^{-1}, because the site had a gravely and sandier soil type that is likely to affect nutrient retention and water holding capacity. The average yield at site 1 was around 2,400 kg ha^{-1}, which was below what was reported at site 2, 3,300 kg ha^{-1} (Figure 1). This is most likely because, site 1 (KRS) is slightly marginal for rainfall, with low clay (lighter) soils than other sites located in Douglas region.

A heatmap was produced with yield designated as the target variable to determine the linear relationship that each variable has with yield (Figure 2). These data will be further investigated to gain a deeper understanding of the multicollinearity among these variables. Nitrate nitrogen and ammonium nitrogen showed moderate correlations of 0.38 and 0.34 with yield, respectively.

A significant influence of cover crop biomass on yield and previous season's crops regenerations was evident and correlated with species. Amongst them, Forage Sorghum was found to positively impact yield, followed by natural regeneration, Cavalcade and Jarra Grass.

Soil Analysis

The results for site 5A and B were not included in this section, because we did not have preseason analysis for comparison. There was an inadequate amount of nitrogen (N) levels in the soil across all the trial sites (Figures 3a and 3b). According to the practical guide to cotton nutrition (Smith and Welsh 2018), around 10 mg of nitrate N per kg of soil (0 – 30 cm depth) is enough for the target yield of 10 bale ha^{-1}. It should be noted that hotter areas like NT require slightly more N to produce the same lint yield as cooler areas.

Historically, the critical phosphorus level for cotton in the 0 to 30 cm soil depth was considered to be 6-12 mg kg^{-1}. Recent research, however, indicates that this critical level may be as high as 25 mg kg^{-1} (CottonInfo 2015). Most sites, except for site 1 and site 4, fell short of this new recommended range.

All trial sites maintained safe levels of conductivity, less than 0.15, and salinity levels that will not hinder plant growth. In general, cotton plants exhibit moderate salt tolerance, having a salinity threshold of 7.7 dS/m (CottonInfo 2015). From our analysis, we discerned that site 3's soils were moderately acidic, with pH values ranging from 4.8 to 5.2, while site 1's soils were less acidic, with pH values ranging from 6.1 to 6.6. (Figures 3h and 3i).

The site 1 recorded high concentrations of cations (specifically Ca, Mg, K, and Na) compared to those at site 2, commercial properties 3,4 and 5 (Figures 3o to 3r), which means higher Cation Exchange Capacity (CEC). Soils with high CEC can hold and retain more cations and anions, making nutrients more available to plants. In contrast, soils with low CEC are susceptible to nutrient losses through leaching. This knowledge is crucial for managing crop nutrition and soil health. To improve CEC in low-CEC sandy soils, organic matter content should be increased, and soil pH (measured in 1:5 $CaCl_2$) should be raised or maintained above 6 (CottonInfo 2015).

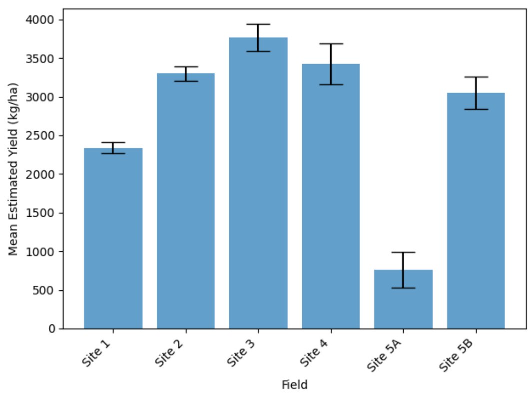

Figure 2. The mean estimated yield across different trial sites.

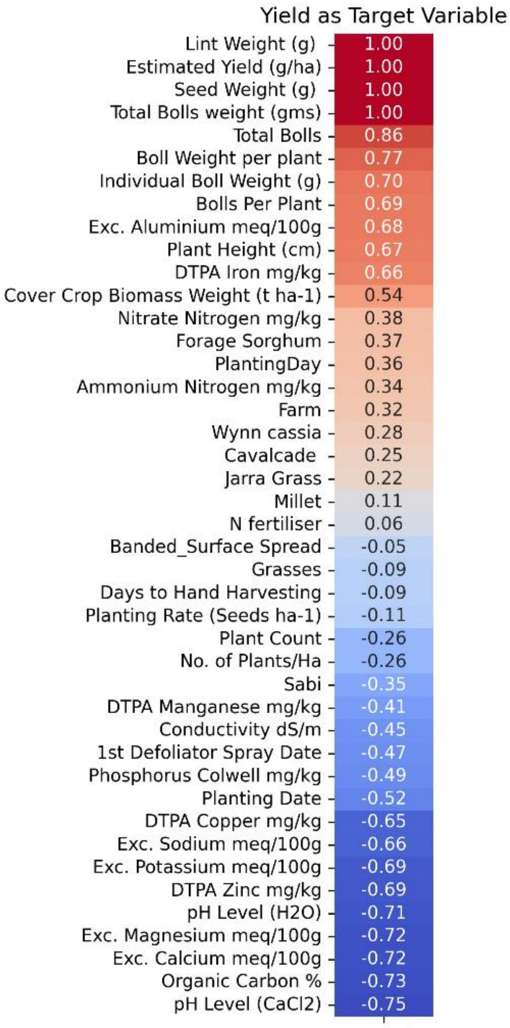

Figure 3. Heatmap displaying correlations of different ground covers and soil nutrients levels from all sites with yield. Red indicates a positive relationship, while blue indicates a negative correlation between two variables.

Conclusion

Rainfed cotton performs well in Douglas Daly region as evident from site 2 to site 5 (wetter and heavier soil) compared to Katherine region at site 1 that receives relatively lower precipitation and has sandy loam soil. This study presented new evidence of the significant effect of soil nutrients and cover crops on cotton yield, demonstrating a strong correlation of soil and environmental conditions of the NT. The findings suggest that optimizing soil nutrient management and incorporating appropriate cover crops can enhance cotton productivity in the region. However, further research is needed to explore the long-term impacts of these practices on soil health and sustainability. Despite the promising results, the study's limitations include the short duration and the specific environmental conditions of the study sites, as the year was relatively drier which may not fully represent the broader region.

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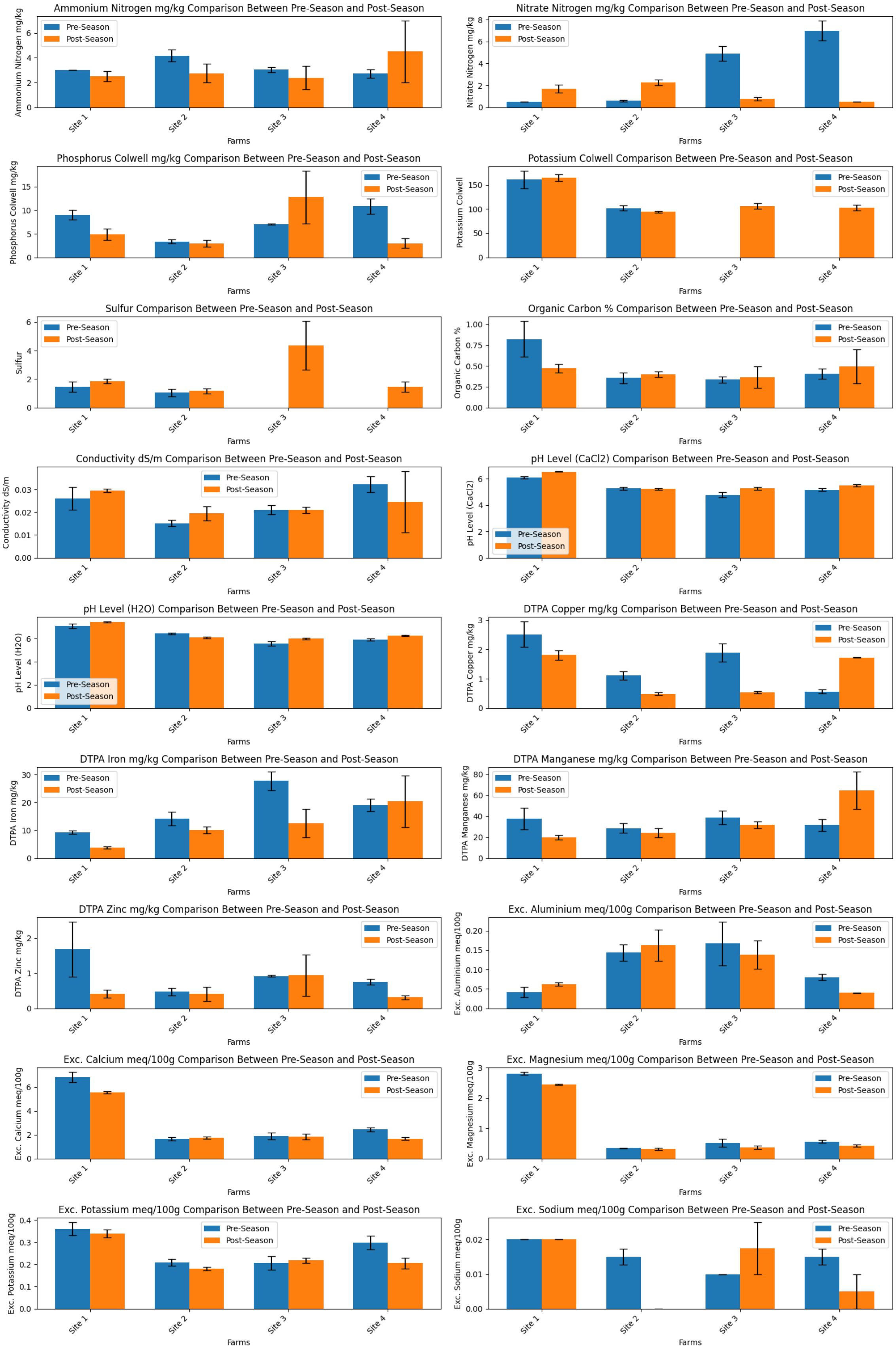

a	b
c	d
e	f
g	h
i	j
k	l
m	n
o	p
q	r

Figure 4. The changes in various soil characteristics across all sites before and after the season, averaged over the 0 to 60 cm soil depth. Error bars indicate the variability of the measurements.