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IDENTIFICATION OF CLIMATE-RESILIENT MERINO SHEEP USING SATELLITE IMAGES

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SUMMARY

This study aimed to evaluate the potential use of data from Landsat 5 TM, 7 ETM+, and 8 OLI and meteorology SILO databases to characterise variation in environmental conditions across farms and identify resilient sheep with a low response in performance to changes in the temperature-humidity index (THI) and normalized difference vegetation index (NDVI). A total of 44,848 Merino sheep from 27 farms across Australia were used in this study. The dataset included sheep with complete pedigree and measurements for weaning weight (WWT) and post-weaning weight (PWT). The average NDVI and THI values during the 9 months prior to the phenotypic measurement were used in a linear reaction norm (RN) model with heterogeneous residual variances. The results revealed genotype by environment (GxE) interaction for WWT and PWT between extreme environments with reranking of sires' estimated breeding values along the NDVI gradient. Higher heritability and genetic variances were estimated in favourable environments. Accounting for GxE interactions could lead to a more accurate selection of resilient sheep to changes in climatic and vegetation variables in Australia, and existing environmental data is enabling for this purpose.

INTRODUCTION

The global rise in more variable and extreme climate conditions has demanded the development of strategies to identify and select resilient animals capable of thriving in challenging circumstances. Selection of resilient sheep will help maximise performance across multiple locations with variable conditions. Reaction norm (RN) models relate the genetic merit of animals to the environment, providing estimated breeding values (EBV) for each environmental condition and identifying genotype by environment (GxE) interactions (Schaeffer 2004). The intercept EBVs represent the overall production potential of the animals, while the EBVs for slope indicate their resilience to different environmental conditions. To characterise environments experienced by animals, the temperature-humidity index (THI) has been investigated as a measurement of thermal stress experienced by dairy and beef cattle (Ravagnolo and Misztal 2000; Bradford *et al*. 2016). Similarly, the availability of forage is expected to have a cumulative effect on animal growth, but direct measurements in extensive production systems are challenging (Johnson *et al*. 2018). As such, the normalized difference vegetation index (NDVI) has been used as a proxy of forage coverage (Johnson *et al*. 2018). The impact of thermal stress and forage coverage, as indicated by THI and NDVI, on the growth performance of sheep has not yet been investigated in extensive production systems. This study aimed to identify Merino sheep resilient to changes in THI and NDVI as indicators of environmental conditions.

MATERIALS AND METHODS

[*] A joint venture of NSW Department of Primary Industries and University of New England

Data. A dataset of 44,848 Australian Merino sheep with weight and pedigree records was used in this study. The dataset includes a full pedigree from 1,420 sires and 20,919 dams spanning four generations. Raw phenotypic measurements, taken between the years 2000 and 2020, included 44,335 measurements for weaning weight (WWT), and 40,265 records for post-weaning weight (PWT). For both traits, records outside four standard deviations from the contemporary group mean were considered outliers and removed from further analysis.

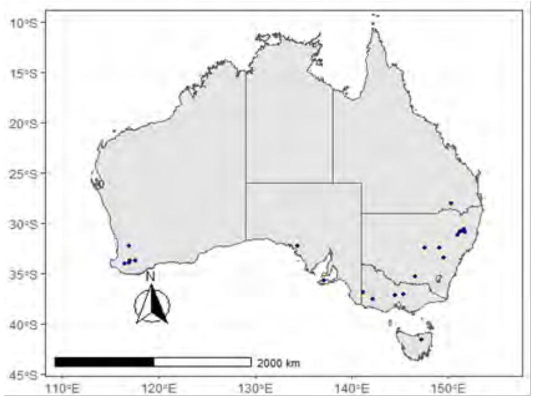

Figure 1. Location of farms across Australia.

Study area. Flocks (N = 27) were located in New South Wales, Queensland, South Australia, Tasmania, Victoria, and Western Australia (Figure 1). Polygons with the coordinates (latitudes and longitudes) were traced on the boundaries of each farm to obtain precise information on climate and forage.

Climatic data. Temperature (°C) and humidity (%) records were obtained for each location from the SILO database (www.longpaddock.qld.gov.au/silo/) to calculate the temperature-humidity index (THI) according to Lallo *et al*. (2018): $THI = (1.8T + 32) - ((0.55\text{-}0.0055Rh)(1.8T\text{-}26))$; where T is the temperature (°C) and Rh the relative humidity (%).

Satellite data. Landsat 5 TM, 7 ETM+, and 8 OLI surface reflectance data (Collection 2, Tier 1) were processed in Google Earth Engine. The cloud mask was applied to all imagery. The red (*R*) and near-infrared (*NIR*) bands were used to compute the normalised difference vegetation index as $NDVI = (NIR\text{-}R)/(NIR+R)$. NDVI values were multiplied by 100 to be used in the following analyses.

Since a reliable association of environmental conditions with forage components can be expected only within a season (Johnson *et al*. 2018), we evaluated the daily THI and NDVI records and averaged the values across 9 months prior to the trait measurement to fit as continuous values in the RN model.

Statistical models. Univariate sire reaction norm models were computed in ASReml v4.2 (Gilmour *et al*. 2021) as a linear function of the environment (NDVI or THI averaged across 9 months) and the traits (WWT or PWT) described in a general form by:

$$\boldsymbol{y} = \boldsymbol{\mu} + \boldsymbol{Xb} + \boldsymbol{Z_{Int}} + \boldsymbol{Z_{Slp}} + \boldsymbol{Z_{pm}} + \boldsymbol{e} ,$$

where y is a vector with weight records, μ is the overall mean, $\boldsymbol{X}$ incidence matrices associating records with the fixed effects, b is a vector of fixed effects solutions for sex (2 levels), birth type (2 levels), rear type (2 levels), age of dam (12 levels), contemporary groups (2,474 levels), covariate (s) for age at measurement, and regression for continuous values of NDVI and THI determined using the average in separate analysis across 9 months prior to the date of phenotypic measurement; $\boldsymbol{Z_{Int}}$ is a matrix linking records to the breeding values to the intercept and $\boldsymbol{Z_{Slp}}$ is an incidence matrix relating records of the breeding values to the slope, $\boldsymbol{Z_{pm}}$ is an incidence matrix associating records with the maternal permanent environmental effect and e is the residual effect. Genetic variances were calculated across either NDVI or THI gradients as $\sigma^2_a = \Phi \boldsymbol{G} \Phi'$, while the breeding values were obtained with $EBV = \Phi E'$; where $\boldsymbol{G}$ is the additive genetic co-variance matrix, $\boldsymbol{E}$ is the matrix with intercept and slope regression coefficients and Φ are the row vectors of a matrix with order one Legendre polynomials (order one) corresponding to the NDVI and THI levels. Genetic correlations across NDVI and THI gradients were defined as $r_{ij} = Cov_{ij}/\sqrt{\sigma^2_{ai} + \sigma^2_{aj}}$. The maternal permanent environmental effect was also modelled using order one Legendre polynomial. Heritability was calculated as $h^2 = \sigma^2_a/\sigma^2_p$ where σ^2_a (sire variance x 4) is the additive genetic variance and σ^2_p corresponds to the phenotypic variance calculated as $\sigma^2_p = \sigma^2_a + \sigma^2_e$. The model fitted heterogeneity in residual variance, allocated based on NDVI (5 levels: 10 to 30, 31 to 40, 41 to 50, 51 to 60, and 61 to 90) and THI (4 levels: 50 to 63, 64 to 67, 68 to 71, and 72 to 82).

RESULTS AND DISCUSSION

Environmental conditions across flocks. Figure 2 depicts changes in NDVI, THI, and temperature between 2000 and 2020 across the studied flocks. Years with favourable conditions are described by relatively high NDVI and moderate temperatures (i.e. 2016), and years with less favourable conditions have relatively high temperatures and low NDVI (i.e. 2019).

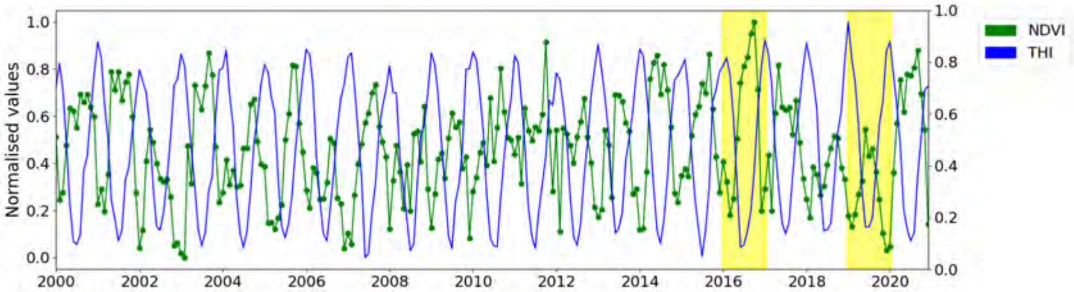

Figure 2. Average monthly temperatures, NDVI, and THI between 2000 and 2020 in 27 flocks located across Australia were normalised for visualisation. *Examples of favourable and unfavourable years are highlighted

Heritability and variances estimated across environmental conditions. Genetic variances (σ^2_a) for WWT and PWT increased with the NDVI (Figure 3A) and decreased for both traits across the THI (Figure 3B). The presence of a scale GxE interaction is evidenced by variation in heritability (h^2) estimates across the environments (Figures 3 C and D). In both traits, h^2 from the RN were higher in favourable conditions (i.e. high NDVI and low THI) and lower in less favourable conditions (i.e. low NDVI and high THI). Similar results were described by Bradford *et al*. (2016) in American Angus cattle with higher heritabilities (WWT) under no heat load (low THI) conditions.

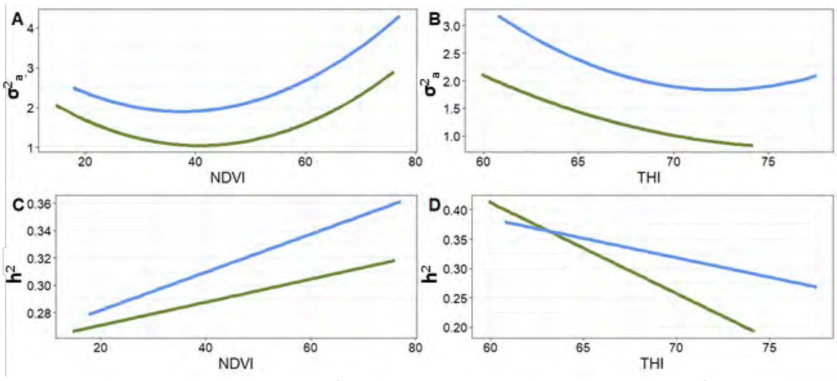

Figure 3. Additive genetic variances (σ^2_a) (A & B) and heritabilities (h^2; linear trend) (C & D) along the NDVI (A & C) and THI (B & D) gradient for WWT (green) and PWT (blue)

The genetic correlations across NDVI and THI gradients were reduced as differences in the environment increased for WWT (Figure 4 A & D) and PWT (plot not shown). The weak genetic correlations between extreme NDVI values contribute to the GxE interactions observed, leading to a higher reranking of sires across NDVI compared to the THI.

Genetic correlations between the intercept and slope of the RN model were positive for WWT (0.17) and PWT (0.27) when NDVI was evaluated. The RN for THI resulted in negative genetic correlations between the intercept and slope for WWT (-0.60) and PWT (-0.24). These results suggested that sheep with higher intercept (EBV) had a more responsive phenotype to the forage coverage as suggested by NDVI. In contrast, such animals (with higher EBV values) exhibited a relatively small response (slope) to THI.

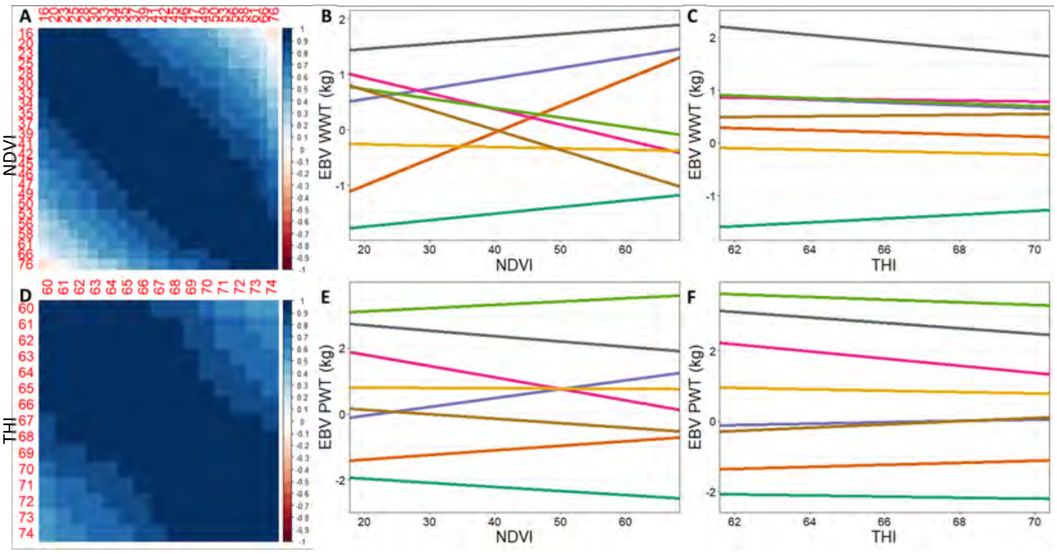

Figure 4. Genetic correlations for WWT (A & D) and estimated breeding values (EBV) for WWT and PWT for eight influential sires (> 100 progeny) along NDVI (A, B & E) and THI (C, D & F) gradients

CONCLUSIONS

This study describes GxE interactions between extreme environments for WWT and PWT in Australian sheep along environmental gradients representing forage coverage (NDVI) and the temperature-humidity index (THI). There was more GxE interactions when NDVI was extremely different, resulting in higher EBV reranking in sires than when THI was considered. Higher genetic variances and heritabilities were estimated in favourable environments. Furthermore, these findings emphasised the opportunity to use climatic and satellite data to describe the environment and identify resilient sheep for THI and NDVI in a national or international context.

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