Assessing early-vigour in oat genotypes for cover crop use in New Zealand

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Abstract
Winter-sown oats (*Avena sativa*) are increasingly used as cover crops to reduce risks of nitrogen (N) leaching in New Zealand cropping systems. It is currently unclear if there is potential to select new oat genotypes with improved phenotypical characteristics that could potentially confer more effective winter N uptake. We assess phenotypical variability in the progression of early canopy expansion (i.e. early-vigour) across more than 200 forage oat genotypes. Underlying morpho-physiological mechanisms behind early-vigour were then investigated under field conditions for two selected lines. Results showed that early-vigour was highly variable across the oat population assessed. The total area of the initial six leaves was the main phenotypical characteristic that explained early-vigour differences in oats. Our results suggest that there is potential to explore early-vigour as a selection trait in breeding programs. Nevertheless, the share of genetically induced variability and potential benefits from high early-vigour oat genotypes as cover crops require further investigation at system scale.

Keywords
Breeding, catch-crop, high throughput phenotyping, genetics, model

Introduction
Forage oats (*Avena sativa*) are sown during winter months in New Zealand as cover crops to reduce risks of N leaching losses from residual soil N left after the harvest of previous arable or forage crops (Carey *et al.*, 2016; Malcolm *et al.*, 2020). Oat genotypes that show high early-vigor (i.e. fast initial canopy development rates) as a phenotypical trait may be more effective as cover crops in these conditions. Early-vigor is a key characteristic already explored in breeding and selection of wheat and barley for enhanced grain production (López-Castañeda *et al.*, 1996; Rebetzke and Richards, 1999). However, the potential to explore early-vigor in oats is still unknown (Sadras, Mahadevan and Zwer, 2017) particularly for alternative usages such as winter cover crops. In this study we assess the degree of genetic variability of early-vigor within a large population of forage oats and investigate the underlying morpho-physiological mechanisms explaining the trait expression. Our insights are expected to inform breeding programs that focus on improvement of oat genotypes for cover crop uses.

Methods
Screening for early-vigour in oats
A high-throughput field phenotyping (HTFP) approach based on the collection of sequential aerial photos of oat canopies was used to assess the degree of early-vigour across 231 oat lines from a commercial forage oat breeding programme (726 individual plots, 5 m x 1.2 m). The photos were taken from an Unmanned Aircraft System (UAS) drone model DJI Phantom 3 Professional set at a 15 m flying altitude. Plots of different filial generations were replicated either four (F_3 and F_8) or two (F_7) times. Normalised fractional canopy cover (0 to 1) was estimated from the proportion of green pixels within each plot across the first 23 days of crop growth, from sowing (04 April 2019) until when most lines achieved full canopy cover (17 May 2019).

Assessing early-vigour mechanisms in oats
From the large HTFP screening of oat genotypes, we selected two lines that showed contrasting canopy cover development rates; specifically beyond upper or lower quartiles of the population distribution (‘Coronet’ and ‘100-05’; see Results). Morpho-physiological characteristics that could explain early-vigour were then assessed in two field trials with genotypes exposed to contrasting environmental conditions and treatments replicated 4 times. The first trial was in spring 2019 (1.35 m x 4 m plots sown on 29 October 2019) and the second in winter 2020 (1.35 m x 10 m plots sown on 23 July 2020). Canopy development was measured as normalized difference vegetation index (NDVI) taken at ground-level with a GreenSeeker (Trimble RT100, Trimble Agriculture Division, Colorado, USA). Canopy forming processes were assessed through measurements of plant population, tiller population, leaf appearance and individual leaf size taken in

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four marked-plants per plot. Additional measurements were performed in the winter trial, these included, leaf area index, specific leaf area of leaf position six and light interception with a SunScan (Delta-T Devices, UK) for the estimation of extinction coefficients. In addition, coleoptile length of the seed lot used in the winter trial was measured under controlled growth conditions (15 days at 20.3±0.8°C). For both trials, results for the vegetative phase of development (before panicle appearance) are reported as this is when cover crops are commonly harvested.

Results and Discussion

Oat crop lines showed a large variability for the presence of early-vigour as a phenotypical trait (Figure 1). For instance, by mid-April, the median canopy cover estimates ranged from ~0.4 in slow canopy expansion lines to ~0.6 in fast ones. Most genotypes converged to nearly full canopy closure by mid-May.

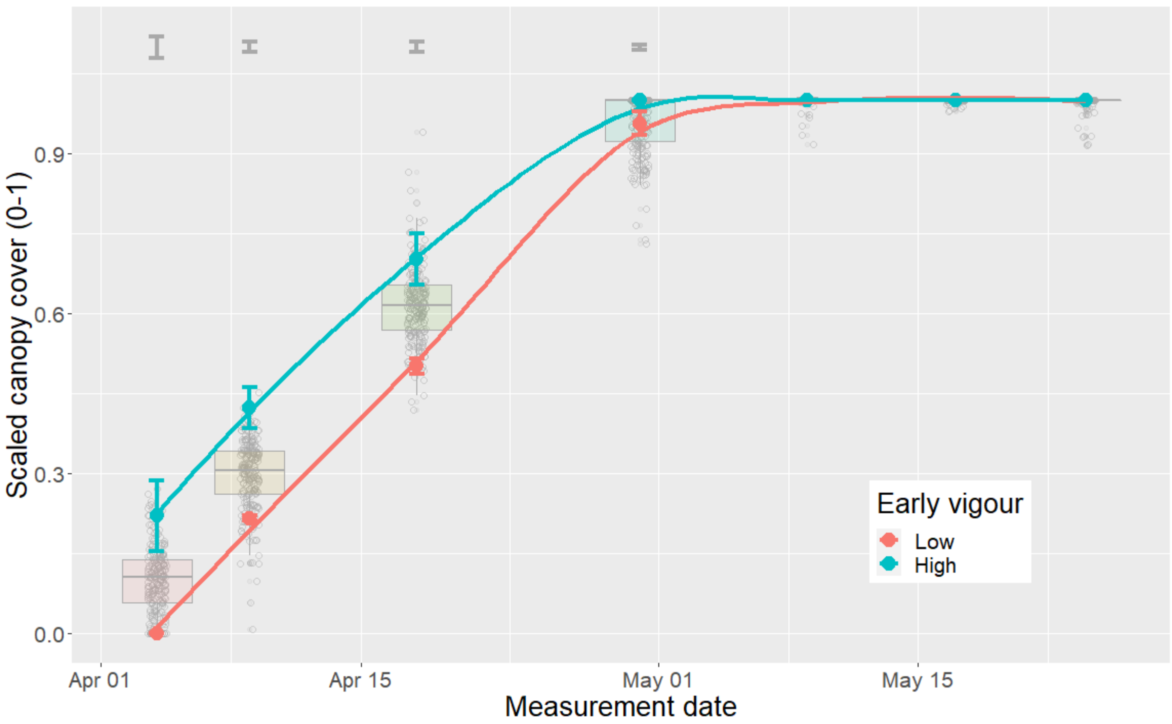

Figure 1. Time-series of estimated green cover from scaled canopy cover values taken with high-throughput phenotyping aerial images from 231 oat genotypes (grey data-points). Two contrasting genotypes were selected for further detailed assessments 'Coronet' (low early-vigour, red) and '100-05' (high early-vigour, blue). Lines are empirical fitted models with error bars showing one standard deviation, grey error bars are the LSD at 5% significance. Box plots show overall distribution (25th, 50th and 75th percentile) of all genotypes for each sampling date.

The size of individual leaves was the main contributor to the expression of early-vigour in oats (Table 1). This was illustrated by the measure of total leaf area per tiller (below leaf position 7). The total area of leaves 1 to 7 was 50-70% larger for the high early vigour genotype. This agrees with previous studies that showed leaf size to be a key phenotypical characteristic to explain early vigour in other cereals such as wheat and barley (Botwright et al., 2002; Hickey et al., 2017).

Table 1. Assessment of canopy related variables for a low ('Coronet') and a high ('100-05') early-vigour genotype.

Experiment	Spring-sown 2019			Winter-sown 2020		
Variable	Low	High	*P*	Low	High	*P*
Total leaf area at leaf position < 7 (cm^2/tiller)*	48	82	0.01	68	103	0.01
Phyllochron (ºCd/leaf)**	83	84	0.80	109	110	0.60
Extinction coefficient (fractional)	NA	NA	NA	0.45	0.48	0.76
Specific Leaf Area of largest leaf (cm^2/g)***	231	201	0.20	221	206	0.30
Plant population at full emergence (plants/m^2)	298	340	0.07	329	381	0.08
Tiller population at stem elongation stage (tillers/m^2)****	1044	1054	0.88	855	938	0.32
Coleoptile length (cm)	NA	NA	NA	8.1	11.2	0.02

*Sum of individual leaf areas below leaf position 7; **Estimate based on air temperature for genotype comparison; ***Specific Leaf Area was measured at approximately leaf position 7; ****Assessed at approximately Zadok stage 30; indirectly estimated in spring-sown trial from tillers/plant and directly measured in winter-trial. Variables with non-available (NA) values were not measured in the first spring trial.

Both genotypes had similar leaf appearance rates for a given environment, with phyllochron values that ranged between 84 and 110ºCd/leaf for the different years. Canopy architecture was also similar between genotypes with an average extinction coefficient of 0.47. Specific leaf area (SLA) of the largest leaf ranged between 200 and 230 cm^2/g of leaf dry matter for both genotypes. However, in addition to differences in leaf size, early-vigour genotypes tended to establish 15% higher plant populations (0.07<P<0.08) in both years, suggesting enhanced germination and/or emergence. This pattern is aligned with the 38% longer coleoptile length found for the high early-vigour genotype when assessing seed germination of the second year trial under controlled conditions. Nevertheless, this magnitude of difference in plant population might have had a less prominent impact on light interception than leaf size due to a compensation in yield components through tillering, as also observed in other cereals such as wheat (Spink *et al.*, 2000), because tiller populations were unaffected by genotype (0.32<P<0.88), with values ranging from ~900 to 1050 tillers/m^2.
Our results suggest that there is potential to target early-vigour in oat breeding programmes and that the size of early leaves is a key determinant of early-vigour in this crop. However, the share of genetically induced variation explaining these differences and their potential to improve the effectiveness of oat cover crops require further investigation. For instance, benefits associated with early-vigour might be affected by multiple interactions and sources of variability inherent to cover crop systems (Teixeira *et al.*, 2016, 2021), trade-offs when scaling from plant organ to the cropping system (Chenu *et al.*, 2018) and changes in future growth conditions (Bourgault *et al.*, 2020).

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