# Phenotypic plasticity of grain yield in oat and its association with agronomic and phenological traits

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## Abstract

Oat production in Australia needs to expand into new, low rainfall regions to meet increasing domestic and international demand for both grain and hay. The objectives of this study were to (i) quantify and compare grain yield plasticity of oat entries in contrasting environments; (ii) relate yield plasticity with yield under favourable (90$^{th}$ percentile) and stressful conditions (10$^{th}$ percentile); (iii) study the associations between yield, agronomic and phenological traits. Variance ratio as a measure of yield plasticity was quantified for 29 entries in nine environments resulting from the combination of locations and seasons. Entries included advanced breeding lines, released varieties of grain, hay and grazing types which vary in yield, height, growth habit and maturity.

Yield was affected by all three sources of variation: environment, genotype and their interaction (all $P<0.0001$). Yield plasticity ranged from 0.26 to 1.38 and correlated with 90$^{th}$ percentile yield, ranging from 2.3 to 5.5 t ha$^{-1}$ ($R^2=0.78$; $P<0.0001$) and 10$^{th}$ percentile yield, ranging from 0.1 to 1.0 t ha$^{-1}$ ($R^2=0.30$; $P=0.0096$). Residual analysis revealed that varieties with GS60 (anthesis) <1430 $^{o}$Cd (base temperature = 0℃) were above average in both high and low yielding conditions. Grain varieties out yielded grazing and hay varieties. Plant height was significantly influenced by all the sources of variation ($P<0.0001$). Plasticity of height ranged from 0.43 to 1.64 and correlated with 90$^{th}$ percentile ($R^2=0.57$; $P<0.0001$). Average plant height across the environments ranged from 45 to 99 cm and non-linearly correlated with yield. Plasticity of plant height negatively correlated with yield plasticity.

## Key words

Yield potential, stress, plant height, phenology, anthesis

## Introduction

Oat production in Australia in 2012-13 was 1.12 million tonnes cultivated in 0.7 million ha (ABARES 2014) which returned an export earnings of $54 million. Oats are widely recognised worldwide for its nutritional and health benefits. Oat production needs to expand into new, low rainfall regions to meet increasing domestic and international demand for both grain and hay (AEGIC 2014) . Hence the importance of improving oat adaptation to water limited environments with no trade-offs in favourable conditions. The objectives of this study were to (i) quantify and compare grain yield plasticity of oat entries in response to contrasting environments; (ii) relate yield plasticity with yield under favourable and stressful conditions (Sadras and Richards 2014); and (iii) study the associations between yield, plant height, and phenology.

## Materials and methods

Twenty nine oat entries were evaluated over three crop seasons (2012 to 2014) in four locations, Pinery, Riverton, Turretfield and Waikerie in South Australia. The entries consisted of advanced breeding lines, released varieties of grain, hay and grazing types which varied in yield, height, growth habit and maturity. Trials were sown in randomised complete block designs with three replicates. Plot size was 4.16m$^2$ (3.2 m x 1.3 m) and seeding rate was 165 seeds /m2 in Pinery, Riverton and Turretfield. Plot size was 7.2 m$^2$ (5 m x 1.44 m) and seeding rate was 180 seeds /m$^2$ in Waikerie. Crops were fertilized with 120kg ha$^{-1}$ of diammonium phosphate. All other agronomic practices were in accordance to the specific requirements of each environment. Phenology was monitored weekly using the scale of Zadoks in Pinery and Riverton in 2013 and 2014. The time of stem elongation (GS31), anthesis (GS60) and hay cutting (GS71) was estimated and expressed as thermal time ($^{o}$Cd) calculated with a base temperature of 0$^{o}$C. Meteorological data from the nearest station from Australian Bureau of Meteorology were used. Plant height was measured in four environments Pinery 2012, Waikerie 2012, Pinery 2014 and Riverton 2014 as an average of three observations per plot at physiological maturity. Yield was measured by machine harvesting the whole plot and expressed at 12% moisture content.

Variance ratio, as a measure of trait plasticity, was calculated as a ratio of the variance of the trait for each entry to the overall phenotypic variance of all the entries (Dingemanse, Kazem et al. 2010). Yield plasticity was related to the yield in low (10$^{th}$ percentile) and high (90$^{th}$ percentile) yielding environments (Sadras and Richards 2014). Regression analysis and analysis of residuals was used to study the association between traits and their plasticities.

**Results and discussion**

Riverton 2013 registered the highest (365 mm) and Waikerie 2012 the lowest (75 mm) rainfall from sowing to harvest. The difference between the evaporative demand and rainfall was the highest for Waikerie 2012 (411 mm) and lowest for Riverton 2013 (263 mm).

Yield was influenced by all three sources of variation environment, genotype and their interaction ($P<0.0001$). The environmental mean yield ranged from 0.3 t ha$^{-1}$ to 4.4 t ha$^{-1}$. The top yielding lines averaged approximately 3.3 t ha$^{-1}$ across environments (05302-19, Dunnart, Bannister) and the lowest yielding lines were Forester (0.98 t ha$^{-1}$), Riel (1.15 t ha $^{-1}$) and Tammar (1.97 t ha$^{-1}$).

Yield plasticity ranged from 0.26 to 1.38 and correlated strongly with 90$^{th}$ percentile yield and weakly with 10$^{th}$ percentile yield (Figure 1A). This means genotypes were similar in performance under stress (10$^{th}$ percentile) but varied in their potential in the favourable environment (90$^{th}$ percentile). Residual analysis for yield at 90$^{th}$ percentile returned significant differences ($P=0.003$) between grain varieties producing above average yields (red symbols Figure 1A) and hay or grazing varieties producing below average yield (green and blue symbols Figure 1A) for a given plasticity.

ANOVA returned significant differences in thermal time from sowing to GS31, GS60 and GS71 among entries ($P<0.0001$) but not for environment or interaction. Breeder lines were as early as 830 $^{o}$Cd for GS31 (05089-31), 1301 $^{o}$Cd for GS60 (05140-3) and 1412 $^{o}$Cd for GS71 (05014-22). Grazing (MA lines) and hay varieties (particularly Forester, Riel, Tammar, Tungoo and Wintaroo) took longer to reach GS31, GS60 and GS71.

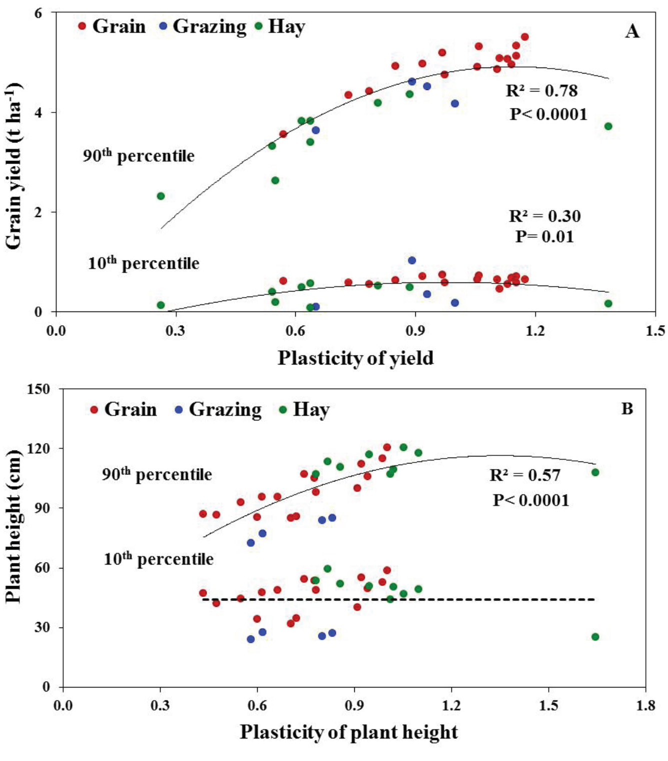


**Figure 1. Relationship between (A) yield and yield plasticity and (B) height and height plasticity of 29 oat entries under favourable (90$^{th}$ percentile) and stressful (10$^{th}$ percentile) conditions.**

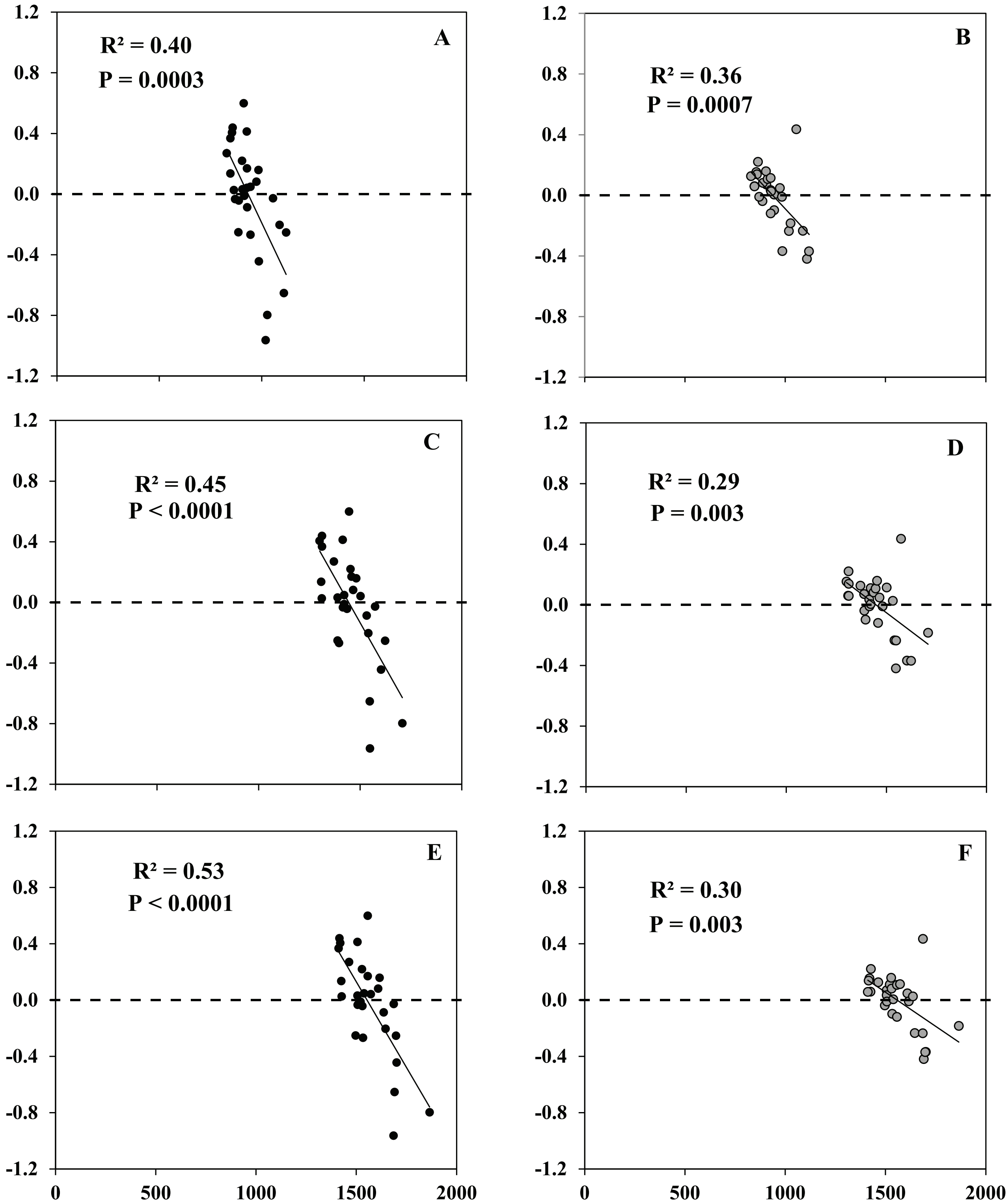


**Figure 2 Relationships between residuals of yield vs plasticity at favourable (90[th] percentile) and stressful (10[th] percentile) environments of 28 entry's thermal time from sowing to GS31 (A & B), GS60 (C & D) and GS71 (E & F). Forester, an extremely late variety (1024 °Cd for GS31, 1923 °Cd for GS60 and 2032°Cd for GS71) was excluded from the analysis.**

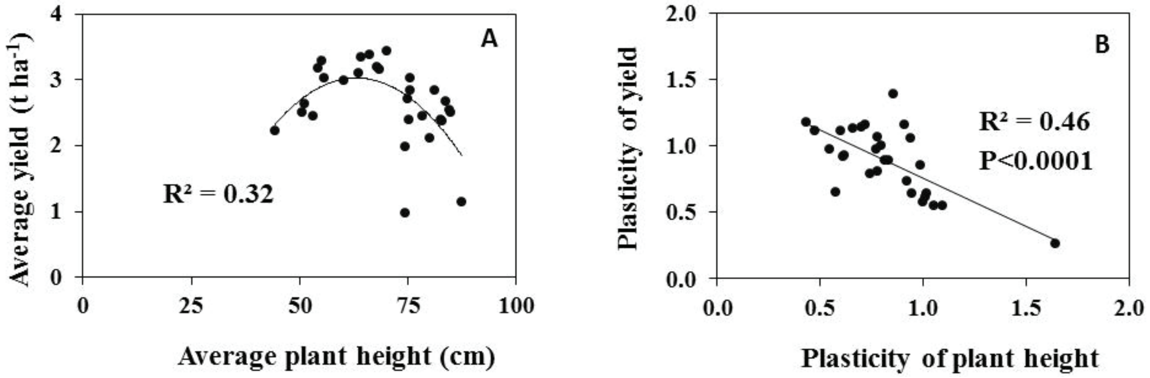


**Figure 3. Association between (A) average grain yield and plant height and (B) Plasticity of grain yield and plasticity of plant height of 29 oat entries across the environments**

Yield residuals at both favourable and stressful conditions correlated with thermal time to GS31, GS60 and GS71 (Figure 2). The relationship showed that the varieties, which attained GS31earlier than 949°Cd, GS60 earlier than 1430 °Cd and GS71 earlier than 1576 °Cd, contributed above average yields under favourable environment. Similar relationships, with similar thresholds, were found for yield under stressful conditions.

Plant height was influenced by all three sources of variation (P<0.0001). Average plant height across environments ranged from 45 to 99 cm. Plasticity of plant height ranged from 0.43 to 1.64 and correlated with 90th but not with 10th percentile plant height (Figure 1B). This means plasticity resulted from responsiveness to favourable conditions with no systematic variation among lines under stress. Average yield was non-linearly related to plant height and there was a negative relationship between plasticity of yield and plasticity of height (Figure 3A & 3B). Analysis of plant height is vital in breeding as this trait influences harvest index and yield (Figure 3B) with dwarf genotypes possessing greater yield potential than the tall genotypes. However, the tall genotypes have greater potential for hay yield.

## Conclusion

Yield plasticity was mostly associated with yield under favourable conditions with no apparent trade-off between potential yield and yield under stress for the collection of entries and environments in this study. Early lines (GS60 < 1430 °Cd) yielded more than their late counterparts at the same plasticity. The relationships between yield and plant height need further study as plant height was confounded with growth habit. The association between plasticity of yield and plasticity of height is interesting and deserves further research.

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