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Improving the growth and yield of barley on sandy soils of low fertility

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Introduction

Crop production limitations on sandy soils are associated with poor establishment and growth, which restrict grain yield potential. This reflects the characteristics of sandy soils such as low inherent fertility, both in terms of macro- and micro-nutrient status; low organic matter; low water retaining capacity and cation exchange capacity; water repellency; a high incidence of root disease; loss of nutrients through leaching; and the propensity to wind erosion. In addition, crops are often subject to sand "blasting". In contrast, heavier soil types have a greater yield potential and this has been attributed largely to improved establishment and early vigour (Hamblin *et. al.*, 1988; French and Ewing, 1989). Varietal improvement and selection for sand `adaptation' is a challenge, by reason of low genetic variance, and high error variance associated with breeders yield trials on sandy soils. In addition, traditional statistical approaches to analysing yield differences have tended to favour high grain yield potential varieties and environments.

Despite this, lines developed in the WA breeding program (*e.g.* Yagan, Forrest and Mundah) have shown an ability to perform well on sandy soils, and are superior to SA bred counterparts, indicating potential genotypic variability for sand `adaptation'. This has been borne out in the long-term yield analysis of varieties in sand evaluation trials conducted by the South Australian Research and Development Institute (SARDI) (Table 1). However, little information on characteristics potentially associated with their improved yield potential on sandy soils is available.

Table 1: Long term yield data of varieties on sandy soils and heavier soils in SA (1988-2000)*

Variety	Sandy Soils	Rank	Heavier Soils	Rank

	(t/ha)		(t/ha)	
Mundah (WA)	1.59	1	2.98	3
Forrest (WA)	1.55	**2**	2.69	**5**
Keel (SA)	1.46	**4**	3.06	**1**
Barque (SA)	1.54	3	3.02	2
Sloop (SA)	1.41	5	2.86	4

*Source: Rob Wheeler (SARDI)

A deep root system, good early vigour, and a high degree of assimilate transfer to the grain during grain fill has been suggested as desirable for drought tolerance on light textured soils (Turner and Nicolas, 1987). In addition, various authors have identified traits to improve early vigour (Lopez-Castaneda *et. al.*, 1996; Rebetzke and Richards, 1996 & 1999; Rebetzke *et. al.*, 1999; Richards, 1991 & 2000) and illustrated how vigour can improve grain yield potential (Brown *et al.*, 1987; Ceccarelli, 1987; Acevedo *et al.*, 1991). This paper reports on experiments conducted to identify traits conferring improved growth and yield using selected varieties, which range in their `adaptation' on sandy soils, when grown in field trials and under controlled environmental conditions.

Materials and Methods

Variety Comparison Experiment

Nine barley cultivars were sown in plots, arranged as a randomised complete block design (RCBD), at three sandy sites in SA, in 1999 and 2000. Traits measured included; establishment, growth habit (upright v prostrate), early vigour (dry matter production (E_DMP) and leaf area development (LAD)), relative developmental stage, grain yield, 1000 grain weight, screenings (<2.5) percentage. At one site (Lowbank, 2000), ethanol soluble carbohydrate (ESC; glucose, fructose, sucrose) and fructan content was measured from main stems at anthesis and physiological maturity.

Seed Size Experiment

Estimating the effect of seed size on growth and grain yield on sand, independent of genetic differences in seed size, can be achieved by utilising the natural variation within every seed sample by screening samples into different size fractions. Mundah seed, sourced from 4 sites, was screened into four size fractions (<2.2, 2.2-2.5, 2.5-2.8, >2.8mm) and the seeding rate adjusted to sow exactly the same number of germinable seeds per unit area (145 seeds/m^2). Each seed source (site) x size fraction sample was assessed for seed nutrient status, seed weight, coleoptile length, early vigour (dry matter production (E_DMP)), grain yield, 1000 grain weight, and screenings (<2.5mm) percentage.

Controlled Environment Experiment (CEE)

Six of the barley varieties used in the field trials were also assessed under controlled environmental conditions in two separate experiments (1999 & 2000). Soil from Cooke Plains (1999) and Lowbank (2000) was ammended with basal nutrients as per Rengel and Graham (1995), and placed in PVC pots (10 x 30cm) at a density of approximately 1.3g/cm^3. The soil was watered to 75% field capacity and was maintained at this moisture content by watering to weight every 2-3 days. Six pre-germinated seeds were sown to each pot before being culled to three immediately following emergence. Sampling occurred at 10, 17, 24 and 31 days after sowing, at which time leaf area development (LAD), leaf number, biomass production, maximum rooting depth and root:shoot (R:S) ratio was assessed.

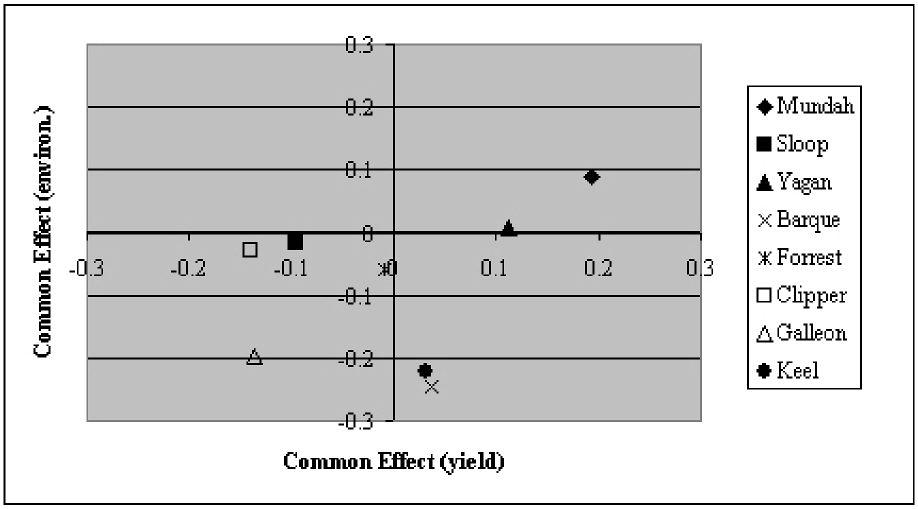
Statistical Analysis

Field experiment results were analysed using spatial statistical methods including residual maximum likelihood (REML) estimates of variance components and multi-environment trial (MET) analysis. The controlled environment experiment was analysed by ANOVA.

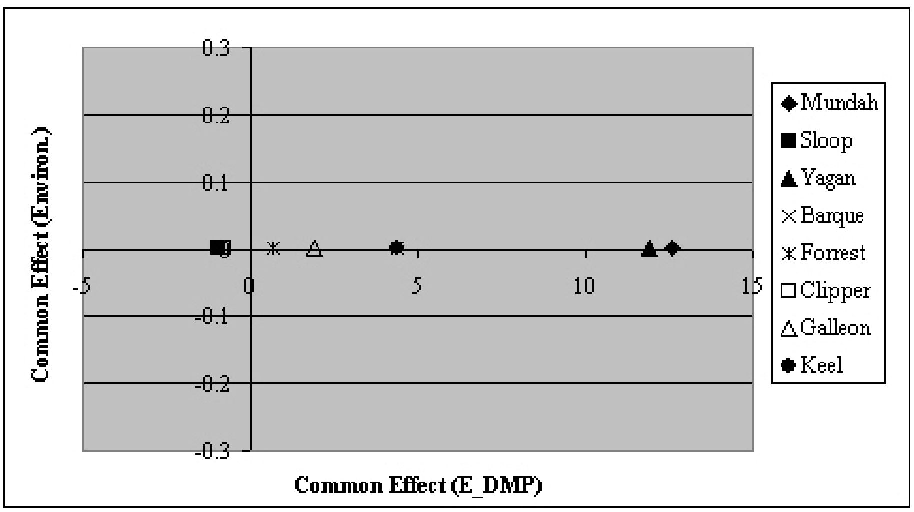
Results and Discussion

Grain Yield

SARDI sand evaluation trials (Table 1) have highlighted the improved yield of WA varieties over SA lines. This is despite the lack of resistance to economically important diseases such as spot form of net blotch (P*yrenophora teres* f. sp. *maculata*), CCN (*Heterodera avenae*), Root lesion nematode (*Pratylenchus neglectus*) and leaf scald (*Rhynchosporium secalis*) in this germplasm. MET analysis of variety evaluation experiments conducted for this project (1999-2000) corroborates the SARDI data (Figure 1a). Mundah and Yagan were the highest yielding varieties on sandy soils. Barque and Keel yielded moderately, but were particularly low yielding in some environments, whereas the WA lines were relatively stable. Of the low yielding lines (Sloop, Clipper and Galleon), Galleon was the most ill suited to sandy soils, with extremely low yields at some environments. The question arises, what characteristics of Yagan and Mundah, given their relatively poor disease resistance, are associated with their improved `adaptation' on sandy soils of low fertility?



a)



b)

Figure 1: MET analysis of a) grain yield and b) early vigour of variety evaluation trials (1999-2000)

Early Vigour

Improvement in grain yield on sandy soils could potentially be associated with early vigour (E_DMP and/or LAD). Indeed improved grain yield potential has been found to be associated with greater early vigour under moisture-limiting conditions (Brown *et al.*, 1987; Ceccarelli, 1987; Acevedo *et al.*, 1991) and on light textured soils (Turner and Nicolas, 1987).

Mundah and Yagan showed significantly higher E_DMP than the other lines tested in the evaluation trials (Figure 1b). The MET analysis of E_DMP also highlighted that early vigour, for all varieties, was stable across environments (Figure 1b). The indication then is that early vigour is likely to be a contributor to improved grain yield on sandy soils. This was further emphasised by the good relationship between the two traits (Figure 2).

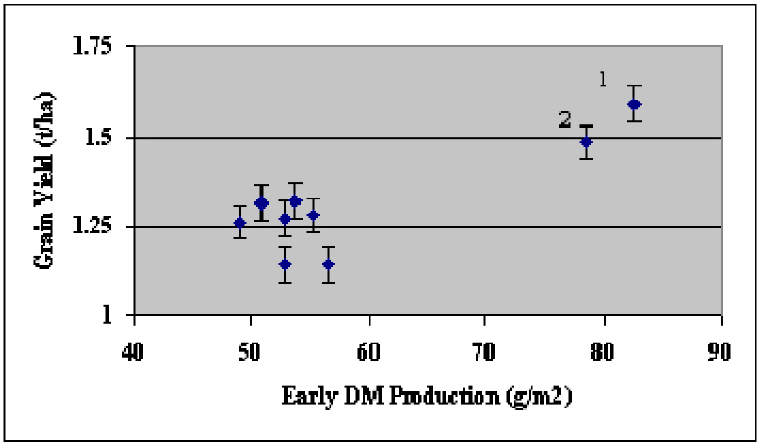


Figure 2:Relationship between grain yield and early dry matter production (Lowbank, 2000).
Key: Mundah[1]; Yagan[2]

The superior E_DMP and grain yield of both Yagan and Mundah also seems to be related to their high LAI (Figure 3a & b). A reduction in time to full light interception by the plant canopy (LAI=3.5) will favour crop photosynthesis and limit the amount of radiant energy reaching the soil surface, thereby enhancing water use efficiency through improved transpiration and reduced soil evaporation (Richards, 1991 & 2000). Other associated benefits of a faster developing ground cover is an improved competitiveness with weeds, a reduction in erosion, and the possibility of reduced effects of sand "blasting".

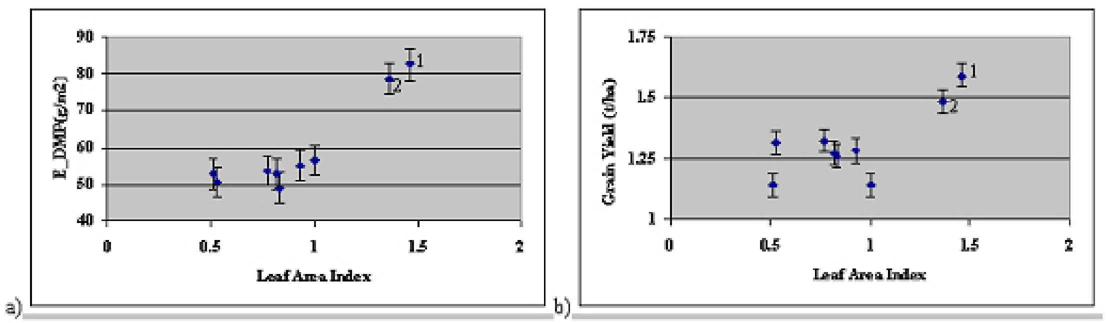


Figure 3: Relationship between E_DMP, and grain yield and leaf area index (Lowbank, 2000). Key: Mundah[1]; Yagan[2]

Seed Size

Large seed size (>2.5mm) significantly improved establishment, early vigour and grain yield (Table 2). This improvement in growth and yield may be related to the enhanced seed nutrition and longer coleoptile length (Table 2), as well as superior starch reserves, of the larger seed size fractions. Both establishment and early vigour have previously been associated with larger seed size, improved seed nutrition and longer coleoptile length (Lopez-Castaneda *et. al.*, 1996; Bollard and Baker, 1989; Rengel and Graham, 1995; Rebetzke and Richards, 1996; Rebetzke *et. al.*, 1999). Principle component analysis of the nutrient concentration and agronomic data suggested, however, that seed nutrient content, in this case, was not as major a contributor to grain yield as were seed size, establishment, E_DMP and coleoptile length (Figure 4).

Table 2: Nutrient analysis and agronomic data for the Mundah seed size trial at Geranium, 2000.

Seed Size[1] (mm)	**Average Seed Weight (mg)**	**Seed P content (ug/grain)**	**Seed Zn content (ug/grain)**	**Seed Mn content (ug/grain)**	**Coleoptile length (cm)**	**Establishment (plants/m^2)**	**Early Vigour (g/m^2)**	**Grain Yield (t/ha)**
<2.2	24.63	83.13	0.60	0.46	65.36	105.6	50.4	2.14
2.2-2.5	35.80	110.55	0.76	0.62	72.75	136.3	51.6	2.96
2.5-2.8	47.20	132.63	0.95	0.74	78.92	154.0	68.4	3.68
>2.8	54.78	146.54	1.07	0.84	79.45	172.0	78.2	3.62
LSD (P<0.05)					**2.54**	**19.11**	**15.35**	**0.854**

[1]sorted over slotted screens of these sizes

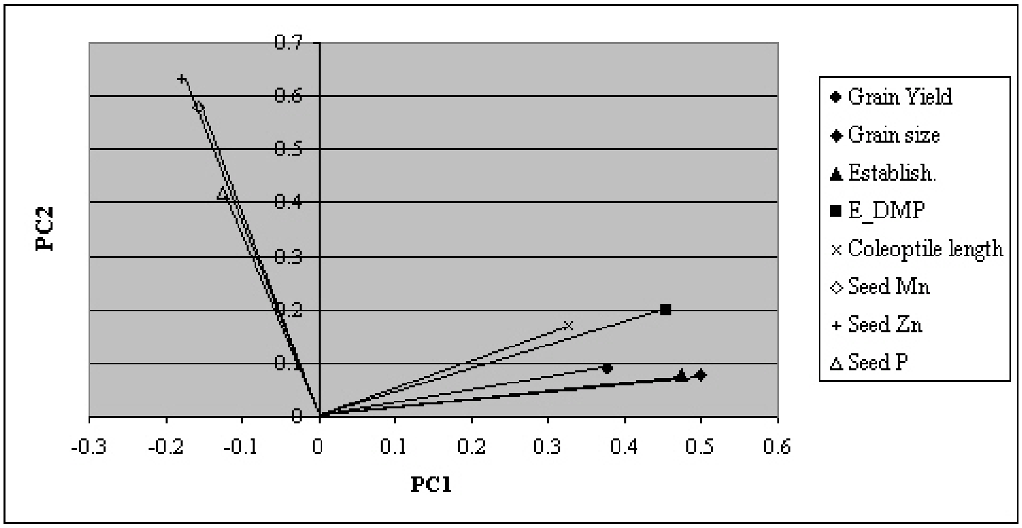


Figure 4: PC analysis of grain yield and agronomic data of the Seed Size trial (Geranium, 2000)

Root Morphology

The low inherent fertility due to erosion, leaching of nitrogen, and the relative immobility of phosphorus, along with the free draining and water repellent nature of sandy soils, intuitively highlights root morphology as a likely critical component of sandy soil `adaptation'. In the controlled environment experiment, maximum rooting depth was a factor which differentiated varieties based on their sandy soil `adaptation' (Figure 5). This was evident by 31 days after sowing, although Galleon and Forrest were an exception. Barque and Mundah exhibited greater rooting depth, than either Keel or Sloop. In field trials, Galleon showed very poor growth and yield on sand. Therefore, its ability to achieve an equivalent rooting depth to Mundah under controlled conditions suggests that the application of basal nutrients to an otherwise low fertile soil, in addition to the supply of adequate moisture, may have assisted the development of Galleons roots. R:S ratio was not a good indicator of improved performance on sandy soils.

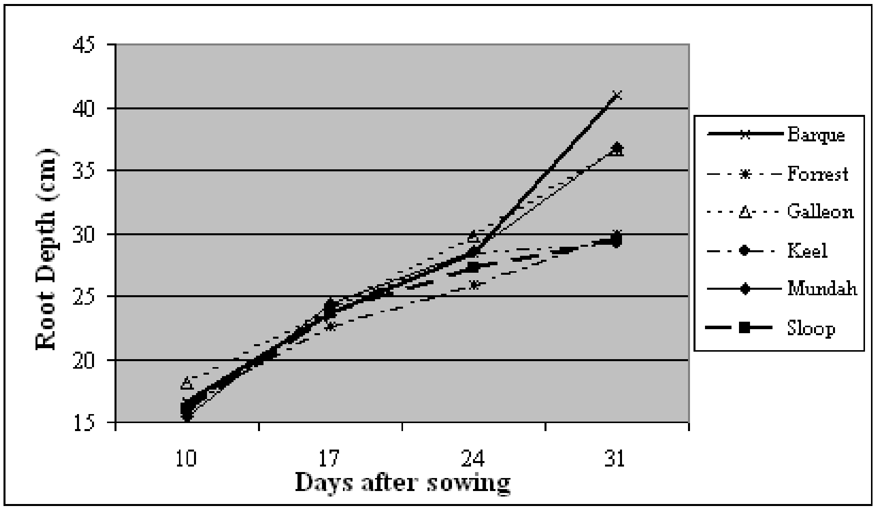


Figure 5: Rooting depth with time (Controlled Environment Experiment, 1999-2000)
$LSD_{(0.05)}$ = 5.556

Pre-anthesis stem carbohydrate reserves

Reserves of non-structural carbohydrates in the stem are considered an important source of assimilate for grain filling, especially during drought stress (Blum *et al.*, 1994; Blum, 1998). Analysis of fructan content at anthesis indicated varietal differences, although the amount of fructan stored did not necessarily reflect `adaptation', or otherwise, to sandy soils (data not shown). However, it may not be the total amount carbohydrate stored pre-anthesis which is important, rather it may be the proportion of stored assimilate which contributes to grain filling that is critical. This requires analysis of mature stems, which was not completed at the time of submitting this paper. Varietal differences in the content of ESC were also identified, but as with fructan, the contribution of ESC to grain filling will be better highlighted by analysis of the mature stems.

Conclusion

From the evidence presented, it seems likely that improved grain yield on sandy soils is most strongly related to early vigour. Early vigor, in turn, is related to both plant and seed characteristics such as LAD, large seed size and a longer coleoptile length. In addition, erect growth habit and earlier flowering were also advantageous (data not shown). Deeper roots were also a feature of Mundah and Barque, and this is important for moisture and nutrient acquisition. The contribution of pre-anthesis carbohydrate, in particular fructan, to grain yield remains unclear from the results at anthesis.

Analysis of mature stems should provide the data required to deduce the role of stored assimilate on grain yield on sandy soils. A putative barley `ideotype' for adaptation on sandy soils of low fertility is illustrated in Figure 6.

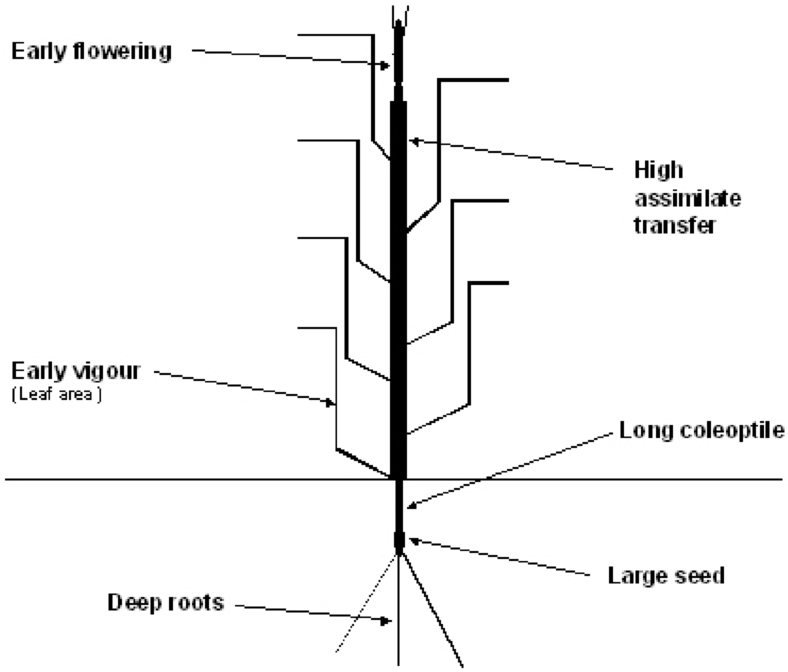


Figure 6: A putative barley `ideotype' for sandy soils of low fertility

Acknowledgments

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