Relationships between growing season rainfall, grain yield and yield components suggest that wheat requires one ear/m^2 per millimetre of rainfall to achieve its water-limited potential

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Abstract

This paper examines the relationship between grain yield of wheat and its yield components in the wheatbelt of southwestern Australia. It was found that grain yield of wheat in southwestern Australia was largely determined by the number of grains per unit area. The number of grains per unit area was highly related to the number of ears/m^2 across the rainfall zone of the wheatbelt. The highest achieved yields in the field experiments were close to the water-limited potential estimated using the French and Schultz equation. Further analysing the yield components of the highest yielding treatments showed a very strong relationship between the number of ears per m^2 and the growing season rainfall across the wheatbelt. This relationship indicated that it requires 1 ear per m^2 for every mm of growing season rainfall to realise the water-limited potential in the southwestern Australia wheatbelt. Although there was no clear relationship between grains/ear and grain yield in the current cultivars, the comparison of yield components and dry matter production between the high rainfall zone of southwestern Australia and other high yielding environments suggests that breeding for more grains/ear may provide opportunities to increase yield potential in the high rainfall zone.

Key words

Wheat yield, yield components, rainfall

Introduction

Grain yield of wheat is determined by the number of grains produced in a given area and the mean weight of these grains. For a given environment, it has been found that the single most important component influencing grain yield is the number of grains per unit area (Fischer 1985). Understanding the factors that affect the number of grains per unit area and its variation is essential for identifying both management options to achieve greater number of grains and breeding options to increase wheat yield potential. This paper used data collected from the wheatbelt in the low, medium and high rainfall zones of southwestern Australia by the authors and other colleagues try to understand ways to achieving more grains/m^2 for high yields. In this paper, we examined the relationships between the highest achieved yields at different locations and their yield components across the rainfall zones of southwestern Australia wheatbelt and our aim was to identify the agronomic management targets to realise the water-limited potential.

Methods

Most cited experiments were carried out across the wheatbelt of south-western Australia from 1990 to 2006. These experiments covered low-rainfall (Mullawa, Merredin) (Botwright et al. 2002; Perry and D'Antuono 1989; Regan et al. 1997; Schmidt et al. 1994; Siddique et al. 1989), medium-rainfall (Northam, Wongan Hills) (Anderson 1992; Perry and D'Antuono 1989), and high-rainfall areas (Kojonup) (Zhang et al. 2004; 2007)of the wheatbelt (Table 1). The cultivars used for analysis in this study were confined to modern semi-dwarf wheats. The experiments were sown at the earliest break of each season at each location. The grain yield of wheat was determined either by hand-harvesting from quadrats or machine. The data for ears/m^2, grains/ear and grain weight were adopted from the individual experiments and/or published work. The French and Schultz (1984) equation was used to estimate the water-limited potential based on the growing season rainfall from April to October.

Results

Grain yield ranged from about 2 t/ha in the low rainfall zone to about 6 t/ha in the high rainfall zone with the number of grains per m^2 ranging from 4000 to 16000 (Figure 1a). The corresponding yield components ranged from about 200 to about 500 ear/m^2 (Figure 1b), 22 to 45 grains/ear (Figure 1c), and 28 to 47 mg/grain (Figure 1d). Across the rainfall zones, the higher grain yield was strongly and positively correlated to the number of grains per m^2 ($r^2 = 0.92$) (Figure 1a) and the number of ears ($r^2 = 0.76$) (Figure 1b). The relationships between the yield and grain weight and grains/ear were much weaker ($r^2 =$ 0.15 and 0.41, respectively) (Figures 1c and 1d).

Across the rainfall zones of the wheatbelt, the number of grains/m^2 was strongly correlated to the number of ears/m^2 ($r^2 = 0.75$) (Figure 2a) but not to grains/ear ($r^2 = 0.26$) (Figure 2c) or grain weight ($r^2 = 0.26$) (Figure 2d). These relationships indicate that grains/m^2 are largely affected by ears/m^2 rather than grains/ear and showed no negative association between increased grains per unit area and the decreased grain size.

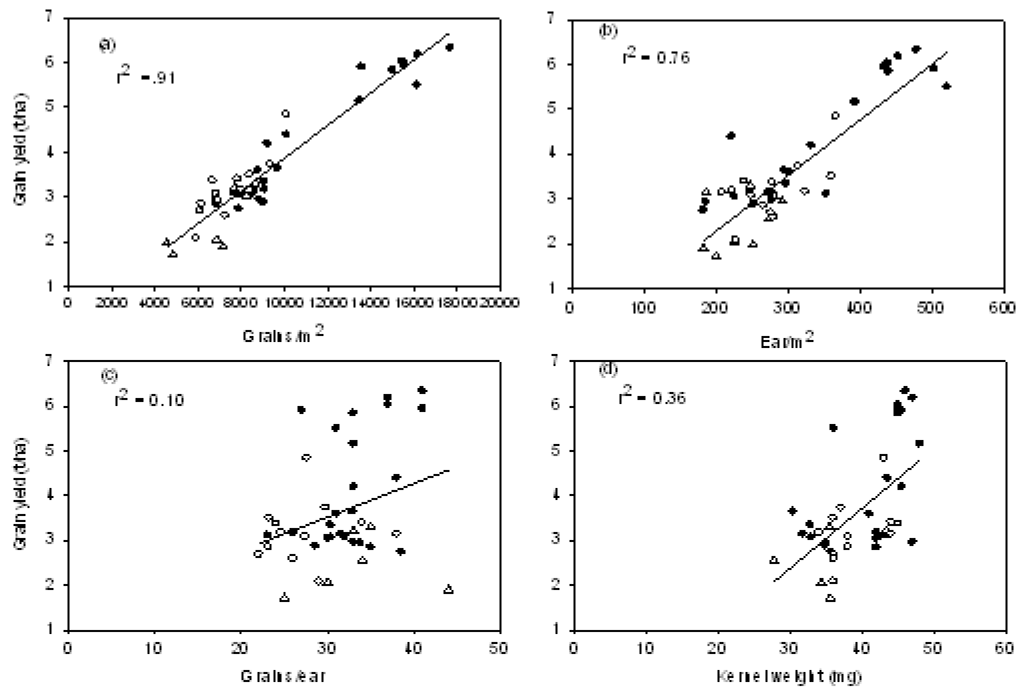

Figure 1. Relationship between grain yield of wheat and (a) grains/m^2, (b) ears/m^2, (c) grains/ear and (d) kernel weight across the wheatbelt of southwestern Australia. Low rainfall zone (Δ), medium rainfall zone (○) and high rainfall zone (●).

A sub dataset was extracted from Figure 1 to evaluate whether the highest achieved yields at different locations of southwestern Australia reached the water-limited potential estimated using the French and Schultz (1984) equation. It was found that the highest yields achieved were close to the potential yields for a given location in given years (data not shown). The highest achieved yields in the high rainfall zone of southwestern Australia tended to be less than those predicted, probably because there was drainage in the high rainfall zone (Zhang et al. 2005). This good relationship indicates that the highest achieved yields at different locations in different years were close to the water-limited potential yields for the given environments.

When we further analysed the number of ears/m^2 of this sub dataset of highest achieved yields and the growing season rainfall, it was found that there was a very strong relationship between ears/m^2 and the growing season rainfall across the wheatbelt (Figure 3). This relationship indicates that it requires 1 ear per m^2 for every mm of the growing season rainfall to set up the wheat crop to achieve the water-limited potential across the rainfall zones.

Discussion

Our aim in this paper was to identify the agronomic targets to achieve the water-limited potential for wheat in the wheatbelt of south-western Australia. Our approach covered three (high, medium and low) rainfall zones of the wheatbelt and large variations in grain yield. This allows us to draw general relationships between yield and yield components, between ears/m^2 and growing season rainfall and therefore the established relationships are applicable to the wheatbelt across the rainfall zones.

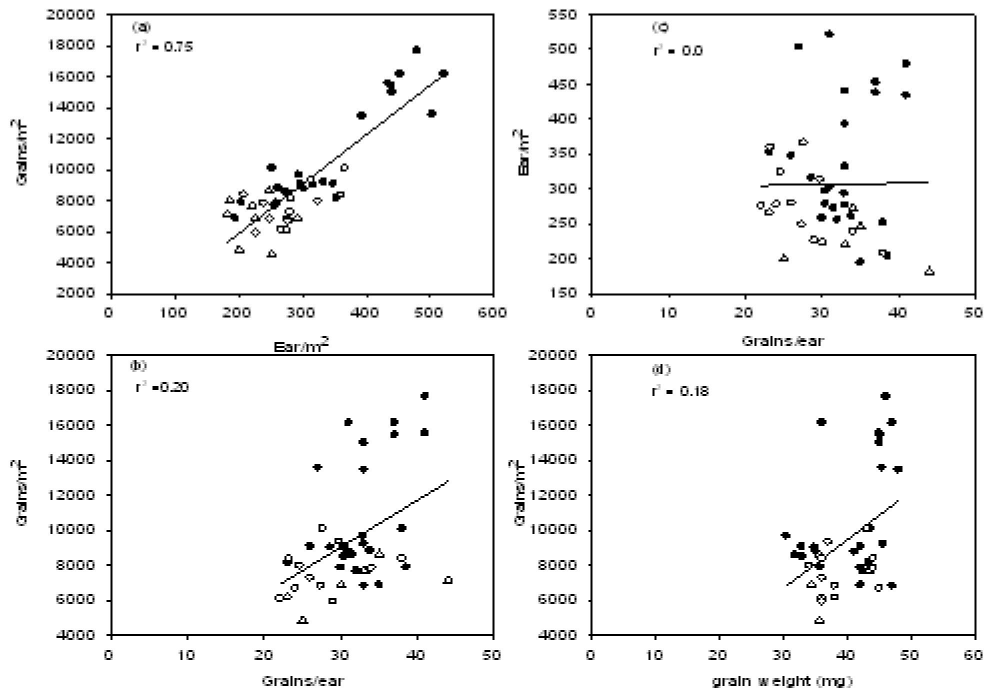

Figure 2. Relationship between grains/m^2 and (a) ears/m^2 and (b) grains/ear and (d) grain weight and (c) between ears/m^2 and grains/ear across the wheatbelt of southwestern Australia. The symbols are the same as in Figure 1.

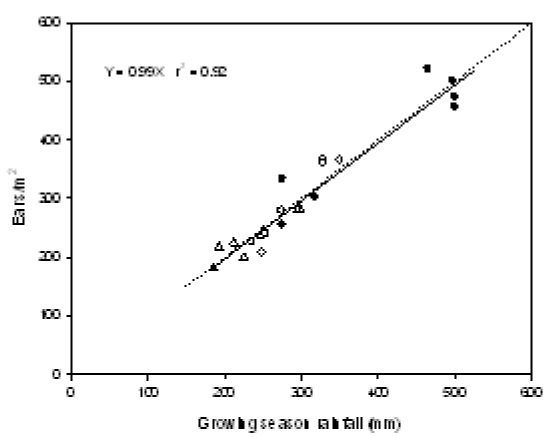

Figure 3. Relationship between ears/m^2 and growing season rainfall at three rainfall zones across the wheatbelt of southwestern Australia for highest achieved yields. The symbols are the same as in Figure 1.

This study has shown that grain yield of wheat in southwestern Australia is largely associate with the number of grains per unit area. By relating the number of grains per m^2 to its two components, it was observed that the number of grains/m^2 was highly correlated to the number of ears/m^2 and was to a much less extent affected by the number of grain per ear. This indicates the importance of achieving a high number of ears/m^2 and the limitation of increasing grains/ear with the current cultivars in increasing the number of grains. This is consistent with our early conclusion that high ear number is key to achieving high wheat grain yield in the high rainfall zone (Zhang et al. 2007). One of the concerns is that yield components can be negatively related to each other (Slafer et al. 1996). These negative relationships indicate that as one yield component increases, others will decrease. However, these negative relationships did not appear to be the case across the wheat belt of southwestern Australia because no negative relationship was observed between ears/m^2 and grains/ear (Figure 2c) and between the number of grains/m^2 and grain weight (Figure 2d).

The most significant result in Figure 3 is that farmers across the wheatbelt of southwestern Australia can set up their wheat crops to achieve high yields by managing ear number per m^2 based on the average growing season rainfall at a given location. The yield potential of 20 kg/ha of growing season rainfall developed by French and Schultz (1984) has provided a useful yardstick for farmers to compare the on-farm performance of their wheat crops. The simple rule of thumb (growing 1 ear per m^2 for every mm of growing season rainfall) developed in this paper provides another useful yardstick for farmers to manage the crop canopy size of wheat to realize the rainfall-limited yield potential according to the growing season rainfall. This simple rule also indicates that there is no need to grow a large number of plants in the low rainfall zone. In contrast, in the high rainfall zone, the growing of relatively small sized crops might result in not realising the potential yield. This simple relationship may not apply to areas where growing season rainfall greater than 550 mm because evidence from the UK and New Zealand (Foulkes et al. 2002; Stephen et al. 2005) shows that yield increases beyond 6 t/ha are mainly from increased grains/ear and grain weight, but not from further increased ears/m^2. This relationship remains to be tested in the wheatbelt of south-eastern Australia. In addition, this simple relationship will not explain the variations in grain yield of the field experiments where the yields were constrained by nitrogen, disease, weeds and waterlogging.

The high correlation of number of grains per m^2 to ears/m^2 indicates that the wheat cultivars grown in the wheatbelt of WA may have limitations to achieving more grains/ear when grown in the high rainfall zone. This may have incidentally been a result of breeding for the terminal water stress experienced in the low and medium rainfall zones in order to reduce small grain screening. This suggests that breeding for more grains/ear may provide future opportunities to lift grain yield potential in the high rainfall zone while maintaining the capacity of ears/m^2.

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