Indian Journal of Agricultural Sciences **88** (9): 1349–53, September 2018/Article

Resource use efficiency of different wheat species under drought stress

S L MEENA[1] and D L SPARKES[2]

University of Nottingham, Sutton Bonington Campus, Loughborough, Leicestershire, LE12 5RD, United Kingdom

Received: 23 August 2017; Accepted: 10 July 2018

ABSTRACT

Genotypes of modern bread wheat (*Triticum aestivum* L.) produced significantly more grain yield over spelt (*Triticum spelta* L.) and emmer (*Triticum dicoccum*) genotypes of ancient wheat. Grain yield was more in bread wheat genotype than the spelt and emmer wheat species because of its higher harvest index. All three bread wheat genotypes had significantly higher harvest index over rest of genotypes while spelt had over both the genotypes of emmer wheat species. Grain/chaff ratio was the maximum in Einstein followed by Spelt, Xi19 and Claire. 1000-grain weight was higher in spelt followed by bread wheat and then emmer genotype. Einstein had maximum grain yield and harvest index among all genotypes. Water use efficiency was higher in emmer and spelt than bread wheat. The maximum water was transpired by Xi19 and least by Spelt SB in given period of time. Emmer and Emmer SB had maximum water-use efficiency followed by Spelt SB and then Einstein, Xi19 and Claire. The water-use efficiency of Emmer, Emmer SB and Spelt SB were significantly higher over Claire. Emmer and spelt genotypes used irrigation water more efficiently than bread wheat genotypes. Linear regression between plant height and water used showed that emmer and emmer SB attained higher plant height consuming less quantity of water while it was reverse in bread wheat genotypes. The similar regression was observed for biomass production.The radiation-use efficiency of emmer and emmer SB were significantly higher over all three bread wheat, i.e. Einstein, Claire and Xi19 and Spelt SB.Traits highlighted to be useful, such as water and-radiation- use efficiencies, could be introgressed into modern bread wheat by making crosses with these related species.

Key words: Ancient wheat species, Modern bread wheat, Radiation-use efficiency, Water-use efficiency

Global climate change threatens agricultural productivity through increasing temperatures and erratic rainfall (Parry and Reynolds 2007). A combination of early domestication of crop plants and modern plant breeding has led to reduced genetic diversity in crop species compared to their wild progenitors making them more susceptible to biotic and abiotic stresses (Frankel and Soulé 1981). This narrow gene pool makes it difficult to select for crop varieties that perform well in harsh environments.Trethowan and Mujeeb-Kazi (2008) highlighted the need to expand available genetic diversity in order to maintain genetic progress. They considered that landraces and progenitors of modern genotypes could provide much greater genetic diversity than modern cultivated varieties. This research programme considers whether 'ancient wheat species' are more efficient in their use of water and radiation than modern bread wheat and whether they are better adapted to hostile environments. It also considers whether traits from these species could be introgressed into modern bread wheat in order to improve yield and adaptation to harsh environments (particularly drought stress).

MATERIALS AND METHODS

The experiment was conducted at the Sutton Bonington campus of the University of Nottingham, Nottinghamshire, England (52° 52'N, 1° 07'W) in the 2009-2010 growing season. The soil was sandy clay loam (John Innes compost number 2). The experiment was arranged in 128 columns (6 X 5+2) under randomised block design with 4 replicates. To determine the soil moisture of the columns at field capacity, two separate extra columns were filled with John Innes compost No.2 and irrigated at maximum soil saturation. The columns were covered with plastic sheet to avoid evaporation and allowed to stay under condition. After 48 hr of drainage, the soil was assumed to be at field capacity. The columns were then transversally opened and the soil extracted in 20 cm layers. The wet soil was weighed, before and after drying for 24 hr at 115 ºC. The bulk density (BD) and the volume basis water content (θ_v) at field capacity (θ_{FC}) for the different layers were determined by Equation

---

[1] Principal Scientist (email: dr_slmeena@yahoo.co.in), Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi 110 012, [2] Professor (email: debbie.sparkes@nottingham.ac.uk), Division of Plant and Crop Sciences, University of Nottingham, Leicestershire, UK.

1 and Equation 2, respectively (Rowell 1994).

$$\text{BD (g/cm}^3) = \frac{\text{Mass of oven dried soil (g)}}{\text{Soil column layer volume (cm}^3)} \quad \text{(Equation 1)}$$

$$\theta_v \text{ (m}^3\text{/m}^3) = \frac{\text{Volume of water (m}^3)}{\text{Bulk volume of soil (m}^3)} \quad \text{(Equation 2)}$$

$$\text{Volume of water (m}^3) = \frac{\text{Mass of water (kg)}}{\text{Density of water (kg/m}^3)}$$

Mass of water (kg) = Mass of wet soil – Mass of oven dried soil.

The available water at field capacity (AW_{FC}) is defined as the θ_{FC} minus the water at the permanent wilting point (θ_{PWP}). In this work, θ_{PWP} was considered to be $\theta_{FC}/2$ (Dani and Wraith 2000) so the water available at FC (AW_{FC}) would then be:

$$\text{AWFC} = \theta_{FC} - \theta_{PWP} = \theta_{FC} - \frac{\theta_{FC}}{2} \quad \text{(Equation 3)}$$

Forty-eight hours before transplantation, the columns were irrigated to saturation and left to drain to ensure that at transplantation the soil was at FC.

To measure the soil moisture using the Theta Probe MLX2, it needed to be calibrated to the specific soil used (Kaleita *et al.* 2005). The Theta Probe ML2x calibration was carried out on a subset of four columns. The columns were irrigated to saturation and left to drain for different times in order to obtain different soil moisture contents. Two columns were allowed to drain for 48 hr. The voltage (mV) for each soil-depth layer was measured. The columns were then opened and the soil extracted in five soil-depth layers. The soil was weighed and left to dry for 24 hr at 115ºC after which the soils dry weight was measured. The θ_v was then calculated using equations 1 and 2. The resultant linear regression between the values of θ_v measured gravimetrically and Theta Probe mV values observed was use to estimate θ_v.

The average soil moisture content for the two columns at field capacity was taken as 0.297 m^3/m^3. These values were used to calculate the amount of water to be irrigated to the plants to maintain the 50% water available at the field capacity for each treatment/column. A total of 120 samples i.e. 6 genotype sampling (with 5 layers) × 4 replicates were measured on weekly basis using theta probe. Water stress was imposed on 18 February 2010 when the plants were at 99 days after sowing (DAS). The treatments were irrigated at 50% field capacity (FC) as and when required. Each treatment and each genotype received different amount of water as per 50% field capacity calculation. Total sixteen soils moisture measurements were taken from 26 February 2010 to 6 June 2010.

Seeds were sown on 9 November 2009 in small tray pots under glass house condition. Watering was done manually on 1-2 days basis. Genotype with trays transferred in polytunnel or CE room for vernalisation on 9 December 2009. Seedlings were transplanted on 5 February 2010, 90 DAS with one plant/column. Seedlings were irrigated daily for two weeks to allow the seedlings to grow at field capacity. Irrigation restrictions were imposed as from 18 February 2010. A total of 120 plants were transplanted. Plants were attacked by Powdery Mildew and aphids on 25 February 2010 and 22 March 2010 sprayed with Corbel @ 1.0 l/ha + Apres @ 0.3 l/ha and Corbel @ 0.5 l/ha + Opus @ 0.5 l/ha (fungicides) and Aphox @ 0.5 g/l (insecticides) respectively. Columns were inspected periodically and dates of onset of different stages of development recorded. The main shoots of each plant were observed on weekly basis. Plant growth analysis was done on critical growth stages i.e. 31 (first node visible), 39 (emergence of flag leaf), 59 (emergence of ear), 61 (flowering) and at final harvest. There were five destructive sampling points based on critical growth stages. Relative chlorophyll content was measured using a portable chlorophyll meter. CIRAS-I was used for measuring the rate of photosynthesis and transpiration at the constant of 400 µmol CO_2/m²/sec, 1800 µmol/m²/sec light intensity and 22-24°C temperature. Green leaf area was measured using leaf-area meter. The samples were then oven dried at 80°C for 48 hr and dry weight was recorded. Thermal time calculated from the daily maximum and minimum temperature figures obtained from tiny tag data logger placed in the experimental glass house. Analysis of variance (ANOVA) was performed on the data using the Genstat Statistical Package software (Lawes Agricultural Trust, Rothamsted Experimental Station, UK). Differences between treatment means were detected by least significant difference (LSD) at 5% probability.

RESULTS AND DISCUSSION

Plant height

Emmer achieved significantly higher plant height over Xi19, Claire and Spelt SB at early stages of plant growth. Emmer was significantly higher over rest of genotypes while Emmer SB was over Claire in middle growth stage (Fig 1). At the time of harvest, Emmer and Emmer SB was at par but significantly higher over the rest of the genotypes. Plant height of Spelt SB was significantly higher over all three genotypes of bread wheat. Plant height of spelt and emmer increased rapidly between the growth stages of 39 and 59 while emmer attained maximum in later stages. Maximum plant height was obtained in emmer (106.5 cm) followed by spelt (81 cm) and bread wheat (60 cm). Maximum plant height was observed in both genotypes of emmer wheat throughout the growth period. Emmer attained higher plant height throughout the growth period but it was crossed by emmer SB at final stage. The plant height of emmer increased steeply in middle stages while emmer had in later stages. Emmer and spelt had similar kind of growth habit.

Number of shoots

The number of total shoots/plant was higher in spelt followed by all genotypes of bread wheat and emmer in the early stage of crop development. Spelt SB had significantly higher number of total shoots over Xi19, Claire and Emmer SB while Einstein found over Xi19 at 2nd stage of plant growth (Fig 2). Xi19 had significantly more shoots over

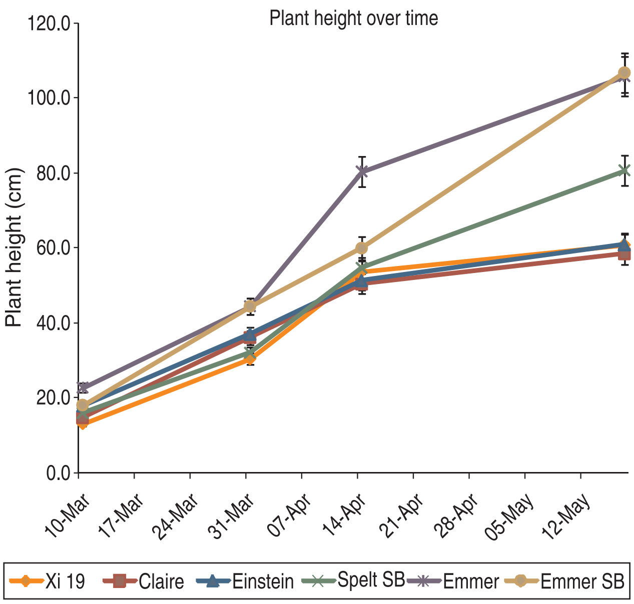

Fig 1 Plant height of different wheat species during growth period

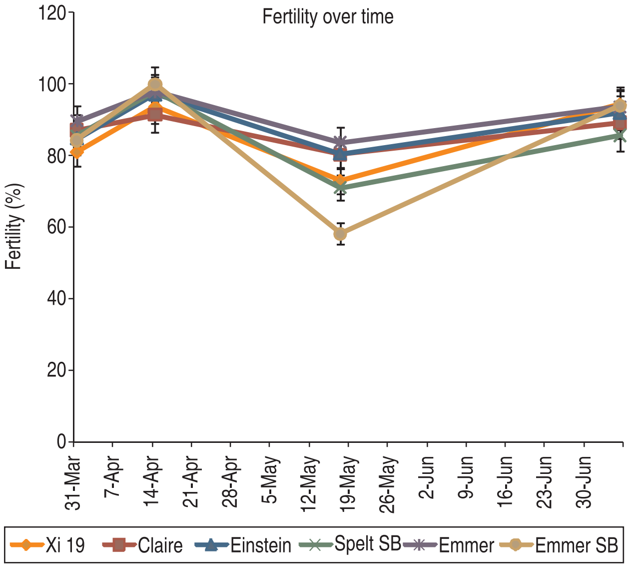

Fig 3 Fertility (fertile/infertile shoot ratio) of different wheat species during growth stages

Einstein at 3rd stage but on par with spelt. In the later stages, Emmer SB had maximum number of shoots significantly higher over rest of the genotypes. Total number of shoots/ plant found in Emmer was significantly higher over all three genotypes of bread wheat and Emmer SB. The number of total shoots/plant increased in emmer throughout the growth period while it decreased in Einstein and Xi19 in middle stages and Emmer SB had drastically decreased shoots at later stage. It might be due to more number of dead and dying shoots.

Fertility ratio (fertile/ infertile shoots)

Emmer had more number of fertile shoots significantly higher over rest of genotypes. Emmer had maximum fertile/ infertile shoot ratio which was significantly higher over Claire, Spelt SB and Emmer SB (Fig 3). Fertile/ infertile shoot ratio was higher in early and later stages of plant growth. The fertility ratio was high in emmer and maintained up to the final harvest. There was high fluctuation in ratio in emmer SB. The ratio was significantly different among genotypes at middle stage of plant growth.

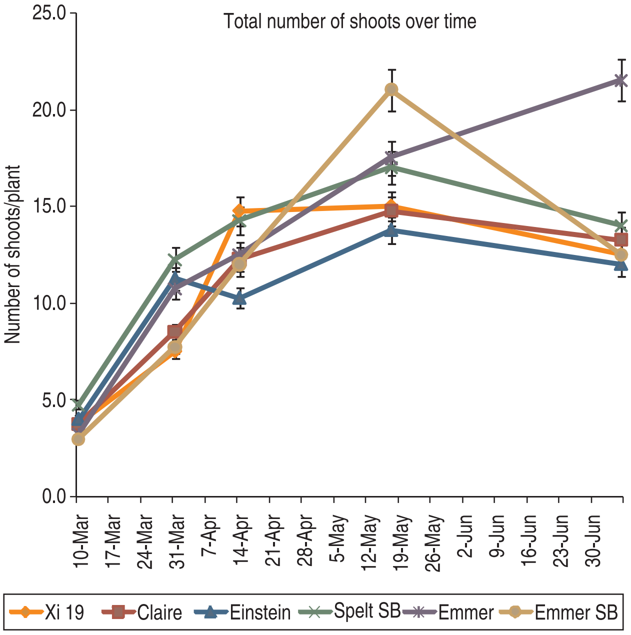

Fig 2 Number of shoots in different wheat species during growth stages

SPAD value/ greenness/relative chlorophyll content

Spelt SB had significantly higher SPAD value over emmer at early stage of plant growth. Einstein had significantly more chlorophyll content over Xi19, Spelt SB and Emmer, and Emmer SB over Spelt SB and Emmer while Claire was over Emmer and Emmer SB in the middle stages. All bread wheat genotypes had significantly higher SPAD value over Emmer SB in the later stage (Fig 4). Chlorophyll content in leaf was the maximum in bread wheat followed by spelt and emmer throughout the growth period. The rate of photosynthesis was the maximum in spelt followed by bread wheat and emmer. All three genotype of bread wheat had higher value of SPAD meter.

Green area/stay green trait

The differential green area was observed in the genotypes. Emmer and spelt had more green area than bread wheat genotypes. The total green area in all species increased sharply between the growth stages of 39 and 59. The decreasing trend of green area was observed in Einstein and spelt at later stages. Emmer had higher green area up to the later stage. It shows the longer stay green trait in emmer. Maximum total green area was in emmer up to later stages. Claire had maximum green area and significantly higher over Spelt SB in early stage. In the middle stage, spelt had more green area significantly higher over Xi19. Emmer had significantly more green area over rest of the genotypes except Emmer SB which was higher

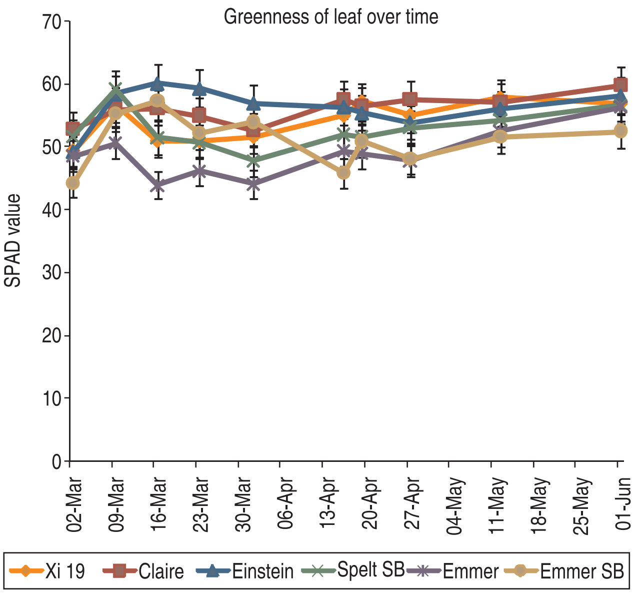

Fig 4 SPAD value/ greenness/ relative chlorophyll content of wheat species during growth period

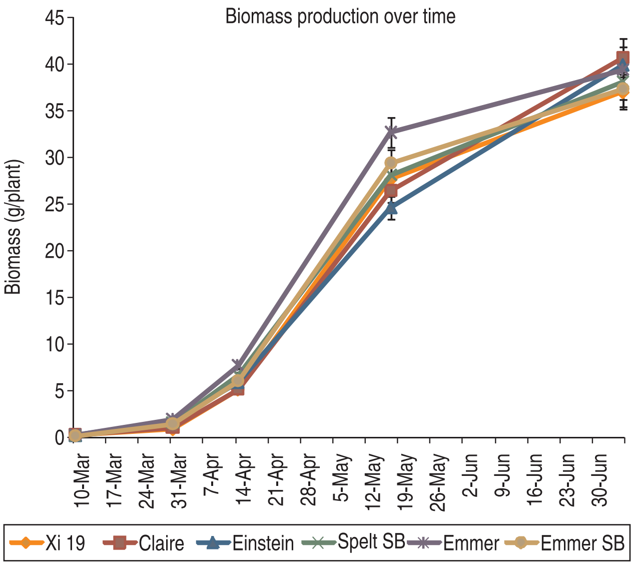

Fig 5 Biomass production of different wheat species over growth period

over Einstein at the later stage. Leaf green area was more in Spelt SB which was significantly higher over Xi19 at the middle stage of plant growth. The shoot green area was significantly higher in Emmer over Xi19 and Claire at early crop growth stage, while over bread wheat genotypes at middle stage. Spelt SB and Emmer SB were at par but significantly higher over Xi19 and Claire while spelt over all genotypes of bread wheat and Emmer SB over Einstein. This could indicate a 'stay green' trait in spelt and emmer that could be useful for increased yield potential. Stay green traits have been associated with increased yield in a number of crops including wheat (Christopher *et al.* 2008). The maximum flag leaf green area was in Emmer, significantly higher over the rest of genotypes except Claire. In the ear green area Emmer and Emmer SB were at par but significantly higher over Einstein and spelt. Emmer had more shoot green area, flag leaf green area, ear green area and total green area while leaf green area was more in spelt.

Biomass production

The trend of biomass production was quite similar in all genotypes grown except Claire and Einstein which showed slightly increased trend at later stage of plant development (Fig 5). The maximum biomass was accumulated in Emmer significantly higher over xi19, Claire and Einstein in the middle growth stages. Maximum biomass was obtained in Claire at first and last stage of plant growth. Emmer produced more biomass throughout the growth period. Accumulation of biomass was higher between the growth stages of 59 and 61 in all genotypes grown. Total dry-matter production at maturity was more or less equal in all three species taken under investigation.

Water-use efficiency

The differential rate of water uptake was exhibited by the genotypes in later stages of plant development. Maximum water was utilised by Claire while all three ancient wheat genotypes used comparatively less quantity of water to produce the similar amount of biomass. Water-use efficiency was higher in emmer and spelt than bread wheat (Table 1). The maximum water was transpired by Xi19 and least by Spelt SB in given period of time. Emmer (8.10 g/l) and Emmer SB (8.10 g/l) had maximum water-use efficiency followed by Spelt SB (8.05 g/l) and then Einstein (7.46 g/l), Xi19 (7.06 g/l) and Claire (6.38 g/l). The water-use efficiency of Emmer, Emmer SB and Spelt SB were significantly higher over Claire. Emmer and spelt genotypes used irrigation water more efficiently than bread wheat genotypes. This was consistent with Peleg *et al.* (2005) and Al-Hakimi (1998) who had previously reported that both wild emmer and cultivated emmer have potential water-use efficiency. Linear regression between plant height and water used showed that emmer and emmer SB attained higher plant height consuming less quantity of water while it was reverse in bread wheat genotypes. The similar regression was observed for biomass production. Within areas of drought stress, the majority of plant adaptive mechanisms involve stress avoidance or tolerance; this is altered according to genotype, WUE may be due to deep-rooting in which plants explore soil to greater avail (Chaves *et al.* 2002) or where plants might use water resource more efficiently at the leaf level.

Radiation-use efficiency

Radiation-use efficiency was greater in both the emmer species of ancient wheat followed by Xi 19 and Claire of bread wheat (Table 1). The radiation-use efficiency of emmer species was significantly higher over all three bread wheat i.e. Einstein, Claire and Xi19. Emmer and Emmer SB also had significantly higher radiation-use efficiency over spelt SB. It means that the genotype Emmer and Emmer SB had utilized intercepted radiation efficiently

Table 1 Biomass production, grain/chaff ratio, 1000-grain weight, water-use efficiency, radiation-use efficiency, harvest index and grain yield of wheat species

Genotype	Biomass (g/plant)	Grain/chaff ratio	1000-grain weight (g)	WUE (g/l)	RUE (g/MJ)	Harvest index	Grain yield (g/plant)
Xi19	37.06	3.95	38.93	7.06	2.52	0.50	18.7
Claire	40.73	3.76	39.96	6.38	2.44	0.50	20.4
Einstein	39.97	4.51	38.16	7.46	2.23	0.55	21.9
SpeltSB	38.14	4.12	41.22	8.05	2.11	0.38	14.4
Emmer	39.45	2.78	29.65	8.10	2.84	0.28	11.2
EmmerSB	37.36	2.37	35.54	8.10	2.85	0.31	11.7
SED	2.88	0.433	3.22	0.52	0.0591	0.024	1.71
LSD (P=0.05)	6.13	0.922	6.86	1.11	0.185	0.051	3.65

than the bread wheat genotypes taken under investigation. The efficiency with which photosynthetically active radiation was converted into biomass differed by genotype, with Emmer SB being the most efficient (2.85 g/MJ), followed by emmer (2.84 g/MJ), Xi19 (2.52 g/MJ), Claire (2.44 g/MJ), Einstein (2.23 g/MJ) and spelt SB (2.11 g/MJ).Muurinen and Peltonen-Sainio (2006) found these ancient wheat species to have increased radiation-use efficiencies (RUE).

Grain yield

Genotypes of bread wheat produced significantly more grain yield over Spelt and Emmer wheat genotypes (Table 1). Grain yield was more in bread wheat than the spelt and emmer wheat because of its higher harvest index. All three bread wheat genotypes had significantly higher harvest index over rest of genotypes while spelt had over both the genotypes of emmer wheat. This emphasises the fact that advances in wheat yield have been largely due to improvements in harvest index, with relatively little contribution from increased biomass production (Shearman *et al.* 2005). Grain/chaff ratio was the maximum in Einstein followed by Spelt, Xi19 and Claire. 1000-grain weight was higher in spelt followed by bread wheat and then emmer genotypes. Einstein had maximum grain yield and harvest index among all genotypes.

The study suggests that emmer species had higher water -use efficiency and radiation-use efficiency than the other species, taken under investigation and this is supported by the literature (Sparkes 2010), therefore crosses between *T. dicoccum* and *T. aestivum* could be made, with the long term aim of introducing greater potential of water- and radiation use efficiencies into the bread wheat gene pool. This could improve productivity, yield stability and sustainability within wheat cultivation.

ACKNOWLEDGEMENTS

The authors greatly wish to acknowledge the Ministry of Tribal Affairs, Government of India for providing financial support to undertake the research study. Thanks are due to the University of Nottingham, England, United Kingdom for providing facilities and technical support during the post-doctoral research programme.

REFERENCES

Al-Hakimi A. 1998. Primitive tetraploid wheat species to improve drought tolerance in during wheat. (*In*) *Triticeae* III. Proceedings of the Third International *Triticeae* Symposium, 4-8 May 1997, Aleppo, Syria, pp 305–12.

Chaves M M, Pereira J S, Maroco J, Rodrigues M L, Ricardo C P P P, Osoria M L, Carvalho I, Faria T and Pinheiro C. 2002. How do plants cope with water stress in the field? Photosynthesis and growth. *Annals of Botany* **89**: 907–16.

Christopher J T, Manshadi A M, Hammer G L and Borrell A K. 2008. Developmental and physiological traits associated with high yield and stay-green phenotype in wheat. *Australian Journal of Agricultural Research* **59**: 354–64.

Frankel O H and Soulé M. 1981. *Conservation and Evolution*. Cambridge University Press, Cambridge, United Kingdom.

Kaleita A L, Tian L F and Hirschi M C. 2005. Relationship between soil moisture content and soil surface reflectance. *Transaction of the ASAE* **48**(5): 1979–86.

Muurinen S and Peltonen-Sainio P. 2006. Radiation-use efficiency of modern and of spring cereal cultivars and its response to nitrogen in northern growing conditions. *Field Crops Research* **96**: 363–73.

Dani O and Wraith J M. 2000. Comment on "On water vapour transport in field soils" by Anthony T, Cahill and Marc B Parlange. *Water Resources Research* **36**: 3103–5 (*fide Water Resources Research* 731–9).

Parry M A J and Reynolds M P. 2007. Improving resource use efficiency. *Annals of Applied Biology* **151**: 133–25.

Peleg Z, Fahima T, Abbo S, Krugman T, Nevo E, Yakir D and Saranga Y. 2005. Genetic diversity for drought resistance in wild emmer wheat and its ecogeographical associations. *Plant, Cell and Environment* **28**: 176–91.

Rowell D L. 1994. *Soil Science: Methods and Applications,* p 350. Addison Wesley Longman Singapore Publishers (Pvt) Ltd, England, UK.

Shearman Y J, Sylvester-Bradley R, Scott R K and Foulkes M J. 2005. Physiological processes associated with wheat yield progress in the UK. *Crop Science* **45**: 175–85.

Sparkes D L. 2010. Are 'ancient wheat species' more adapted to hostile environments than modern bread wheat? *South African Journal of Plant Science* **27**: 331–3.

Trethowan R M and Mujeeb-Kazi A. 2008. Novel germplasm resources for improving environmental stress tolerance of hexaploid wheat. *Crop Science* **48**: 1255–65.