Screening for waterlogging tolerance of wheat in the field in Western Australia

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Abstract

During 2001 to 2004, replicated field trials were conducted throughout the Southwest of Western Australia (WA) using natural waterlogging gradients in order to rank wheat varieties for waterlogging tolerance. Such gradients enable measurement of waterlogging tolerance as the grain yields under waterlogged relative to drained (or less waterlogged) treatments. Prior to this, the waterlogging tolerance of almost all wheat varieties in the field was unknown in WA conditions.

Successful waterlogging tolerance results were obtained from 7 locations resulting in 11 different waterlogging situations. In total, 17 varieties were used with a core group of 7 varieties sown in all locations. Results showed that there is a strong genetic diversity for waterlogging tolerance in wheat. Waterlogging tolerance for varieties can also change dramatically from one location to another. Variation in results may be due to a combination of [1] soil physical and chemical properties, [2] waterlogging duration and depth, [3] plant stage when waterlogged, [4] nutrition, or other factors. This has important implications for cereal research where tolerance is a product of environment by soil interactions.

We have been successful in ranking current WA varieties for waterlogging tolerance, and have been able to offer a measure of reliability for these rankings through assessing variation between locations. Different approaches to interpreting data are suggested. In this process we have also identified a number of environmental and soil factors that may influence waterlogging tolerance. The impacts of this work are likely relevant to screening for waterlogging tolerance of other crops in diverse target environments.

Key Words

Waterlogging tolerance, wheat, waterlogging screening, soil types

Introduction

Waterlogging occurs across a large part of cropping land in Western Australia, Australia and internationally. In Western Australia this is primarily due to insufficient drainage in low lying areas and duplex soils. The effect of waterlogging is difficult to quantify as water in the soil can completely drain away in days and sometimes within hours. In these situations it is only frequent rainfall that maintains waterlogging conditions resulting in fluctuating levels of water within the soil profile. A simple way of assessing waterlogging intensity is to measure the cumulative Sum of Excess Water in the top 30cm of the soil (SEW30) which is described below.

Waterlogging in the field is extremely complex with soil physical and chemical properties, waterlogging duration and depth, waterlogging frequency, plant stage at waterlogging and plant nutrition all combining to give an infinite number of potential waterlogging situations. By controlling some of these factors in the field we aimed to provide a ranking of wheat varieties commercially available in Western Australia and compare the tolerance of these varieties with breeding lines, national and international varieties.

Methods

Between 2001 and 2004 twelve field locations with strong histories of frequent waterlogging were selected as replicated trial sites based on an identified natural waterlogging gradient, with seven sites becoming sufficiently waterlogged for detailed assessment. Each waterlogging gradient was usually on a slight slope 0.1-5.0%, and sites were approximately one hectare located within an area of about 30,000 sq. km in the SW of WA. In total, 17 varieties from Western Australia, Australia and internationally were used with a core group of seven varieties sown in every location. All varieties were sown in a continuous strip down the waterlogging gradient. This enabled certain areas from anywhere along each variety strip of a pre-determined waterlogging intensity to be sampled as transects across all varieties. The waterlogging intensity was determined through monitoring the amount of water (cm) in the top 30cm of the soil profile using a network of piezometers (Setter and Waters, 2003). These measurements were used to calculate the cumulative sum of excess water in the top 30cm (SEW30) of the soil (e.g. 10 days @ 20cm water = 20 days @ 10cm water = 200 SEW30). Through the use of SEW30 data, aerial photography and ground truthing based on field observations, harvest maps were constructed for high/severe, medium, low/nil waterlogging intensities.

The waterlogging tolerance of a variety was then determined as grain yield under waterlogged conditions relative to drained (or less waterlogged) treatments.

Results and Discussion

Trials experienced enough rainfall for severe waterlogging to be observed at five locations (Culbin02, South Stirling02, South Stirling03, Mount Barker03, Kalgan04) and enough at two further locations (Cranbrook02, Congelin03) to cause measurable waterlogging. Most sites were assessed at more than one waterlogging intensity level, and therefore eleven different waterlogging situations were evaluated. Trials were unsuccessful at all other locations (5 sites) due to insufficient rainfall to cause natural waterlogging. Evaluating the waterlogging tolerance of the varieties tested proved to be problematic in that many of the tolerance rankings were highly variable from one site to the next, and in some cases rankings were even reversed. Variation in results may be due to a combination of [1] soil physical and chemical properties, [2] waterlogging duration and depth, [3] plant stage when waterlogged, or other factors.

In order to evaluate the data, each waterlogging situation was grouped into either severe (5 situations), moderate (3 situations) or low (3 situations) waterlogging based on SEW30 values obtained in the field: up to >1000 SEW30, >550-1000 SEW30, up to <550 SEW30 respectively (these SEW30 values are equivalent to 33, 15-33 and <15 d waterlogging to the soil surface). Table 1A summarises this data for all successfully waterlogged situations. Note that data for waterlogging tolerance is calculated from grain yield of waterlogged plots relative to non (or less) waterlogged plots. The site averages for waterlogging tolerance show that these waterlogging conditions in the field reduced the overall grain yield to only 28-64% in the severe waterlogging situations, 83-93% in the moderately affected situations, and 89-94% in the least affected situations relative to the non (or less) waterlogged plots. The results described in Table 1A should not be averaged across all situations due to the large variations observed in waterlogging intensity that occur in the field. The most important conclusion from Table 1A is that waterlogging tolerance is highly variable and often inconsistent between sites eg for Brookton, GBA Ruby and Cascades. The two most waterlogging tolerant and least waterlogging tolerant varieties in Table 1 are indicated by an underscore and italics respectively.

There are several ways that this variation between sites can be addressed. One of these is to standardise results for each variety relative to the site mean and average across varieties (Table 1B). Data in Table 1B are calculated by standardising the percent tolerance values for each variety in Table 1A relative to the situation mean (shown in Table 1A). This enables an estimate of the standardised waterlogging tolerance for each variety as well as an estimate of the variation due to site differences through calculating a standard error of the mean (SEM). Using the SEM as an estimate of site variation supplies us with a measure of reliability to the average standardised waterlogging tolerance value. Varieties with a high SEM, for example Cascades, indicates that there is low confidence in the waterlogging tolerance level being replicated. Whilst the variety Spear has a low SEM so there is much more confidence in the accuracy of the waterlogging tolerance level of Spear than Cascades. The data in Table 1B need to be used with caution in that a number of varieties were not at all sites which can lead to some incorrect conclusions if only looking at mean tolerance and site variation results (Norin46 cf. GBA Ruby). The varieties Norin46 and GBA Ruby have similar waterlogging tolerance in Table 1B but Norin46 was only assessed at two situations (both same year, site, waterlogging intensity), whereas GBA Ruby was assessed at more locations and more severely waterlogged situations. By using this standardised approach and understanding these limitations, sites can be directly compared.

Table 1. Results from waterlogging gradient trials (A) expressed in % waterlogging tolerance relative to non (or less) waterlogged plots, and (B) standardised using site average in Table 1A.. Bold underlined values are the two highest ranked varieties for each situation and italic values are the two lowest ranked.

	Tolerance to severe waterlogging					Tolerance to moderate waterlogging			Tolerance to low waterlogging		
Site	Congelin03	Culbin02	MtBarker03	Kalgan04	SStirl03	Congelin03	MtBarker03	SStirl03	SStirl02	Cranbr02	Cranbr02
Soil Group	Lateritic	Lateritic	Lateritic	Coastal	Coastal	Lateritic	Lateritic	Coastal	Coastal	Valley	Valley
SEW30	1000-1600	500-1000	1000-1450	>1500	700-1100	700-1000	400-1000	350-800	0-550	100-550	0-200
Brookton	52	64	56	***17***	**73**	89	84	**99**	86	93	94
Calingiri	**56**		**76**	26	59	85	**109**	89			
Camm	50	**67**	68	**38**	54	89	94	93	***85***	**107**	**111**
Carnamah	***24***	64	54	35	66	***48***	80	94	***83***	101	**101**
Cascades	***27***	***59***	73	**43**	***53***	**100**	78	***82***	**93**	78	88
Chara	38		66	35	61	**114**	80	95	87	**108**	97
EGA Bonnie Rock	**59**		***53***	23	**73**	81	83	**105**			
GBA Ruby	31		**80**	***10***		86	95				

GBA Sapphire	32		68	26		***50***	**<u>106</u>**				
GBA Shenton			***48***				**73**				
Krichauff									**<u>93</u>**		
Norin46										82	***83***
Spear	48	***60***	56	32	***53***	92	84	***88***	88	***73***	87
WAWHT 2668									88	89	100
Westonia	50	**<u>70</u>**	65		63	68	***76***	95	91	90	98
Worrakatta										**75**	***77***
Wyalkatchem	30		62	20	59	89	84	92	**101**		
Site Average	41	64	63	28	61	83	87	93	89	90	94
WL Intensity Avg					50			87			91

Table 1B

	Tolerance to severe waterlogging					Tolerance to moderate waterlogging			Tolerance to low waterlogging			
Site	Congelin03	Culbin02	MtBarker03	Kalgan04	SStirl03	Congelin03	MtBarker03	SStirl03	SStirl02	Cranbr02	Cranbr02	WL tolerance
Soil Group	Lateritic	Lateritic	Lateritic	Coastal	Coastal	Lateritic	Lateritic	Coastal	Coastal	Valley	Valley	

SEW30	1000-1600	500-1000	1000-1450	>1500	700-1100	700-1000	400-1000	350-800	0-550	100-550	0-200	Avg	SEM
Camm	1.18	**1.05**	1.07	**1.37**	0.88	1.08	1.09	1.00	***0.95***	**1.19**	**1.19**	1.09	0.13
Calingiri	**1.32**		**1.20**	0.94	0.96	1.03	**1.26**	0.95				1.09	0.16
Chara	0.90		1.04	1.26	0.99	**1.38**	0.92	1.02	0.97	**1.21**	1.04	1.07	0.16
EGA Bonnie Rk	**1.39**		***0.84***	0.83	**1.19**	0.98	0.96	**1.13**				1.04	0.20
Krichauff									**1.04**			1.04	
WAWHT 2668									0.98	0.99	1.07	1.01	0.05
Westonia	1.18	**1.09**	1.02		1.03	0.82	***0.88***	1.02	1.02	1.00	1.05	1.01	0.10
Brookton	1.22	1.00	0.88	***0.61***	**1.19**	1.08	0.97	**1.06**	0.96	1.04	1.00	1.00	0.16
Cascades	***0.64***	***0.92***	1.15	**1.55**	***0.86***	**1.21**	0.90	***0.88***	**1.04**	0.87	0.94	1.00	**0.24**
Spear	1.13	***0.94***	0.88	1.15	***0.86***	1.11	0.97	***0.94***	0.98	***0.81***	0.93	0.97	***0.11***
Carnamah	***0.57***	1.00	0.85	1.26	1.07	***0.58***	0.92	1.01	***0.93***	1.13	**1.08**	0.95	0.21
Wyalkatchem	0.72		0.98	0.72	0.96	1.08	0.97	0.99	**1.13**			0.94	0.15
GBA Sapphir	0.75		1.07	0.94		***0.61***	**1.22**					0.	0.2

e												92	5
Norin46										0.92	***0.89***	0.90	0.02
GBA Ruby	0.73		**1.26**	***0.36***		1.04	1.10					0.90	0.36
Worrakatta										***0.84***	***0.82***	0.83	0.01
GBA Shenton			***0.76***				***0.84***					0.80	0.06

Another way of addressing variation is to attempt to group sites by generalised soil types such as lateritic derived soils, broad valley floors and coastal soils (Table 2). By using the standardised tolerance results (from Table 1B) and grouping sites into generalised soil types we can identify the sensitivity of waterlogging tolerance of a variety to soil type. For example, Calingiri is more tolerant to waterlogging in lateritic soils than coastal soils whilst Carnamah is less tolerant to waterlogging in lateritic soils than coastal soils. This is a good way of determining whether the waterlogging tolerance for any variety is likely to be affected by the soil type in which it is sown.

Table 2. Results from Table 1B averaged across generalised soil types.

	Generalised soil type		
	Lateritic	Coastal	Valley
Brookton	1.03	0.96	1.02
Calingiri	**1.20**[a]	**0.95**[a]	
Camm	1.09	1.05	1.19
Carnamah	**0.78**	**1.07**	1.10
Cascades	0.96	1.08	0.91
Chara	1.06[a]	1.06	1.12
EGA Bonnie Rock	1.04[a]	1.05[a]	

GBA Ruby	1.03 [a]	0.36 [b]	
GBA Sapphire	0.91 [a]	0.94 [b]	
GBA Shenton	0.80 [b]		
Krichauff		1.04 [b]	
Norin46			0.90
Spear	1.01	0.99	0.87
WAWHT2668		0.98 [b]	1.03
Westonia	1.00	1.02 [a]	1.03
Worrakatta			0.83
Wyalkatchem	0.94 [a]	0.95	
Average	0.99	0.96	1.00

[a] not at one situation

[b] not at more than one situation

An alternative to standardising waterlogging tolerance values is to simply average waterlogging tolerance at differing waterlogging intensities based on SEW30 data (severe, moderate or low) and attribute stability rankings based on the variation between sites (Table 3). As with the other methods described above, averaging similar waterlogging intensities and the use of a stability ranking is biased by an incomplete set of data for varieties across all sites. By ensuring that these biases are understood, the results still could provide valuable waterlogging tolerance information. Comparing the ranking of varieties using this method with the rankings in Table 1B, the top five varieties for waterlogging tolerance in Table 3 are in the top eight varieties in Table 1B. This gives increased confidence in the rankings since two of the top eight (Krichauff, WAWHT2668) in Table 1B were not included in the severe waterlogging rankings from Table 3, and another variety (Westonia) is less tolerant at moderate or low waterlogging intensities. The analyses used for Tables 1B and 3 also both supported that varieties with low overall waterlogging tolerance were GBA Ruby, GBA Sapphire, Wyalkatchem and Carnamah, when ranked under severe waterlogging conditions in Table 3.

The data used to rank waterlogging tolerance of varieties (Table 1B) highlights a limitation to assessing waterlogging tolerance in the field. The two most waterlogging tolerant varieties in one situation are often among the two least tolerant varieties at another (underscore and italic numbers respectively in Table 1B). Out of 10 varieties screened in most situations, this applies for Camm, EGA Bonnie Rock, Westonia, Brookton, Cascades and Carnamah (Table 1B). The most consistent waterlogging tolerant varieties are Camm and Calingiri. The most inconsistent variety was Cascades, which was in the two lowest varieties in four situations and in the top two varieties in three situations (Table 1B).

The difficulties in interpreting field based results for waterlogging have led us to develop a waterlogging screening facility in Katanning, Western Australia using specially made pots. At this facility we have the ability to screen up to hundreds of varieties in one season in multiple soils from historically waterlogged field sites, at the same location under natural temperature and light conditions. This provides practical benefits in that we can control the waterlogging intensity and waterlogging frequency; the site is easily accessible, significantly less expensive and is in the same geographic location each season. The disadvantages are that field conditions can be much more complex and there is only one experimental "window" when all environmental conditions are suitable per year. Furthermore, once reliable trends across seasons and soil types are determined from pot research in the natural environment, we will ultimately need to go back to the field locations to validate and "ground truth" results from the screening facility.

Table 3. Mean percent waterlogging tolerance (WL Tol) of wheat varieties using sites grouped according to waterlogging intensity.

Severe Waterlogging Intensity			Moderate Waterlogging Intensity			Low Waterlogging Intensity		
	WL Tol	Stability		WL Tol	Stability		WL Tol	Stability
[a]Westonia	62	1	Westonia	80	3	Westonia	93	1
Camm	55	2	Camm	92	1	Camm	101	4
[a]Calingiri	54	4	Calingiri	94	3			
Brookton	52	4	Brookton	91	2	Brookton	91	1
[a]EGA Bonnie Rk	52	4	EGA Bonnie Rk	90	3			
Carnamah	49	3	Carnamah	74	5	Carnamah	95	3
Cascades	51	3	Cascades	87	3	Cascades	86	2
[a]Chara	50	2	Chara	96	4	Chara	97	3
Spear	50	2	Spear	88	1	Spear	83	2
[a]GBA Shenton	48	-	[a]GBA Shenton	73	-			
Wyalkatchem	43	3	[a]Wyalkatchem	88	1	[a]Wyalkatchem	101	-
[a]GBA Sapphire	42	3	[a]GBA Sapphire	78	5			

[a]GBA Ruby	40	5	[a]GBA Ruby	90	1			
						[a]Krichauff	93	-
						[a]Norin46	82	1
						WAWHT2668	92	2
						[a]Worrakatta	76	1

[a] Not included at all sites.
Stability rating (1 = most stable, 5 = least stable) is an indication of variability within waterlogging intensity.

Conclusion

All of the approaches used have assisted in explaining the variation in previous attempts to assess waterlogging tolerance. In the process we have also identified some tolerant (i.e. Camm, Calingiri), some less tolerant (i.e. Wyalkatchem, GBA Sapphire, GBA Ruby) and soil type responsive varieties (i.e. Calingiri, Carnamah) that can be used in future research as indicator varieties to assist in the interpretation or waterlogging tolerance results. The variation described above in waterlogging tolerance between different waterlogging situations (eg Cascades) helps explain why there has been little progress in germplasm improvement aimed at waterlogging tolerance of wheat.

It is just as important when assessing waterlogging tolerance of a variety to know what level of variation there is between sites and/or the stability of the results as it is to know the actual tolerance value for a particular soil or site. A concern that we have raised is that it is incorrect to simply average the percent waterlogging tolerance across all situations without further information and more detailed assessment. This is potentially dangerous due to the infinite number of waterlogging situations that can arise in the field.

Assessing waterlogging tolerance in the field is complex. Screening in pots using soil from the natural environment is an incremental approach to understanding reasons for this complexity and what often appears to be confusing results from field trials where there may be large temporal or spatial variations in the stress, e.g. as in Table 1A, or where other environmental factors may confound results. Recent research conducted in Australia and India support that different rankings of waterlogging tolerance in different field sites is often a consequence of specific element / microelement toxicities that are exacerbated during waterlogging (Setter, 2006). This research is therefore continuing to elucidate causal factors in varietal responses to waterlogging. Ultimately, information and recommendations from the pot experimentation need to be validated in the field to determine whether tolerance under such controlled conditions equals tolerance in the field.

References

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