High-Yielding Irrigated Wheat Crop Management

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Key words: variety choice, sowing rate, row spacing, canopy management, lodging risk, frost risk, nitrogen timing, fungicides, growth regulators, grain quality, crop monitoring, Zadoks growth stages

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Summary

The report discusses the important findings and conclusions of the GRDC *Irrigated Wheat Evaluation Project*, conducted from 2001 to 2005. It highlights a range of factors that could contribute to building a crop structure (*ie* canopy management) necessary for achieving high grain yields with reduced lodging risk, and with best use of solar energy (growth), residual and fertiliser nitrogen, and *available* water.

The project's conclusions have been summarised in the guidelines below:

Choice of variety:

- <u>Short season</u> varieties were most efficient with nitrogen and water,
- <u>Flowering early</u> within the 3-week optimum period around 1 October can save one irrigation for similar yields,
- <u>Stem strength and anchorage</u> of varieties is highly dependent on management.

(Pre-)sowing management:

- <u>Soil conditions</u> should allow good root growth for plant anchorage, being well aerated, with good organic carbon content, no hard pans, minimum tillage, well managed traffic,
- <u>Deep sowing</u> (6-7 cm) will enhance strength of plant anchorage,
- <u>Lower sowing rates for wider row-spacing,</u> to attain a within-row plant distance of at least 2.5 cm, will achieve best anchorage strength,
- <u>Plant densities</u> of 60 to 80/m^2 will minimise lodging losses while maintaining high yields.

Post-sowing management:

- <u>Limited early growth</u>, <u>restricted tillering</u> and <u>delayed canopy closure</u>, resulting in ground cover at Z30 (start stem elongation, Zadoks crop growth stages, see Appendix 1) of less than 70%, will enhance stem strength and better the balance between "source" size (leaves, stems) and "sink" numbers (spike, kernels); with a shoot density target of 600-800 shoots/m^2 at Z30,
- <u>Nitrogen fertiliser application to promote yield</u> is most efficient when topdressing is between Z30 and Z32 (see Appendix 1),
- <u>First spring irrigation</u> during early stem elongation is important, *when required*, if high yield potential has been set,
- <u>Topdressing near flowering</u> with 30-40 kg N/ha can increase grain protein by 0.5-1% and yield with 0-0.5 t/ha, if there has been an earlier topdressing for yield,
- <u>Green leaf area at flowering</u> needs to be more than 3.5 green leaves per shoot to achieve greater than 8 t/ha yield,
- <u>Green leaf area duration</u> is maximised with timely irrigation after flowering to fill the "sink" to potential.

These guidelines seem valid under irrigation on the plains of southeastern Australia. There are no recipes to secure consistently high yields and a key message in striving for high yielding crops is that ***you can't manage what you don't measure***. Crop knowledge and monitoring are important to achieving profitable results as described here and in the separate feature about monitoring[1]. *TOPCROP* monitoring can be used to learn more about crop–soil–environment interactions[2]. The factors presented can be used with key checks for best management practice in *Wheatcheck*[3] to determine with one's own experience local guidelines for efficient use of resources in high yielding grain production, which of course will be dependent on the availability of water. Comprehensive management guidelines for growing eight tonnes a hectare using many of the recommendations from this study have been described by John Lacy and Kirstie Giblin[4].

[1] M.Stapper, 2007, *Crop Monitoring and Growth Stages for Wheat* - Irrigated Cropping Forum
[2] http://topcrop.grdc.com.au/main2.htm
[3] Wheatcheck Recommendations, 2003, NSW DPI, Vic DPI, GRDC, ICF.
[4] NSW DPI Primefact 197, 2006

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Introduction

The GRDC *Irrigated Wheat Evaluation* Project for the irrigation areas in the Southern Region was conducted from 2001 to 2005, following the research from 1983 to 1986 by Maarten Stapper and Tony Fischer[5]. The aim was to identify under irrigation and good management wheat genotypes with high yields and quality attributes required to meet customer needs. Management packages were to be developed for such genotypes to improve farm profitability and sustainability in irrigated farming systems. Some 200 (inter)national genotypes (*ie.* released varieties and breeding lines) of bread wheat, durum and triticale were evaluated, with a core trial at Griffith, Benerembah and Deniliquin in southern N.S.W. over three seasons. Additional experiments at Griffith involved sowing dates, sowing rates, nitrogen timing, growth regulators and fungicides.

Results highlight some important factors in avoiding yield losses of up to 3 t/ha caused by lodging. Progress reports have been presented on the GRDC website under *Research Updates* – Irrigation, Southern Region and High Rainfall, IREC website and in *IREC Farmers' Newsletter Large Area* editions no. 164, 166 and 169.

The seasonal weather (May–Oct. in Appendix 2) in the study period was between normal (2003) to above (2002), with rainfall much below average in 2002 and 2004 resulting in high water deficits (see Irrigation – Demand). The month before flowering was cool in 2004. Mean seasonal maximum temperature for 2002 was 1.4 ^{o}C above the long-term mean of 17.9 ^{o}C.

This paper will describe guidelines derived from these and other studies to achieve high yields with the least risk of lodging and frost, and most efficient use of water and nitrogen. Firstly an overview of factors determining growth and yield is presented. This will be followed by the knowledge needed to apply those principles and anticipate the management required. Current variety status is dealt with next to see what we have gained since the eighties. Early flowering, with frost risk and optimum period, and green leaf area duration, with required green leaves at flowering, are described as these are important factors to achieve high yields with the least risk. Variety choice for a given paddock and sowing date is the first management decision, with maturity, stem strength and tillering as important characteristics. The required plant configuration for the chosen variety is then the next point, resulting in decisions about sowing rate and depth for the row spacing used. Subsequent sections deal with management factors that can be used to manage the canopy to optimize grain yield with the least lodging risk through timing of nitrogen and irrigation, and the possible use of plant growth regulators and fungicides. Grain quality issues are described in the final section.

Factors determining growth and yield

The success of the management of agronomic inputs depends on the ability to meet crop demand *and* to protect the crop from yield reducing factors. Lodging in winter cereals is a major yield reducing factor in the southern irrigation areas as spring irrigations occur in the windiest months (Appendix 2). Saturated soils during irrigation greatly reduce the anchoring strength of heavy-crop plants in high densities, and heavy winds then may blow them over (see Fig. 6); as with saturated soil during a rain storm. Provide therefore soil conditions that allow good anchorage by strong roots, that is, a well aerated soil with good organic carbon content[6], no hard pans, minimum tillage and well managed traffic. Raised beds are a solution on difficult soils in providing quicker surface drainage.

Lodging is a major risk when targeting high yields and may result in high screenings, low test-weight, weather-damage risk and slowed harvesting. Lodging is scored as the lodging angle from vertical multiplied with the fraction of the area affected. Lodging duration increases grain losses and that loss is 1% for every 2 unit increase in lodging score from the start of grain filling (see footnote 5). Lodging before flowering is not as damaging as plants can right themselves to a certain extent.

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[5] Australian Journal of Agricultural Research, 41(6): 997-1056, 1990

[6] M.Stapper, 2006, *Soil fertility management – towards sustainable farming systems and landscapes*. http://www.bml.csiro.au/susnetnl/netwl61E.pdf

The aim is to grow dry matter for grain and have the smallest stubble remaining, that is, having a high harvest index (HI). Early sowing and early growth in general tend to increase lodging risk, decrease HI and increase residual stubble. Grazing is an option when faced with early growth in a fertile paddock while remaining on track for good grain yield. High water and nitrogen use efficiencies are important factors in producing the most grain relative to inputs.

High yields can be chased with inputs but returns on that investment may be low if other factors are limiting the response. Paddock choice (soil condition, disease & weed risk, fertility, *ie.* history), pre-sowing moisture, sowing time, variety choice, plant establishment and pre-sowing nitrogen management are important first steps in building a crop responsive to solar energy, water and nitrogen as the season progresses.

Relatively warm winters with ample solar energy (blue skies) keep plants tillering and growing when nutrients and water are freely available. Hence, the “source” (green matter) becomes too big and competes with the developing “sink” (spike and kernel number & size) during the critical 30-day period prior to flowering. Lodging-risk also increases. Pre-sowing fertiliser needs therefore to be conservative for high yield targets, and the crop then needs to be managed with herbicides, fertilisers, irrigation water and fungicides to achieve proper shoot density, green leaf area duration, and reduced lodging risk.

From the plant configuration established, management before flowering has to build a canopy structure which can carry and fill the most grain. That is, manage the canopy to achieve the desired outcome. Efforts in canopy management can go to waste with poor combinations of both variety/sowing-date and sowing-rate/row-spacing (*ie.* plant establishment).

After flowering, temperature and evaporative demand increase rapidly and, compared with cool-temperate climates, the source senesces quicker than grain development (the sink) advances. Hence crops may become more source limited when water stressed, that is, leaves senescing before physiological maturity (maximum grain weight) is reached, thus resulting in low kernel weights and lower HI.

Hence, under high yielding conditions, “source” (leaves/stems) and “sink” (spike/kernels) need to be balanced with canopy management to achieve the potential. At the higher production levels crop yields are becoming more sensitive to the correct timing of management practices in relation to both stage of development and plant configuration. Faster crop growth rate shortens the period available to apply key inputs required for maximum yield and timeliness of management decisions becomes critical. The plant configuration achieved will determine management options. Inappropriate or incorrect applications of fertilizers, herbicides or fungicides may result in low or even negative economic returns. Therefore, accurate identification of crop status is important. Crop monitoring and growth stages, with Zadoks Decimal Code, are summarized and described in a separate feature (see footnote1).

Required knowledge

There are no recipes to secure consistently high yields and *you can’t manage what you don’t measure*. Crop knowledge and monitoring are important in achieving the most profitable result. Crop observations are required to adjust timing and quantity of management to actual crop condition. Also timing of the occurrence of such yield reducing factors as lodging, waterlogging and frost will, in combination with their severity, determine their effect on grain yield. It requires knowledge about a developing and growing crop.

Plant development – Knowledge about a developing and growing crop is important to observe and measure the right crop parameters in the use of yield determining management guidelines. Growth stages and numbers of plant components are important in the language of management for high yields. Figure 1 gives an overview of the growing season of a wheat plant from sowing till start of grain-filling with the Zadoks Decimal Code (Z)[7] for each shoot shown (NB. timing not to scale). It shows when leaves and tillers appear, tillers survive, spike initiates, spike grows, potential kernel number and size forms, actual kernel number is set,

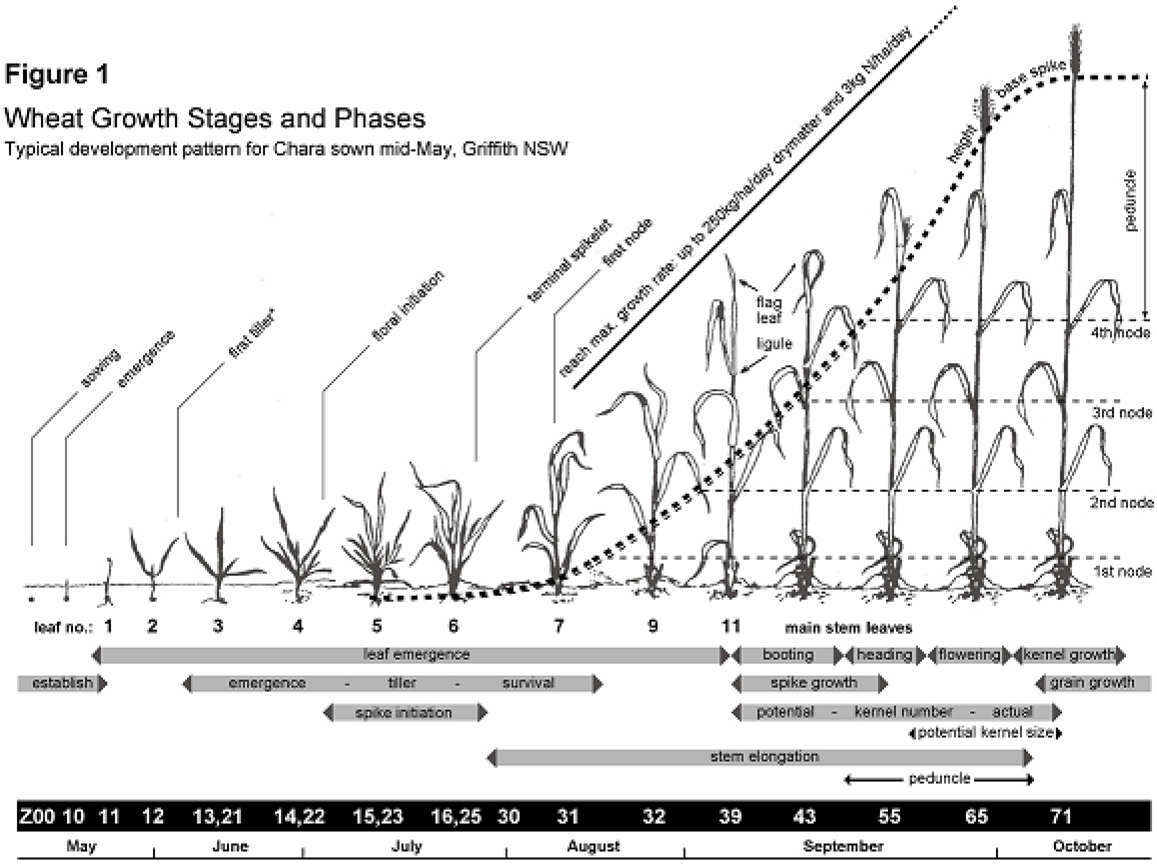
[7] J.C.Zadoks *et al*., 1974, Weed Research 14:415-421

kernels develop and grow, grain grows, nodes formed during stem elongation, and the increase in height following the base of spike with the peduncle being the last part of the stem that elongates (see footnote 1).

Figure 1

Wheat Growth Stages and Phases

Typical development pattern for Chara sown mid-May, Griffith NSW



* under good condition some plants will have a colepile tiller appearing between Z11 and Z12.

Table 1. Maturity groups derived from three years of core trials with 54 genotypes at Griffith, Benerembah and Deniliquin in southern New South Wales. Sowing dates were between 15 May and 9 June with resulting flowering dates mostly in the optimum flowering period. Varieties of group 6 were used in an early April sowing at Griffith.

Maturity group		Variety
1	very early	H46, H45, Hybrid Mercury
2	early	Hunter, Babbler, Drysdale, Wentworth, Ruby, Ventura
3	medium	Giles, Sunvale Annuello, Janz, Chara, Arrivato, Bellaroi
4	medium late	Snipe, Pardalote
5	late	Rosella, Whistler, Wylah, Wedgetail, Currawong
6	very late	Mackellar, Rudd

Maturity – A maturity rating was made for the varieties used in the core trials based on time to flowering for sowing dates between 15 May and 9 June. These sowing dates resulted mostly in flowering dates in the optimum period (see Fig. 3). An overview of varieties in maturity groups is presented in Table 1. Average flowering dates for these sowings were for the medium maturity (3) varieties between 28 September and 11 October. Early (2) and very-early (1) varieties were on average 4 to 5 days and 8 to 10 days, respectively, earlier flowering then those for group 3. Medium-late (4) and late (5) varieties were on average 3 to 4 and 6 to 8 days, respectively, later flowering compared to group 3. Results within and between groups 4 and 5 were variable. Increasing vernalisation requirement, from 4 to 5 and across varieties from left to right, affected their maturity differences depending on sowing date and seasonal temperature.

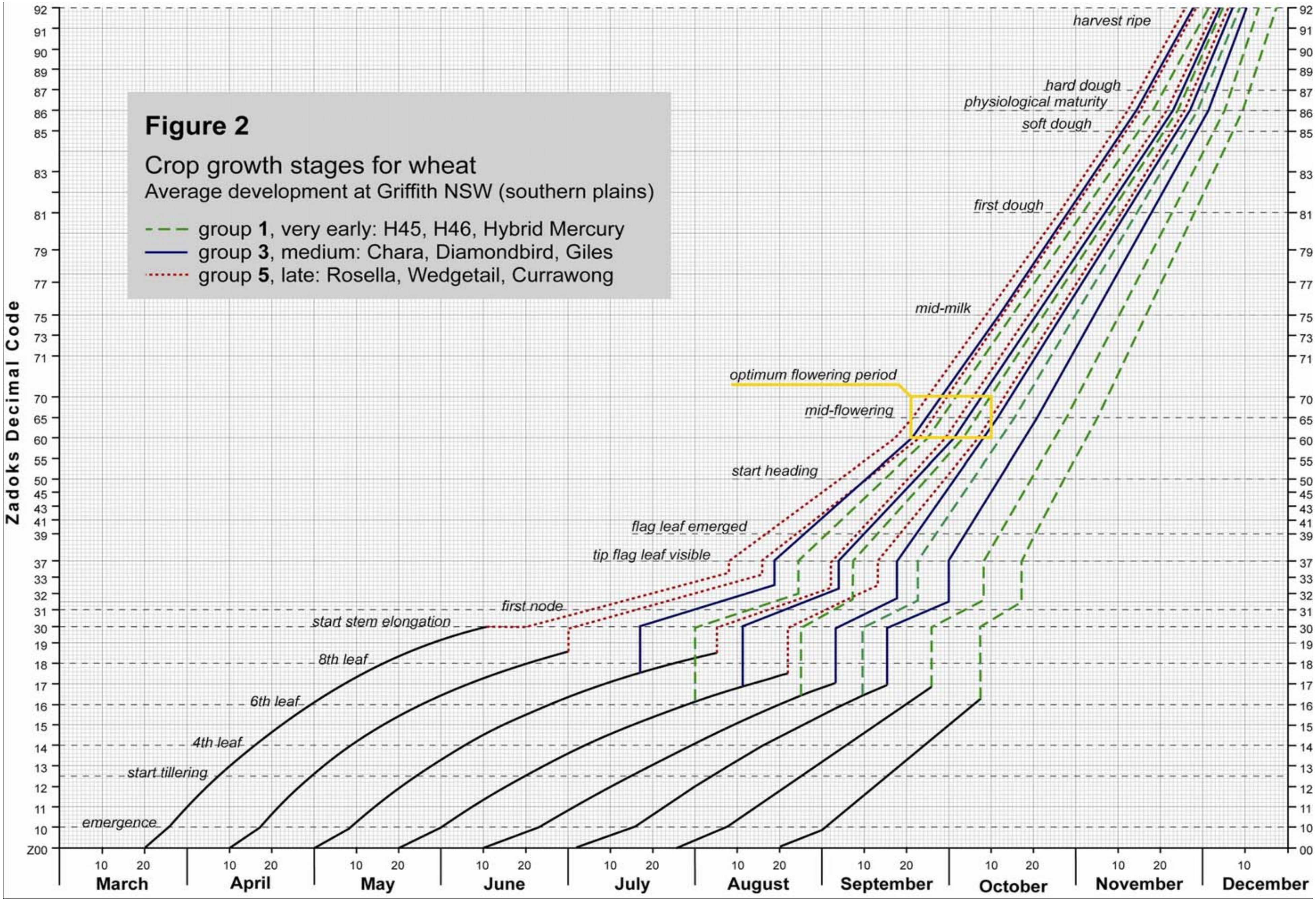


Figure 2

Crop growth stages for wheat

Average development at Griffith NSW (southern plains)

Figure 2 shows examples of average observed Z-stages over the season from various sowing dates. The Decimal Code during leaf emergence is independent of maturity. Maturity is mostly defined by the number of leaves on the main shoot which is set at floral initiation (Fig. 1; see under maturity below), and the resulting timing of start of stem elongation, Z30. The three maturity groups shown in Figure 2 are late (group 5: Rosella, Wedgetail, Currawong), medium (group 3: Chara, Diamondbird, Giles), and very-early (group 1: H45, H46, Hybrid Mercury) for early to late sowing, respectively; listing varieties used in recent trials along with other key varieties in Table 1. Curves for groups 2 (Drysdale, Hunter, Tamaroi-d, Credit-t, Kosciuszko-t) and 4 (Snipe, Borlaug) can be projected between those for 1 and 3, and 3 and 5, respectively, or 3 to 5 days away from the drawn curves of maturity groups nearest to them. For reference, varieties from the eighties for these five groups were, from early to late, Dua (triticale), Vulcan, Egret, Grebe and Osprey, respectively. Figure 2 is further explained for use with ones own observations in footnote 1.

Curves in Figure 2 are for average conditions with average temperature. During periods in the season phasic development could go faster or slower (*eg.* warmer *vs* cooler). Crop management (healthy *vs* stressed plants) and location (topography, soil type) may also affect rate of development. Changes in soil type may cause bigger variations to the curves in Figure 2 than regional differences. For example, the core trial at Benerembah on grey-cracking clay reached flowering 5 to 8 days later when sown on a similar date to the one at Griffith on red loam, 20 km away, with Deniliquin more akin to Griffith which lies 170 km northeast. The wet, dark clay remains cooler during winter which slows development. Very low sowing rates (see Table 3) may cause flowering to be two (*eg*. 2004) to six (*eg*. 2003) days later than shown, while visible nitrogen stress at Z30 may cause it to be two to five days earlier. Differences between seasons are caused by temperature and solar irradiance interactions and sequences.

Current variety status

In the core trial of the recent project a group of 54 (re)selected genotypes were grown in mid-May to early June sowings during three seasons at the three locations. Table 2 shows the averages of yield and percentage of site mean for thirteen varieties over the nine site-years of the core trial. All varieties expressed their genetics under similar availability of resources. The highest and lowest yields and the level of variability through the coefficient of variation (cv) are given for each variety. A lower cv indicates more stable performance around that average yield across sites and years. The lowest yields were for the 2002 Deniliquin trial due to late availability of water.

The very early maturity group 1 is not represented in Table 2 as H45 and Hybrid Mercury were not included in the last season core trial because of their susceptibility to stripe rust. In the first years their site means were 97 and 90%, respectively, caused by lodging as H45 yielded close to 10 t/ha when protected from lodging and leaf disease (see Table 5). Shattering losses is another problem for very early genotypes sown together with late varieties that delay harvesting. Biscuit (ASW Soft) varieties are not in the final list as Lorikeet was removed in the last season because of stripe rust. It had been yielding well below site mean as had Snipe.

Lodging score is given as the average for all the trials, but plant height (tip of spike) is only given for the non-stressed trials to show true genetic difference. Plant height only explained 27% of the variation in lodging score. Lodging is therefore more influenced by genetic differences in the stem and anchorage strengths that determine the force required to pull a top-heavy plant over. Arrivato, for example, has relatively stronger stem and anchorage strengths for height compared to Rubric, and Kosciuszko more than Giles. Plant height for a variety decreases with later sowing and is shortened by up to 5 cm per 1 week delay in flowering (see footnote 5). As height is not a main factor in lodging, later flowering would not reduce lodging risk as much due to height, but more through loss of weight.

Standard grain tests were done and six are shown in Table 2 for the varieties listed, as is the AWB grain quality class. Grain protein for the two durums was significantly higher than the bread wheats. It is promising for the industry to see the average durum protein nearing the

Table 2. Variety characteristics, grain yield, lodging score (Lodg.), crop height (Hgt) and grain quality means for released varieties sown in each of the core trials at Griffith, Benerembah and Deniliquin in 2002, 2003 and 2004. Yields are given against average site mean with coefficient of variation (cv), their highest (Max.) and lowest (Min.) yield, and as the ranking in irrigated variety evaluation trials by NSW DPI from 1997 to 2004. Grain quality presents screenings (Scr.), kernel weight (Kwt), test weight (Twt), protein content (Prot.), Falling Number (FN) and occurrence of black point (BP). The mean values at the bottom are averages for all 54 genotypes in each trial.

		Yield parameters					DPI			Grain quality[A]						
		Yield	site	cv	Max.	Min.	Yield	Lodg.	Hgt[B]	AWB	Scr.	Kwt	Twt	Prot.	FN	BP
		g/m^2	%		g/m^2	g/m^2	%	-	cm	Class	%	mg	kg/hl	%	sec.	%
Genotype [C]																
Arrivato - d	3[D]	727	107	27%	977	293	-	9	100	D	3.2	48.4	81.5	12.0	453	0.2
Seri M82 - M	2	717	107	21%	873	392	-	10	97	-	3.8	44.0	78.7	11.0	200	0.5
Chara	3	711	106	23%	878	368	110	4	89	APH	4.3	37.8	79.4	11.3	356	0.7
Mitre	3	701	105	20%	847	429	-	11	88	AH	3.6	36.4	79.1	11.0	368	1.3
VN870	3	703	105	26%	864	373	-	3	93	-	4.7	36.2	76.4	10.6	343	0.4
Rubric	2	692	103	25%	931	350	-	31	101	AH	4.9	45.4	80.5	11.3	386	0.2
Giles	3	691	103	18%	841	422	108	22	93	APH	3.8	37.9	78.8	11.0	399	1.3
Kosciuszko - t	2	689	103	23%	847	406	106	23	118	T	3.0	44.8	72.4	10.4	na	0.0
Borlaug - M	4	689	103	22%	851	376	-	9	93	-	2.9	44.0	80.6	11.4	421	0.0
Bellaroi - d	3	687	102	24%	849	334	-	12	92	APDB	3.5	46.6	79.2	12.6	446	0.0
Drysdale	2	684	103	20%	840	403	104	15	102	AH	4.1	40.8	80.9	11.4	395	0.4
Janz	3	663	99	22%	844	333	103	15	90	APH	3.0	37.9	80.4	11.2	376	1.2
Wedgetail	5	626	96	21%	803	365	104	7	92	APH	3.1	39.7	77.2	11.7	380	0.8
Diamondbird	3	610	92	18%	728	371	101	17	99	AH	3.4	41.0	80.9	11.5	391	0.2
Mean top 14		685	103	22%	855	372	105	13	96		3.7	41.5	79.5	11.3	378	0.5
Trial																
Mean 9 Core trials		671	100	18%	782	397	100[E]	16	96		4.1	39.6	78.6	11.6	347	0.6
Mean min. 9 Core		480	72	19%	569	293		1	79		1.5	30.9	82.5	9.9	116	0.0
Mean max. 9 Core		847	127	19%	977	507		52	120		8.4	50.9	68.5	13.7	522	3.6
s.e.[F]		41.1						5.7	1.8		0.77	0.97	0.55	0.35	39.5	0.41
C.V. (%)		8%						46%	3%		24%	3%	1%	3%	10%	111%

[A] Agricultural Research Institute, NSW DPI, Wagga Wagga
[B] representative height for high yielding trials
[C] d = durum, t = triticale, M = CIMMYT Mexico
[D] maturity group: 2-early, 3-medium, 4-medium late, 5-late
[E] Snipe is the standard with 5.6 t/ha, NSW DPI 2004 "Green Book"
[F] s.e. is the standard error of environment and genotype means
na, not available

13% mark, which is the required ADR1 quality (see nitrogen and protein section below). Other genetic differences are expressed in kernel weight, Falling Number (FN) and black point, a genetic grain disorder favoured by moist conditions during late grain-filling and ripening. It is interesting to see that more than half of the top 10 yields are varieties with big kernels. The two CIMMYT varieties showed a big contrast in FN, with Seri M82 very low and Borlaug ranked highest bread wheat. Such a low FN can only be used as feed wheat for cattle, and dough tests for Borlaug were not acceptable. Black point can be bad under irrigation and has an acceptable threshold of 5%. Janz, for example, was outclassed because it was susceptible. These trials, however, showed that recommended variety Giles was as susceptible as Janz. In various other trials Rubric was above the threshold three times and Chara, Drysdale and Giles twice. There is more about grain quality in the section below.

No variety improvement – The CSIRO research of the eighties concluded with a description of an 'ideotype', desirable genotype characteristics, under high-yielding irrigation (see footnote 5). Around then breeders started targeting wheat for irrigation areas. Yields seemed to have increased recently in the NSW DPI irrigated wheat evaluation trials on farms in the Murrumbidgee and Coleambally Irrigation Areas (Fig. 3). However, recent DPI yields appeared to have been overestimated by a change in trial design in 1999. Since then the two outside rows of the 8-row plot-seeder were blocked to create a 6-row plot in the 8-row plot spacing while continuing to harvest the whole plot, including outside rows. Yield of the present CSIRO studies was based on inside rows only (*eg*. 'Best CSIRO trial variety' in Fig. 3). The 2002 and 2004 core trial was sown the same day next to the NSW DPI trial at Benerembah. In 2002 the DPI and core yields ranged for four genotypes in common from between 7.0 and 8.4 t/ha to between 8.5 and 10.8 t/ha, respectively, calculated from a regression equation that explained 91 percent of variation. The yield ranges in 2004, from a regression equation for ten genotypes in common explaining 83 percent of variation, were for DPI 7.0 to 9.0 t/ha and for core 6.5 to 7.5 t/ha. Average yield increases were 1.9 and 0.9 t/ha for 2002 and 2004, respectively, and increasing with yield. The grain yields of two outside rows and four inside rows were measured for the ten genotypes in DPI 2004. Yields per meter row length were 31 to 102% higher in an outside row compared to average inside row, thus explaining the high NSW DPI yields as likely overestimates. Figure 3 shows yield corrections based on accounting the yield as from an 8-row width rather than the 6-row width used. The resulting curves of mean and best yields do not seem to be different from the ones in the eighties.

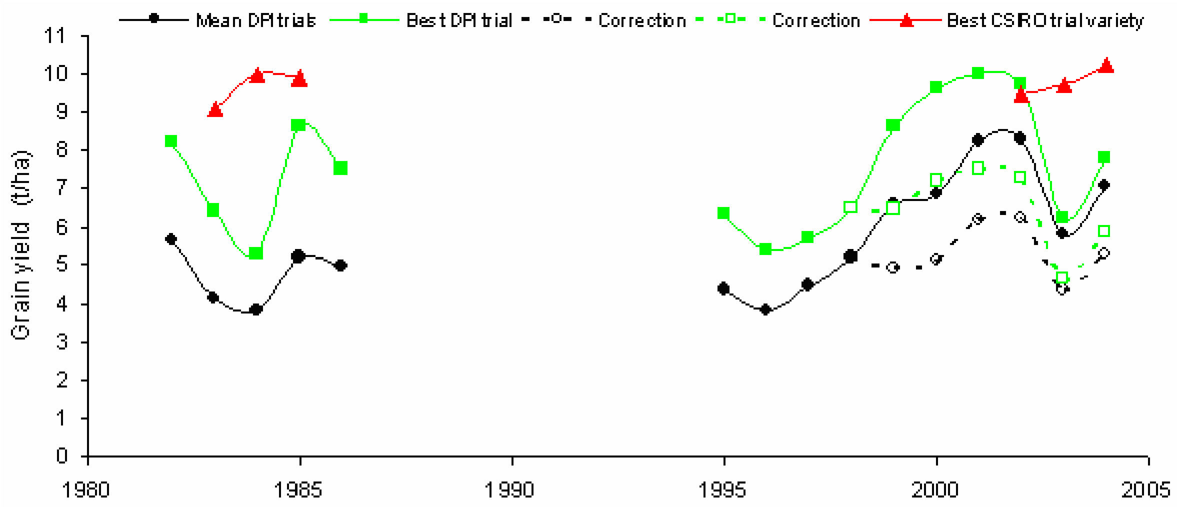


Figure 3. The mean grain yields for all irrigation trials and the best trial of DPI NSW conducted in the Murrumbidgee and Coleambally Irrigation Areas available from the annual "Green Book". Plot size corrections to DPI yields are shown to account for 1999 change in plot design and harvesting of outside rows. Also given is the yield for the best variety in CSIRO experiments at Griffith in the study periods.

Thus, varieties may not have increased in yielding ability and are again not being bred for high-yielding irrigated conditions in the Southern Region, as is also evident from the origin of top 10 varieties in the core trial (Table 2). Most originate from outside the area and, with the exception of the CIMMYT varieties Seri M82 and Borlaug, are selected under dryland conditions: Chara and Mitre (Vic DPI), Giles (Qld DPI), durums Arrivato and Bellaroi, and Kosciuszko a triticale. Also shown in the Table is the relative ranking from the NSW DPI '*Green Book*' of those varieties included in irrigation evaluation in the Southern Region. Generally the ranking is similar, with Chara and Giles confirmed as the current top varieties. However, the variation in performance between varieties is larger in this study, especially for Diamondbird and Wedgetail.

The bad lodging years 1984 and 2003 are clearly visible in Figure 3, while there was always a genotype yielding well in CSIRO experiments. The challenge is to breed a variety that matches these experimental yields under commercial conditions across the Southern Region.

Sowing date and location – Table 3 shows some outcomes of experiments for sowing dates at three locations and on-farm N-test strips over three years in the recent project using current varieties and breeding lines. Number of spring irrigations, mean lodging, and mean and maximum yield are given for the experiments together with the mean of important grain tests. It shows the low yields, high screenings, low test and kernel weight and high grain protein for

Table 3. Sowing date and location effect, including irrigation, on final lodging score, grain yield and grain testing attributes for experiments in the three years at the three locations, and for N-test strips in Chara crops on-farms in the Lachlan, Murrumbidgee and Murray valleys. See Table 2 for description of grain tests.

Sowing date	Experiment	Irr.[A] no.	Lodg.	Grain yield mean	Grain yield max.	Scr.	Twt	Kwt	Prot.	FN	BP
		-	-	t/ha	t/ha	%	kg/hl	mg	%	sec.	%
04-Apr-02	Griffith - G1	5	56	5.3	6.3	6.4	77.0	34.9	13.7	394	0.1
15-May-02	Griffith - CG1	5	11	7.4	9.3	2.8	81.5	43.5	9.6	345	0.0
15-May-02	Benerembah - CB1	2	2	7.8	9.8	3.9	82.9	42.9	10.5	374	0.0
19-Jun-02	Deniliquin - CD1	1	0	4.0	5.1	2.8	80.2	39.4	13.3	362	0.1
22-Aug-02	Griffith - G2	7	0	3.9	4.8	7.5	74.5	31.1	16.3	386	0.1
28-May-03	Griffith - CG2	4	46	7.3	9.7	4.2	78.7	42.2	12.0	324	0.7
29-May-03	Benerembah - CB2	1	21	6.2	8.0	8.0	76.5	35.1	12.4	389	0.1
04-Jun-03	Deniliquin - CD2	2	18	5.8	6.8	2.6	76.4	38.5	11.1	317	0.1
20-May-04	Griffith - CG3	4	32	7.5	8.9	3.0	80.2	44.2	9.9	320	1.4
31-May-04	Benerembah - CB3	2	8	7.3	9.3	1.8	77.4	41.7	9.9	372	1.0
9-Jun-04	Deniliquin - CD3	3	5	7.1	9.4	4.2	75.1	39.3	11.9	256	1.3
Regional on-farm trials (treatment no.)											
13 farms-02	Chara test strips (70)			5.8	9.4	2.4	82.2	39.4	11.8	412	0.0
18 farms-03	Chara test strips (92)			5.6	8.1	3.5	75.9	36.2	11.4	291	0.1
58 strips	appropriate grade			6.0	8.1	3.7	77.3	36.5	11.5	373	0.1
34 strips	weather damaged			5.1	6.3	3.2	73.5	35.7	11.3	152	0.0
8 farms-04	Chara test strips (31)			6.3	9.2	2.6	78.8	39.7	9.7	303	1.8

[A] number of spring irrigations

the early April and mid-August sowing dates of 2002, each with genotypes of appropriate maturity. Mid-May to mid-June sowing date was judged to be most efficient in use of the resources water and nitrogen for high yields. The 2003 Benerembah experiment, CB2, had the highest screenings of the core trial. All varieties had screenings above the 5% threshold and were up to 10% when the yield (*ie*. kernel number) had been set for 8 t/ha with topdressing and early irrigation, but not backed up with a second irrigation. Kernel weights across the sowing dates reflect the full irrigation at Griffith with Benerembah coming close in 2002 and 2004. Kernel weights at Deniliquin were consistently some 10% lower compared with Griffith, caused by less frequent irrigation. There were only two experiments that had a mean protein content of 12% or above to reach AH, after accounting for those with protein above 13% caused by low yields (G1, CD1, G2). FN for the core trial was consistent over the years for Griffith (345, 324, 320 sec.) and Benerembah (374, 389, 372 sec.) but variable for Deniliquin (362, 317, 256 sec) where many genotypes were below the receival standard of 300 sec in 2004 following some weather damage. Results for black point showed a relatively high occurrence for 2004, the only year the mean for a variety, Currawong, and two breeding lines was above the 5% threshold at Griffith.

The on-farm N-test strips were all in paddocks with Chara, judged at the start of the project as the best irrigated wheat variety to be confirmed in the studies (Table 2). The best results were attained on many paddocks in the first year. The second year had water allocation problems and rain after maturity causing extensive weather damage. Separation of weather damaged strips clearly showed its impact on FN and test weight (Table 3).

Aim for early flowering

For most wheat production systems in Australia, optimum flowering falls between being too early with risk of frost damage, and being too late under increasing water-use rates and requiring more irrigation water when available. Across all full-irrigation trials from the eighties, maximum yields were attained with mid-flowering (Z65, anthesis) occurring in some twenty days around 1 October (Fig. 4; see footnote 5). The Figure shows that even with optimum inputs average yields tend to decrease by 100 kg/ha per day delay in flowering between mid-October and mid-November. In the very dry and hot 2002 season yields then decreased by 150 kg/ha per day delay in flowering. On the other side of optimum in the same year, frost caused a 30% yield loss with flowering on 17 September compared to the 9 t/ha, that trial's maximum, with flowering on 20 September. The damage was caused by frosts on 11 and 12 September.

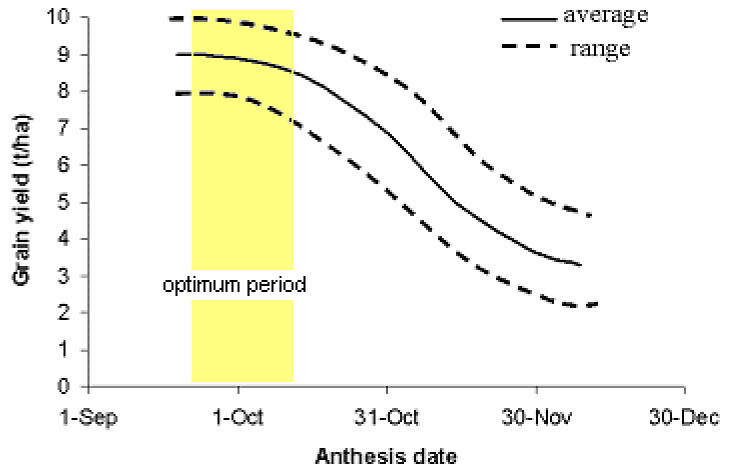


Figure 4. Maximum yields are attained when mid-flowering (Z65, anthesis) occurs in the last week of September or the first week in October (Stapper and Fischer, 1990).

The consistent yield loss following the maximum is caused by higher temperature. Wheat yields decrease by 5% for every 1 ^{o}C increase in average daily grain-filling (post-flowering) temperature above 14 ^{o}C (see footnote 5). In northwestern Europe this temperature is usually well below 14 ^{o}C. In southeastern Australia, however, this average temperature is 14.9, 15.5, 16.4, 16.8, 18.0 and 19.5 ^{o}C for Tatura, Wagga, Kerang, Griffith, Condobolin and Narrabri, respectively, when flowering on 1 October. Appendix 2 shows for Griffith the long-term mean and monthly average temperatures for trial years. Flowering early in the three-week optimum flowering period can save one irrigation, with that early flowering achieving the same yield as the later flowering one with its extra irrigation. Thus frost risk has to be weighed up against the grain loss and reduced water use efficiency occurring every year there is no late frost.

Frost risk – Shoots can be killed during stem elongation with temperatures below -5 ^{o}C and frost during a major part of the day, an event rarely happening on the plains. First frost damage may occur during spike emergence which shows as a band of dead and empty spikelets, those that emerged the day before a frost. Next frost damage is during flowering when fertilization fails due to sterility, which shows as the florets affected opening up wide for days after frost. The last stage of frost damage is when the young growing kernel is killed by frost. Acceptable frost risk would be a chance of one year in ten to have a 20% yield loss as a result of a substantial band of spikelets, one-third, being frosted. The yield loss is however less than spikelet loss as compensation occurs in kernel number and weight in the surviving ones because the "source", the green leaves, is largely unaffected. Resulting higher grain protein may be another compensation for lost yield.

Appendix 2 shows the number of days per month of minimum screen (= 2 m. above soil) temperatures below 2 ^{o}C (= frost at canopy height). However, we can't wait to avoid the last ever frost date. Supported by experience at various locations on observed frost damage, the last acceptable frost date in spring was defined as the 10% probability of having (*i*) two days per week with minimum screen temperatures below 1.3 ^{o}C or (*ii*) one day with a minimum temperature lower than -1 ^{o}C, whichever is later.[8] This was calculated as September 20 from Griffith long-term weather data. Experience of farmers has shown that frost damage

[8] M.Stapper *et al*., 1998, Proc. 9th Aust. Agron. Conf., Wagga Wagga, pp 539-540

substantially increases with late topdressing of nitrogen as demonstrated in split-topdressed paddocks.

Optimum flowering – Figure 4 from the eighties was confirmed with current results. The starting date of the optimum period was calculated above as 21 September. Analysis of available temperature records showed the first acceptable date to be very similar across the irrigation plains in the Southern Region. The broad range of plus or minus one tonne around the average reflects seasonal differences in weather (Appendix 2). Lower yields for cloudy seasons (*eg*. 1983) or hot finishes (*eg*. 2002) and higher yields for favourable springs (*eg*. 2004), with 2003 being an average year. Yields of 10.8 t/ha in experiments and 9.8 t/ha in paddocks were achieved with flowering in this optimum period in 2004.

The recommended sowing dates in the NSW DPI *Winter Crop Variety Sowing Guide* can be followed for flowering to occur in this critical period. Ideal sowing time is recommended for quarters of months, starting with '>' and finishing with '<' to indicate earlier and later, respectively. Generally the '>' marked sowing dates are the first ones flowering within the optimum period defined in this study and '<' the first ones outside. Also, a simple rule of thumb is a 1-day delay in flowering for every 3-day delay in sowing.

Green leaves for grain-filling

A high yielding crop needs a healthy green leaf area and duration to keep fully intercepting solar energy for as long as possible. This requires sufficient nitrogen having been taken up mostly before grain-filling (see Fig. 12). Longer green leaf area duration also means that water use for such crops remains at potential rates longer (see monthly daily potential evapo-transpiration, Appendix 2). Keeping irrigation timely therefore could provide returns. Source limitation is exacerbated by faster leaf senescence when water becomes in short supply during grain-filling. This happens especially following an increase of the sink-size (=demand) by topdressing, risking haying-off with high screenings if not followed up with irrigation. Leaves also senesce quicker if not enough nitrogen has been taken up by the crop. Nitrogen is then translocated sooner from the leaves to the grain, from leaf tip to base and from lowest green leaf towards flag. In cool-temperate climates with adequate water there is usually green leaf area left at maturity (= yellow spikes, green flags), that is, crops being sink limited.

Figure 5 shows for crops with an appropriate spike density (500-600/m^2) the green leaves per shoot required during the grain-filing period to reach grain yields of 4, 5, 6, 7, 8.5 and 10 t/ha. For example, 3.5 green leaves per shoot are required at Z65 to enable reaching 8 t/ha. The Figure shows examples of leaf disease affecting green leaves per shoot, which will result in a substantial yield loss.

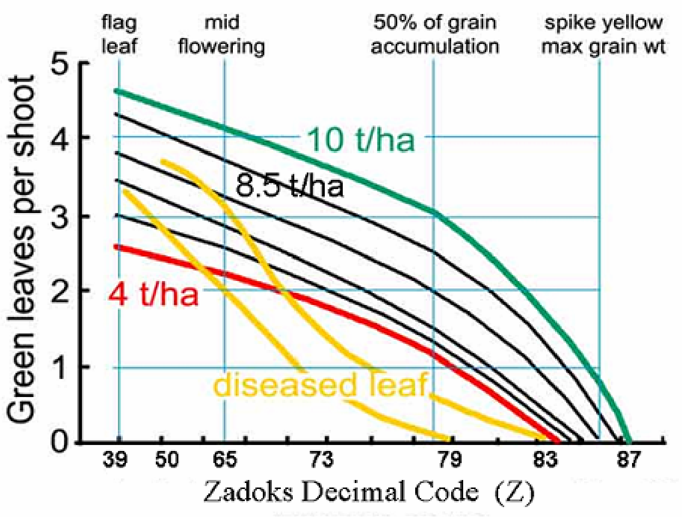


Figure 5. Green leaves per shoot between flag leaf and maturity required to reach grain yields of 4, 5, 6, 7, 8.5 and 10 t/ha with the required shoot (= spike) density of 500-600 per square meter.

Sowing decisions

Variety choice for a given paddock and its likely time of sowing is the important first step. Seed quality and sowing operations in relation to seed bed quality are other important sowing decisions. The sowing date determines the maturity group (Table 2) for the variety to be flowering in the optimum period (Fig. 4).

Seed quality (*ie.* germination percentage), seed size and seed bed conditions (*ie.* emergence percentage) determine plant establishment. A uniform, non-stressed plant establishment is important for high yields as early stress restricts the resulting root system.

Depending on the tillering habit of the chosen variety, sowing rate, sowing depth and row spacing are important decisions determining the probable plant configuration to be managed for creation of an effective canopy structure.

Variety choice

Varieties consistently achieving 8 t/ha under irrigation with efficient use of resources were identified as requiring a combination of the following traits:

- Short season maturity (*eg.* H45)
- Good stem and anchorage strength (*eg.* Chara)
- Restricted tillering capacity (*eg.* H45)
- High sink strength, always yielding more than it looks (*eg.* H45)
- Big grains to lower screenings (*eg.* Arrivato)
- Longer green leaf area duration (*eg.* Arrivato, Chara)
- Not susceptible to black point
- Competitive abilities with weeds.

Having disease resistance will facilitate ease of achievement. The first three factors are described next.

Maturity – Maturity ranking on flowering time is relatively stable across varieties and environments (G x E). In the Southern Region the highest yields were achieved most efficiently (*ie.* high HI) with earliest maturing varieties flowering at optimum time. Grain-filling durations are similar across maturities flowering on a given date. Therefore, it is the shortening of the vegetative phase that is important in achieving high yield with reduced stubble. Canopy management then becomes less difficult as “source” develops more in balance with “sink” potential.

The length of the vegetative phase is determined by the final number of main stem leaves (*eg*. 11 in Fig.1). This leaf number is set when spike initiation starts (Fig. 1; see footnote 5). This event happens later with increasing maturity. Hence final leaf number is greater the later the maturity from a given sowing date. For example, likely leaf numbers are given in brackets for early April, Mid-May and late-July sowings, respectively, for H45 (8.5, 9, 8), Chara (13.5, 11.3, 12), Rosella (15.8, 12.0, 12.8) and Mackellar (17,12.4, no initiation); representative of very-early (group 1), medium (3), late (5) and very-late (6) maturities, respectively. A late-July sowing at Griffith is too warm for Mackellar (maturity group 6) to vernalise and it remains therefore vegetative. Maturities 1, 3 and 5 are shown in Figure 2 as sown together on 20 May, resulting in mid-flowering dates around 1 October, the optimum period (Fig. 4). The number of main shoot leaves for maturity group 1, 3 and 5 varieties is then typically 9.5, 11 and 12.5, respectively.

Stem strength and anchorage to avoid lodging – Stem strength determines how far from vertical a top-heavy stem with spike can be blown by heavy wind. With weaker stems and heavier spikes a greater angle will put more force on the crown anchored by roots. Anchorage strength has to prevent the crown from tilting as shown in Figure 6. This force especially can cause lodging when soil strength is weakened during and following irrigation when the soil is saturated. A plant with good stem and anchorage strength would under heavy wind retain the position pictured on the left. Nodal roots anchor the plant in the subsoil. Anchorage strength is determined by number and strength of nodal roots on the crown which is optimized, being evenly distributed in a circle if wheat plants are at least 2.5 cm apart, as explained below under plant configuration. Hence, a wider crown will also help. These factors were contributing to lower lodging of Chara, with strong stem and anchorage, and the very low densities used in the present studies (see Table 4) and shown in the photo of Figure 6.

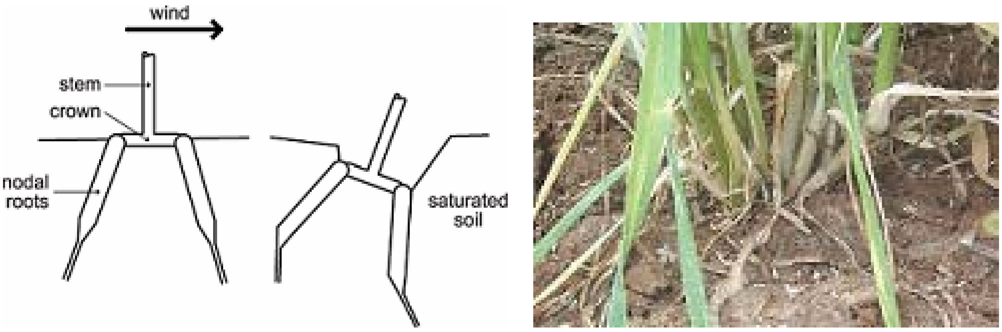


Figure 6. Weak anchorage causes lodging when a wind force pushes the stem, especially if soil strength is weakened by irrigation or rain. Many strong nodal roots will anchor the crown in the subsoil so crown can remain stable in saturated soil and plant doesn't lodge (after Crook and Ennos[9]). The photo shows anchoring strength for a plant at a sowing rate of 35 kg/ha, supported by many nodal roots from main shoot and tillers in a circle around a wide crown.

Stem strength and anchorage are highly variable as they depend on genetic, environment and management (G x E x M) factors. Physical, chemical and biological soil condition significantly influences the anchorage of plants through their impact on root growth and strength (see footnote 6). Too much freely available nitrogen makes stems weaker and taller, and reduces root strength and branching. Therefore, soil conditions that allow good anchorage should be provided and early nitrogen availability restricted.

Figure 7 shows lodging as a major factor in genotype response under high-yielding irrigated conditions. Results show a 2 to 4 t/ha yield difference between genotypes with similar lodging score. This yield variability was not caused by nitrogen stress or plant diseases. The high yields at lodging score of 40 were late stem lodging caused by solid crops starting to lean over by 40 degrees as spike weight increased, without causing disturbances in canopy. Below and beyond that for crops also affected by poor anchorage strength, yield loss was some 60 kg/ha for every unit increase in lodging score. Losses increase with duration of lodging with a 1% yield loss for each two units of lodging score when lodging starts the week after flowering. Lodging is scored as the lodging angle from vertical multiplied with the fraction of the area affected (see footnote 1).

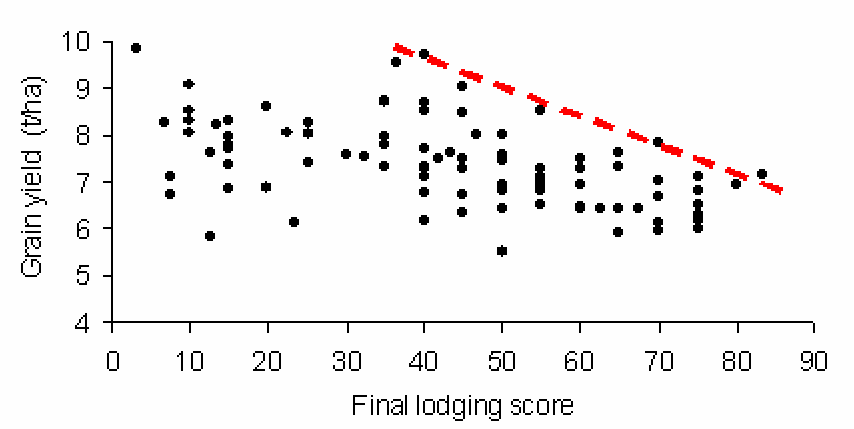


Figure 7. Grain yield and final lodging score for 90 genotypes sown 28 May 2003 at Griffith NSW.

Shorter varieties tend to lodge later and plant growth regulators may help achieving that (see Table 6). Environment though is also the determinant factor. H45 and Hybrid Mercury, for

[9] Mechanics of Wheat Lodging, J. Exp. Bot., Vol.44: 1219-1224, 1993

example, generally have very weak stems in the Southern Region while they can be average to good in the Northern Region (northern N.S.W and southern Queensland). Very strong stem strength in CIMMYT lines from Mexico turned out to be average to weak in our trials. Stem and anchorage strength also needs to be combined with other factors. For example, Whistler, a late maturing variety, has reasonable straw strength as it had a relatively high yield of 7.6 t/ha in the May 2002 sowing for the highest shoot number with only 12% lodging (see Fig. 9a, closed circle most to right). However, the yield remained the same in 2003 with 38% lodging when others yielded close to 10 t/ha with similar lodging (Fig. 7). Whistler therefore seems to be lacking sink strength.

Tillering – Tillering habit is an important factor in canopy management and has to result for most varieties in a spike density of 500-600 per square meter to achieve highest possible yields. This is most effectively obtained from 600-800 shoots/m^2 (see Fig. 9). Tillering can vary greatly between sowing dates and varieties, with genetic expression regulated by competition and fertility (Fig. 8).
– Six tillers are typically achieved under non-limiting conditions in a 150 plants/m^2 stand sown in May, reaching the stage Z16,26 and resulting in some 1000 shoots/m^2.
– Variety differences exist, for example, H45 is low and Cook high tillering, with typically two and seven tillers, respectively, for a 200 plants/m^2 stand (~100 kg/ha, sowing rates were generally seed size adjusted). This is a genetic factor which sets a required daily drymatter growth per plant for a new tiller to develop, with the factor high for H45 and low for Cook.
– Low seedling density increases growth per plant and thereby extends the tillering process, for example, H45 did have 8 tillers for a sowing rate of 35 kg/ha (see Table 4).
– Low nitrogen availability reduces growth and thereby slows and reduces tillering.
– Sowing before early April creates a longer tillering-window with increasing vernalisation requirement of varieties. For example, very late (*eg*. Mackellar, Rudd; group 6), late (*eg*. Rosella, Currawong; group 4) and medium (*eg*. Janz, Chara; group 3) maturities were sown on 4 April 2002 and typically had about 30, 15 and 8 tillers per plant, respectively, from an average of 110 plants/m^2 (~70 kg/ha; drying seed-bed). Figure 9a shows these with shoot densities in groups around 3400, 1800 and 1000 shoots/m^2, respectively. The Chara-type had the lowest shoot density but flowered in mid-August and was frosted. A Mackellar plot with 73 plants/m^2 reached 40 tillers per plant (3000 shoots/m^2) for a yield of 5.6 t/ha under 43% lodging.

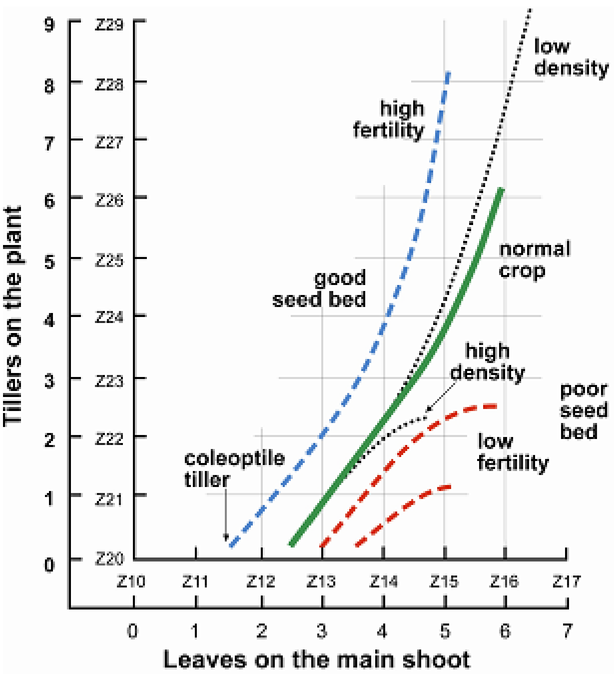


Figure 8. Tillering as a function of leaves per plant and being dependent on management and variety. Low density, normal crop and high density show tillering in 70, 150 and 375 plants/m^2 stands, respectively. The low density trajectory may also be followed for early sown very late (winter) wheat and may lead to 14 tillers at Z17 and 30 tillers at Z19.

– Tiller survival at start of stem elongation (Z30) is also governed by the available daily growth per plant which decides how many tillers survive and develop into independently growing grain-bearing shoots, another genetic factor and dependent on environment and management (G x E x M).

Plant configuration

Sowing rate – A sowing rate trial was conducted over two seasons with rates of 35, 100 and 200 kg/ha for each of H45, Hybrid Mercury and Chara (Table 4), all with seed size of around 39 mg. Average plant establishment over the two years was, from low to high sowing rates, 71, 217 and 375 plant/m^2 and within row plant spacing 10, 3 and 1.5 cm, respectively. Grain yields were significantly higher for the low sowing rate in 2003, the lodging year, and not significantly different between rates in 2004. Tiller number per plant for Hybrid Mercury and Chara ranged typically from 2 at high density to 12 at low density. However, tiller numbers of H45 were half of that for the high density increasing to three-quarters for the low density. Resulting shoot densities are shown in Figure 9b.

Figure 9 shows inverse relationships between shoot number (tillers plus main stem) at Z30 and yield as caused by weakened stem strength and source–sink imbalance with resulting lodging damage. The relationship in Figure 9a is caused by free tillering under fertile conditions for varieties sown in April and May 2002 at Griffith. Figure 9b shows results of a management solution to lodging by substantially lowering the sowing rate (Table 4).

Table 4. Grain yield (t/ha) and lodging score (only 2003) for three varieties sown 28 May 2003 and 20 May 2004 with three sowing rates at Griffith NSW. Treatment l.s.d. for a variety is 0.4 t/ha.

Variety		Low	Medium	High	Mean
	Plant density (/m^2)	71	217	375	
	Sowing rate (kg/ha)	35	100	200	
Grain yield (g/m^2)					
H45	2003	7.3	6.2	6.7	6.7
	2004	8.2	8.0	8.0	8.0
	Mean	**7.7**	**7.1**	**7.3**	**7.4**
Hybrid Mercury	2003	8.0	6.7	6.1	6.9
	2004	7.9	8.1	7.5	7.8
	Mean	**8.0**	**7.4**	**6.8**	**7.4**
Chara	2003	7.5	7.0	6.0	6.9
	2004	9.0	9.4	9.5	9.3
	Mean	**8.2**	**8.2**	**7.8**	**8.1**
Mean	2003	7.6	6.6	6.3	6.8
	2004	8.3	8.5	8.3	8.4
	2-yr mean	**8.0**	**7.4**	**6.8**	**7.4**
Final lodging score (-)					
H45	2003	53	63	73	63
Hybrid Mercury	2003	47	63	70	60
Chara	2003	17	37	65	40

Lodging was a problem in 2003 (Table 4, Fig. 7) with low sowing rates having the lowest occurrence and the latest start of lodging, resulting in the highest yields (Fig. 9b). There were no consistent yield differences between rates in 2004, the non-lodging year. Chara, with relatively strong straw-strength, lodged later and less. Figure 9b shows that it deviates from the trend of lower yields for higher shoot densities in 2004, a season without severe lodging. Chara showed its stem and anchorage strengths, but was also weakened in the high rate (lodging score 65) compared to low (17). Total production over two years was significantly higher for the lowest sowing rate (Table 4). Average final spike densities for low, medium and high normal tillering varieties (Chara, Hybrid Mercury) were about 480, 625 and 640 spikes/m^2, respectively. Spike densities for low tillering H45 were 45 and 100 spikes/m^2 lower

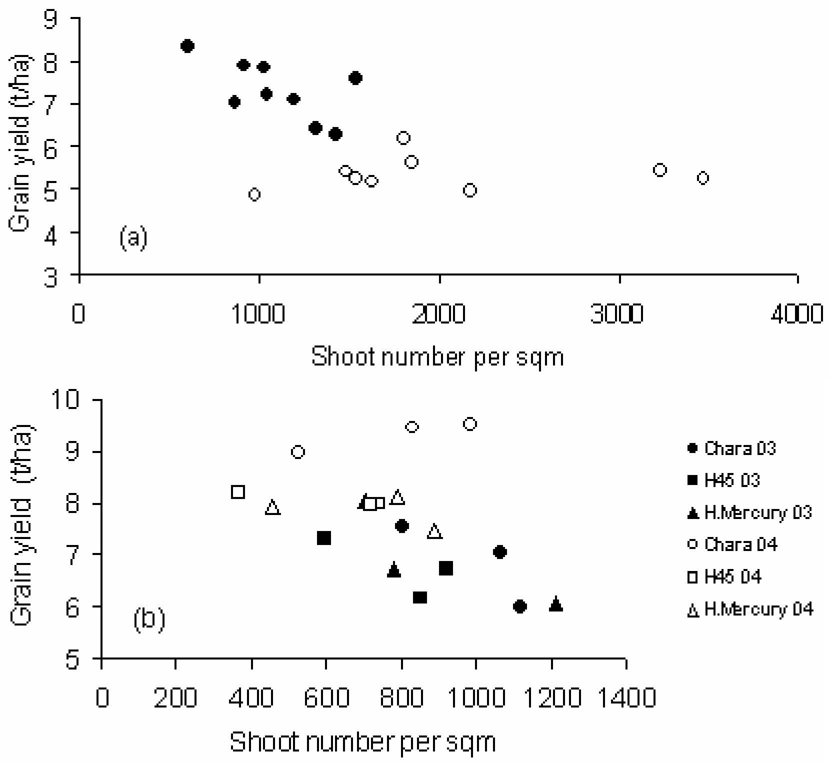


Figure 9. Relationship between Z30 shoot number and grain yield at Griffith NSW for (*a*) sowing dates of 4 April (open cymbals) and 15 May (closed) 2002, and (*b*) three varieties by three sowing rates over two May sowings at Griffith NSW in 2003 (closed) with severe lodging and in 2004 (open) without major lodging.

for low and medium/high rates, respectively. Spike densities were achieved from the shoot numbers in Figure 9b.

All screenings were below 5% and were the same or better for the low rate, as kernel weight in both years was significantly higher than for medium and high rates. This could be different under poor irrigation. Falling Number was also better both years for the low rate and the very low sowing rate therefore didn't affect grain quality.

Similar yield results for low sowing rates are being achieved on farms at the 5 to 6 t/ha yield level as shown in *IREC Farmers' Newsletter Large Area No.166* and *No.172*. The first one was at the Coleambally Demonstration Farm in the present studies, where Chara was sown on beds in one-acre blocks at 35 and 90 kg/ha sowing rates with the aim of achieving high yields on difficult soils. The low rate was sown on the beds only, while in the other treatment the furrows were also sown, resulting in yields of 5.4 and 5.2 t/ha, respectively. The second Newsletter article reports a trial by Barry Haskins and Todd Peach with the collaboration of ICM Cowl Cowl Station at Hillston.

Sowing depth – The three varieties in the 2003 and 2004 sowing rate trials were also sown as broadcast at the medium rate. Lodging for that treatment was as high as for the deep-sown drilled high rate, as the shallow crown caused weakened plant anchorage during irrigation (Fig. 6). This would, for example, have been a risk for the shallow sown plant on the left in Figure 10. Observations across different trials showed that the deeper sown ones, 6 to 7 cm, seemed to have less lodging and plants with better anchorage. Deep sowing, which appeared to be a negative in Figure 10, turns out to provide a good start of the season for crops with a high yield target. Both tillering and early growth are then reduced, causing late canopy closure (see below) and resulting in better anchorage and lower lodging risk.

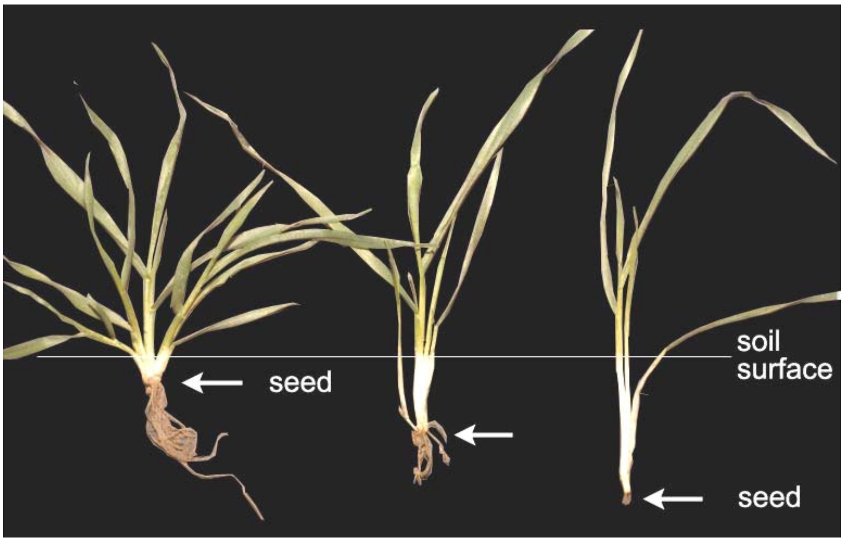


Figure 10. The impact of sowing depths of 1, 3 and 6 cm on development and growth of wheat seedlings are shown. Roots had broken off the deep sown seedling as seedlings had been pulled out rather than dug.

Row spacing – Row spacing determines the plant configuration achieved from sowing rate and emergence percentage. Wider row spacing is increasingly being used to facilitate direct-drilling into stubble. The experiments here were done with standard 18 cm row spacing. In a wider row spacing individual plants can intercept more solar energy and have more soil to explore, thus growing heavier but with stronger stems and roots as more light reaches the base of the plant. Chara, for example, seemed not to be losing yield with row spacing of up to 25cm as measured on farms. However, there are genetic differences in the ability to compensate for wider row spacing which is important for crops on beds with bare furrows. With a wide plot spacing of 60cm, for example, the outside rows of plots were on average 69% heavier in grain yield per meter of row then inside rows, with a range of 31 to 102% for ten genotypes measured; so no complete compensation. Chara, H45, Janz and Rosella were at the top of that range while Diamondbird was down. Hybrids will also do well as they are selected at low densities. When going from 18 cm row spacing to 25 or 30cm, for example, the yield compensation per meter row length needs to be 47% and 76%, respectively, which seems feasible, especially with extra space on *both* sides. Depending on slope and length of run, bare furrows could be preferred and choosing the right variety then becomes important. Refer to the Coleambally Chara-on-beds trial above.

Plant anchorage was strongest with the nodal roots evenly distributed around the crown, when neighbouring plants were at least 2.5 cm away. The average within-row spacing with increasing rates in Table 4 decreased from 10 to 1.5 cm. Farmer crops monitored had row spacing of up to 25 cm without apparent yield penalty and with reduced lodging. For example, a Chara paddock yield of 9.3 t/ha was achieved with 25 cm row spacing and 150 plants/m^2 established (*ie.* 2.7 cm within-row). To lower lodging risk, therefore, it seems important to adjust sowing rates at wider row spacing to obtain a within-row plant distance of at least 2.5 cm.

Canopy closure – Crop growth is determined by incoming solar energy, temperature, water, nutrients and ground cover during the season. The first two factors are beyond control, water and nutrients can be managed to a degree but ground cover depends completely on management. Ground cover is affected negatively by water and nutrient shortages, water logging, leaf and root diseases and sparse or deep seed placement (Fig. 10). Maximum growth rates are achieved when effective green cover is reached (>90%). Canopy closure before Z30 makes crops heavy, as more solar energy is intercepted, and stems weak, prone to lodging. Plant configuration and nitrogen timing are important factors in avoiding such outcomes, as demonstrated in the sowing rate trial (Table 4).

The earliest possible canopy closure is desirable for crops sown early for the purpose of grazing. However, experience suggests that the more open canopy at Z30 is not conducive to improved stem and anchorage strength. New growth after grazing is directed to recovery of lost green matter in preparation for flowering, and not to strengthening stems and roots. Hence lodging can still occur but 5-6 t/ha grain yield remains achievable in addition to the grazing returns.

Average ground cover for the lowest sowing rate in 2004 was just 70% at Z32 when nitrogen was topdressed (see Fig. 12), while high rates had already reached 95% cover and were 10 to 15 cm taller due to competition. The average crop drymatter then was 1.1 and 2.5 t/ha, respectively, increasing to 11.2 and 15.4 t/ha, respectively, at Z72; the average crop growth rates during this period, September, were 215 and 250 kg/ha/d, respectively. Final dryweights came together at maturity with 19.0 and 20.4 t/ha, respectively. Hence a very different path to the same yield outcome and one that in 2003 prevented major lodging for best yields (Table 4).

A shoot density of 600-800 per m^2 at start of stem elongation, Z30, is the target to minimise lodging (Fig. 9) and balance “source” with “sink”. That is, 2-3 tillers per plant for some 200 plants/m^2 from 100 kg/ha sowing rates, where up to six tillers can be achieved for most varieties when nitrogen is freely available.

Lower sowing rates and wider row spacing, therefore, make it easier to achieve this target under higher fertility conditions. The aim is to keep ground cover around 70% at Z30 when stem elongation starts and spike number is being determined from available shoot density and prevailing conditions. Then final nitrogen can be topdressed to meet requirements for target yield. Thus delaying canopy closure, with more light reaching the base of the plant during this initial period of early stem elongation (Fig. 1), improves stem strength and anchorage. However, weed risk must be low under such conditions.

Attainable grain yield

Grain yield depends on the number of spikes per unit area and the grain weight per spike. A shoot density of 600-800 per m^2 will result in a sufficient number of spikes, 500 to 600, under normal conditions. A grain weight of 1 gram per spike can be expected under those conditions but 1.5 gram can be the weight under excellent conditions on the same resulting spike density. Grain weight per spike has two components: kernel number per spike and kernel size. These components are dependent on genetic factors and on growing conditions during the season, especially between Z39 and Z71 (Fig. 1) when setting number and potential size.

Poor conditions during a 30-day period leading up to flowering and until the start of grain-filling will decrease kernel number per spike (Z39 to Z71, Fig. 1). Lower spike densities can be compensated to a certain extent by a higher kernel number per spike. Kernel size is determined by the duration of grain filling (*ie.* green leaves, Fig. 5) and the potential size laid down through cell division during kernel growth following fertilisation (Fig. 1). This potential size seems to increase with the amount of reserves stored in the stem in the period prior to grain-filling when stem elongation is ceasing, that is, shoots without an actively growing sink.

Nitrogen and protein

The aim of nitrogen management for high yields with low lodging risk is to restrict tillering and early growth as indicated above. Tillering can be kept low by providing enough nitrogen at sowing to reach a target of 600-800 shoots/m^2, ideally not more than 1000 (*eg*. Fig.9), and have 500-600 spike-bearing shoots surviving. This would mean only applying up to 60 kg N/ha before sowing on paddocks with low fertility. Topdressing is then required between start (Z30) and mid-stem (Z32) elongation (Fig. 1) to be applied before rain or first irrigation as was determined in the irrigated wheat studies of the eighties[10]. Earlier topdressing would be required if shoot density is well below target. The low sowing rate treatment in the Arrivato trial below, for example, still reached a yield of 9.6 t/ha with topdressing at Z32 on 590 shoots/m^2

[10] Field Crops Research, 33:37-56, 1993

(Table 5). The aim is to have no more than 70% ground cover at Z30 (see canopy closure). Very late topdressing until flowering with 30 to 40 kg N/ha may be used to increase grain protein content and help secure a quality grade. Irrigation allows effective topdressing before or during watering, which may increase the percentage of N taken up.

Table 5 presents results of a nitrogen trial with durum Arrivato with the nil topdressing treatment (000) yielding 7.3 t/ha with 8.5% protein for the 30 kg N/ha at sowing resulting in 760 shoots/m^2. The first topdressing of 60 kg N/ha at Z32 (N00) was immediately followed by the first spring irrigation and thus increased yield to 9.1 t/ha with 8.8% protein. Another 40 kg N/ha with the next irrigation at early flowering, Z63 (N0N), raised the yield to 9.7 t/ha with 10.4% protein. Delaying the first topdressing till late boot stage, Z46 (0N0) with rain, yielded 8.3 t/ha with 12.0% protein, a loss of 0.8 t/ha following the 3-week delay in topdressing for a 3.2% protein gain. The delayed topdressing, followed by the second topdressing of 40 kg N/ha at Z63 (0NN), only increased yield and protein by a small amount. Figure 11 shows these topdressing treatments and the control without topdressing. Another N0N treatment was included with a 60 kg/ha sowing rate (Table 5) which attained 590 shoots/m^2 at Z30. Results were not significantly different from the comparable N0N treatment with 100 kg/ha sowing rate, again affirming success with low sowing rates.

Table 5. Grain yield, total dry matter, harvest index, N harvest index, N uptake, protein, screenings, kernel weight and kernel number of nitrogen treatments for Arrivato sown 20 May 2004 at Griffith NSW.

	treatment	000	N00	N0N	N0N	0N0	0NN	s.e.	Treatment	C.V. (%)
Grain yield (g/m^2)		726	911	968	959	827	881	38	**	4.3
Total dry matter (g/m^2)		1890	2093	2159	2120	1977	2065	87	ns	4.2
Harvest Index (%)		38	44	45	45	42	43	1.4	**	3.4
N harvest index (%)		85	83	86	87	85	86	2.8	ns	3.2
N uptake (kg/ha)		118	155	188	188	188	206	12.7	**	7.3
Grain protein (%)		8.5	8.8	10.4	10.6	12.0	12.5	0.7	**	6.6
Screenings (%)		1.9	2.6	2.8	3.4	3.5	3.4	0.4	*	14.0
Kernel weight (mg)		54.4	55.6	57.7	58.7	58.6	58.9	1.2	**	2.2
Kernel number (*1000/m^2)		13.4	16.4	16.8	16.3	14.1	15.0	0.9	**	5.7
Nitrogen applications:		1-sowing, 2-2nd node, 3-late boot, 4-early flowering								
1. 20-May	Z00	30	30	30	30	30	30			
2. 26-Aug	Z32	0	60	60	60	0	0			
3. 16-Sep	Z46	0	0	0	0	60	60			
4. 30-Sep	Z63	0	0	40	40	0	40			
	Total N fert. (kg/ha)	30	90	130	130	90	130			
	sowing rate (kg/ha)	100	100	100	60	100	100			

**P<0.01. *P<0.05. ns, not significant

So how were these differences in yield achieved? There were no differences in spike densities as they had already been set around 475 spikes/m^2 before the first topdressing at Z32 (see Fig. 1). The main difference was in the higher number of kernels per spike for the three treatments that received nitrogen at Z32, just before rapid spike growth started rather than at Z46 when it was nearly finished (Fig. 1). This resulted in some 16,500 and 14,500 kernels per square meter, respectively, both with similar kernel weights around a mean of 57.9 mg (Table 5). The nil treatment had both lower kernel number and weight.

What about topdressing around flowering to increase protein? In the Arrivato trial of Table 5 this strategy of topdressing at Z63 raised yields by about 0.5 t/ha and protein by 0.5 and 1.6% compared to late (Z46) and early (Z32) previous topdressing, respectively. These protein increases to 12.5% and 10.4%, respectively, failed to reach a better quality grade and the biggest increase was for the lower protein, highest yielding treatment. Increases of protein for Chara in various project trials on station and farms were between 0.5 and 1.6% for topdressing 30-40 kg N/ha near flowering. Protein increases of 2% have been regularly achieved by supplying 35 kg N/ha with lateral-move irrigator around flowering (M. Colbert, personal communication). Foliar application of nitrogen seems to be more efficient but was not able to be confirmed in this project due to trial failure. Following rule of thumb is to calculate the likely increase in grain protein. For example, for a 30 kg N/ha application and the assumption of 50% uptake (N in spray irrigation may be 80%) gives a 30*0.5*5.6=84 kg/ha protein increase or 1.4% (=84/6000) to 1% (=84/8000) for estimated grain yields between 6 and 8 t/ha, respectively.

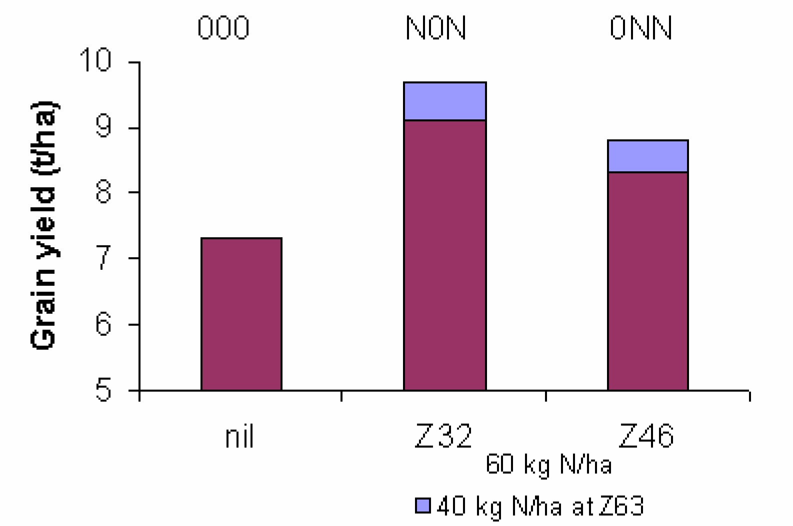


Figure 11. Yield response of first topdressing 60 kg N/ha at second-node (Z32, N0N) or late boot (Z46, 0NN) stage followed by second topdressing of 40 kg N/ha at early flowering, Z63, for Arrivato sown on 20 May 2004 at Griffith NSW. Yield l.s.d. is 0.6 t/ha.

Variety choice does make a difference in attaining a certain protein target under identical nitrogen management practices. Table 2 showed that over the nine core trial years the two durum varieties, especially Bellaroi, had a significantly higher protein than the hard wheats. A biscuit wheat line not shown had the lowest protein at 10.6%. The research during the eighties showed a 1.5 to 2% increase in protein for hard wheat Yecora compared to biscuit wheats Egret (see footnote 5) and Corella (see footnote 10).

Nitrogen uptake – The total nitrogen uptake for the topdressed treatments of the Arrivato trial (Table 5, Fig. 11) was around 200 kg/ha with some 180 kg/ha, or 87%, ending up in the grain; this is the HI of nitrogen (NHI). This is very high as typical values for wheat are around 80%. Total uptake for the 100 kg/ha sowing rates in the sowing rate trials was similar (Fig. 12), but the NHI was only 74% with total drymatter in both cases at around 20 t/ha. Durum therefore may not use more N to obtain the higher proteins as in Table 2, but may translocate more of the nitrogen taken up to the grain.

Figure 12 shows average nitrogen uptake in the sowing rate trial of 2004 (Table 4) at mid-stem elongation (Z32), very early milk stage (Z72) and maturity (Z87), with time of topdressing (N), irrigations (I, refill point 75 mm) and anthesis (Z65) given. It shows the efficiency for the low sowing rates with nitrogen uptake till Z32 almost halved and uptake rate during stem elongation remaining less than the typical 3 kg N/ha/day of the other densities that reached canopy closure at or before Z30, but yielding similar at around 8.4 t/ha (Table 4). The average for all densities was around 147 kg N/ha in the grain, a NHI of 80 (low rates) to 74% (medium/high rates). The two higher densities in Figure 12 lost some nitrogen during grain-filling which had been taken up, but couldn't reach, or wasn't needed by the grain, common to high yielding crops under irrigation (see footnote 5). Final total drymatter was about 20 t/ha but was achieved differently, increasing between Z32 and Z72 from 1.1 to 11.2 t/ha for low and from 2.5 to 15.4 t/ha for medium-high.

With the "source"-"sink" imbalance also comes inefficient nitrogen use in early sown crops. The NHI, which is the nitrogen removed in the grain as protein, can be as low as 54% for early April sown late maturity varieties (see footnote 5).

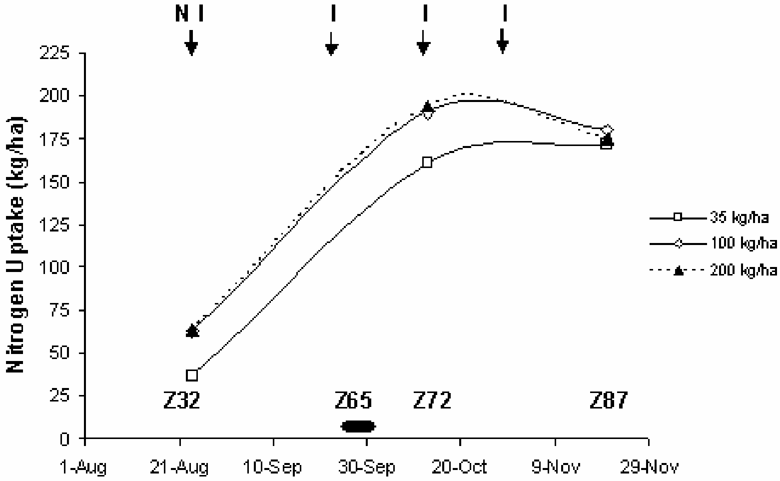


Figure 12. Average nitrogen uptake of three varieties for three sowing rates sown on 20 May 2004 at Griffith NSW and yielding ~8.4 t/ha, with timing of growth stages, topdressing (N) of 60 kg N/ha and irrigations (I).

Chara farm crops – On-farm nitrogen trials on a commercial scale were conducted on Chara paddocks during the three seasons at 8 to 18 farms across the Lachlan, Murrumbidgee and Murray valleys. Results were disappointing and only three trials in each of the seasons did achieve treatments with yields greater than 7 t/ha. Tight soils, irrigation timing and frequency, too much nitrogen too early, and dependence of nitrogen-topdressing on rainfall were major factors. The overall outcome showed a yield decline the earlier nitrogen was applied, especially pre-sowing. Table 5 presents for the three seasons mean grain yield and grain tests. Note the good grain quality in 2002 and the impact of weather damage in 2003. Two trials have been presented in *IREC Farmers' Newsletter Large Area,* Graham Menzies' 2003 crop at Willbriggie in no.166 and Mal Prichard's in 2004 at Hillston in no.169. They show the importance of topdressing at Z31 and timely irrigation before flowering following that topdressing as more nitrogen makes the crop thirstier.

The 2003 Willbriggie crop, 2nd wheat after rice, was topdressed with 58 kg N/ha at Z15 which resulted in a yield of 5.8 t/ha with 7.5% protein. Topdressing another 58 kg N/ha at Z30 lifted the yield to 6.8 t/ha with 8.7% protein, an extra return of 88 $/ha. Yield increased to 7.3 t/ha and protein to 9.7% with the 3rd topdressing at Z41, but this application had zero returns with the increases of 0.45 t/ha yield and 1.0% protein. The first impact on yield was tiller survival after the second topdressing at Z30 (Fig. 1). This lifted spike density from 480 to 530 per square meter from the approximate 850 shoots/m^2 established. Grain weight per shoot increased from 1.1 to 1.25 g/spike. Number of green leaves per shoot was affected by stripe rust and restricted further weight gains despite an extra irrigation at Z75 in the high nitrogen treatment.

A trial in the Murray Valley on a red clay loam following canola (-wheat-chickpeas) was sown 5 May 2004. It yielded 6.2 t/ha with 9.2% protein from about 800 shoots/m^2 with 58 kg N/ha pre-sowing. Topdressing treatments with 58 kg N/ha at either Z31, Z32 or both increased spike number from 480 to 540 per square meter, and raised yields by 25 percent to 7.7 t/ha. Grain protein for the treatment with two topdressings was increased from 9.7 to 10.5%.

Eight Tonne challenge – The Eight Tonne Club was started in 2002 and a feature about management factors has since been published in Primefact 197 (see footnote 4). Many of the factors for achieving eight tones per hectare were also obtained from this study. The nitrogen management rules, however, have not been confirmed by outcomes in the field. The last topdressing for yield at flowering was questioned at the launch in 2002. In irrigated nitrogen-topdressing experiments Tony Fischer had shown yield responses and 8 t/ha yields for topdressing until Z32 with lower responses thereafter (see footnote 10). This was confirmed in the current studies with substantial yield loss when delaying topdressing even from Z32 to Z46 (Table 5, Fig. 11). This rule for the Club has since been revised to "between head emergence

(Z50) and flowering" and is still based on evidence of yield responses to late applied nitrogen for crops from John Angus and John Lacy[11]. However, their only irrigated crop yielded the highest at 8.2 t/ha with topdressing at tillering. Their three dryland crops topdressed at flowering yielded about 7 t/ha and were only significantly different from applied nitrogen at sowing.

Other nutrients – Leaf tissue tests for 15 nutrients were done in 2003 on leaf 5 as the youngest emerged for 7 Chara treatments spread over Griffith, Benerembah, Deniliquin, Coleambally and Kerang. Results showed the N status was normal to high as expected for the treatments chosen. Several other nutrients were slightly low to very low even though a pre-season soil test had rated them satisfactory or optimal. Chara on the Coleambally Demo Farm, for example, showed problems with availability of magnesium, boron, copper and molybdenum where a soil test for magnesium had been optimum and for copper satisfactory. These nutrients were applied over a strip by helicopter in recommended amounts at Z30. This strip at Coleambally never became visible and yield differences were not detectable with the yield monitor at harvest. Four of the seven treatment samples indicated that chloride content was high, above 1% up to 1.5%. More research is required to see whether nutrients are limiting high yields and the connection with soil or tissue tests.

Irrigation

Demand – Well managed irrigated wheat crops may have a water use efficiency (WUE) of around 15 kg/ha/mm. That is, the amount of water, rainfall and irrigation used by the crop over the season to produce grain. Best results are achieved with adequate subsoil moisture at sowing through a pre-sowing irrigation if necessary. All core trials received a pre-sowing irrigation and the following number of spring irrigations, in the order of year, 5, 4, 4 for Griffith, 2, 1, 2 for Benerembah and 1, 2, 3 for Deniliquin. Their typical irrigation applications were 0.8, 1.25 and 1.0 ML/ha, respectively. Including the seasonal rainfall for each site (see for Griffith Appendix 2) and discounting any soil water left at harvest, WUE for average yields was around 14 kg/ha/mm for 2002 and 2004 and 11.5 kg/ha/mm for 2003, the year with (above) average rainfall and the greatest effects from lodging. This indicates that rainfall may be at the wrong time and may not be stored in the soil profile, thus being unavailable to the crop. Average WUE for Benerembah was 14.7, for Griffith 12.9 and for Deniliquin 12.5 kg/ha/mm. With maximum yielding varieties in each site-year the mean WUE was 17 kg/ha/mm, from around 16 kg/ha/mm for Griffith and Deniliquin to almost 19 kg/ha/mm for Benerembah.

When effective ground cover had been reached, Griffith was irrigated if the accumulated water deficit, the daily difference between potential evapotranspiration (ETo, *Water Watch*) and rainfall, had reached 80 mm. The number of irrigations depends on seasonal rainfall, water demand (*ie.* ETo) and the plant-available water holding capacity of the soil. Examples here are for an average soil with 150mm plant available water (*eg*. Griffith) and irrigated at 50% depletion. Typical soils vary around this average from 200mm (grey-cracking clay; *eg.* Benerembah) to 100mm (duplex clay). The latter entails a doubling of irrigations to get similar results but experience shows high yields will be less likely because of the tight soil.

The average seasonal water deficit, the difference between average ETo and rainfall, over May to October was 643 (2002), 332 (2003) and 475 (2004) mm, compared with 303 mm for the long-term average (Appendix 2). Hence, the 2002 deficit was more than twice the 44-year mean for Griffith. The evaporative demand was 39, 7 and 14% higher than average in 2002, 2003 and 2004, respectively. Increased occurrence of wind was one contributing factor, as daily wind-run increased by 30, 25 and 13%, respectively. Over time wind has been increasing on the plains, with a 10% increase between the mean of 1962-81 and 1982-2006 for the CSIRO Griffith weather station. This is worrying for spring irrigation. However, September and October wind-run in lodging-year 2003 was generally better than for the other two years (Appendix 2). The significant lodging event with the 3rd irrigation at Griffith on 29 October was associated with a daily wind run of 372 km/day that day (you can't stop the water when wind

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[11] Farming Ahead, no.129, September 2002

starts!). Windy conditions though were avoided several times at Griffith because of likely lodging (Fig. 6). However, this may not be possible with an irrigation rotation on a farm and some paddocks are therefore likely to lodge unless canopy management had been applied to lower the risk. NB: comparison between means for the two 20-odd year periods showed increases for maximum temperature (1.7%), solar irradiance (6.6%; solar energy), ETo (2.7%) and wind run (10.5%), and decreases for minimum temperature (-1.9%) and rainfall (-1.3%), with the means for the whole period listed in Appendix 2.

Canopy management, as described above, gives management options for reducing lodging risk. Lodging damage during irrigation can be minimized by keeping periods with a saturated top soil as short as possible. Surface drainage following irrigation is therefore important. On soils where this is difficult raised beds could be used to minimize occurrence of saturated top soil. Duration of irrigation is also an important factor which may also need to be shortened (with increased head) to obtain a better water use efficiency, making water available to the root zone only (see your irrigation officer).

First irrigation – When aiming for 7-8 t/ha, it is important to irrigate during the critical period of stem elongation to prevent water stress. Crop height can be an indicator of yield potential, as important yield determining processes take place simultaneously with stem elongation (Fig. 1). During that critical period, between the start of stem elongation (Z30) and grain filling (Z71), tillers are becoming spike-bearing shoots and the size of spikes is being determined through numbers and potential size of kernels. The latter process starts at full flag leaf emergence and takes place concurrently with peduncle elongation, the stem between spike and top node (Fig. 1). A short peduncle may indicate water stress in that period and therefore will also result in reduced spike size and potential yield. For example, the over 7 t/ha yields for experimental and farm Chara crops had average crop heights above 83 cm (up to 92 cm; Table 2) and a peduncle length greater than 33 cm. Yields of Chara were also reduced if the peduncle had the right length but plant height was shorter than 83 cm. This occurs if early nitrogen or water stresses shorten the lower stem internodes and reduce tiller survival (Fig. 1).

Timely irrigation is therefore important during this critical early-mid period of stem elongation if high yields are the target and irrigation water available. This critical period usually coincides with water becoming available for the first spring irrigation, the need for which is often greatly underestimated as crops generally look good coming out of winter and a soil surface regularly wet from a weekly shower. However, the crop then grows at full potential rates (Fig. 1), evapotranspires at potential rates when effective ground cover (>90%, see footnote 1) has been reached, uses stored soil water and can thus quickly run out of available water thereby reducing the attainable yield. The mean long-term ETo for September, for example, is 3.6 mm/day but was 5.6 mm/day in 2002 (Appendix 2). Therefore, be ready to irrigate the high yield potential paddocks first when water becomes available. This may be followed by 2 more irrigations to achieve the 7-8 t/ha.

That first irrigation can be delayed till heading stage when aiming for a 5-6 t/ha crop with a second irrigation likely after flowering.

Last irrigation – The average return from irrigation water could be 1.5 tonne of grain per ML supplied to the paddock, that is, 15 kg/ha/mm. Decisions on the requirement for a last irrigation during grain filling are dependent upon the status of the crop, availability and price of water, soil moisture status in relation to recent and forecasted rainfall, and expected price of grain. Maximum yield is likely to be attained with some water from the last irrigation remaining in the root zone as was the case for the full-irrigation management at Griffith. This made WUE for Griffith lower than for Benerembah. Also a problem in trials with a range of maturities, as the last irrigation was not necessary for the earliest flowering varieties in Griffith. Theoretically, under average conditions and with no rainfall a last irrigation would be given at Z83, Z82 and Z81 for the 100, 150 and 200 mm plant available water profiles. However, don't irrigate when there is less than 1 green leaf per shoot left, that is, the flag (Fig.5). A water deficit at maturity, Z86 (Fig. 2, Appendix 1), beyond the amount required at refill point would mean the start of a yield loss. However, this could be the best commercial outcome with least risk, best returns and highest WUE.

Plant growth regulators

Plant growth regulators (PGR) are used extensively oversees to avoid lodging in high yielding cereals. Their use often returns grain yields greater than just that lost through lodging, as carbohydrates that are spared from shortened stem are used productively elsewhere *(ie*. sink size, roots). Cycocel and Ethrel had been evaluated in southern N.S.W. during the eighties and were found not to increase yield in high yielding irrigated wheat (see footnote 5). These were used again at Griffith in 2002 on five weak-strawed varieties: H45, Hybrid Mercury, Diamondbird, Sunvale and Wylah. Again they failed to show yield benefits even though average lodging score for best treatment was reduced from 19 to 5; the most lodged variety, Sunvale, from 43 to 12. This confirmed previous research outcomes for some current varieties. Moddus©, a new product used oversees, was evaluated in 2003 and 2004 on H45, Drysdale and Chara (improving in genetic stem-strength), by itself and in combination with Cycocel (780 g/l Chlormequat) and Ethrel. These were compared with the best treatment of 2002 with 'old' PGR. The results of this study showed an inconsistent and variable outcome between years and varieties (Table 6). Chara was the variety with the best stem and anchorage strength and always lodged less and later.

Average yields for the non-sprayed control were around 6.8 and 8.2 t/ha for 2003 and 2004 seasons with average lodging score of 52 and 19, respectively (Table 6). The most effective treatment of 2002 is shown in Table 6 as treatment 5. In the lodging year 2003 treatment 5 did show significant yield increases of 1 t/ha for H45 and Chara, but only 0.1 t/ha for Drysdale. Lodging scores for the varieties in 2003 were similar to control (60, 27 and 68, respectively), but started later, and crop height was reduced by 11 to 14 cm. It again showed no yield response in 2004 while lodging score was reduced by 0 to 16 with similar height reductions as in 2004. However, there was a Moddus© treatment with a 0.7 t/ha yield increase.

Table 6. Grain yield, crop height and lodging for three varieties sown 28 May 2003 and 20 May 2004 with four growth regulator treatments at Griffith N.S.W..

	Yield (t/ha)		Height (cm)		Lodging score	
	2003	2004	2003	2004	2003	2004
	Variety effects					
H45	6.6	8.1	98	82	62	16
Drysdale	8.0	8.2	103	86	57	14
Chara	7.1	8.3	93	82	21	1
l.s.d. (P=0.05)	0.3	0.6	2	3	7	7
	Growth regulator effects					
1. Control	6.8	8.2	102	92	52	19
2. Moddus 0.4 l/ha Z30	6.8	8.9	100	89	49	13
3. Moddus 0.2 Z25 and Z31 plus Cycocel 1.25 Z31	7.7	8.0	96	73	32	1
4. Moddus 0.4 l/ha Z30 and Ethrel 1 l/ha Z41	7.2	7.6	97	79	40	8
5. Cycocel 2 l/ha Z30 and Ethrel 1 l/ha Z41	7.6	8.2	91	79	47	9
l.s.d. (P=0.05)	0.4	0.8	2	4	9	10
	Protected from lodging and leaf diseases					
H45 [A]	9.6	9.8	99	92	0	0

[A] lodging protection with raised mesh wire

The Table shows that best results in 2003 and 2004 were for Moddus© treatments 3 and 2, respectively, with no response in the other year. In 2003 treatment 3, the split application of 0.2 l/ha at Z15 and Z31 (Fig. 1) increased yield by an average of 13%, that is, 1.1, 0.9 and 0.6 t/ha for H45, Drysdale and Chara, respectively, with final lodging halved and crops 4 to 9 cm shorter. This split application in 2004 had a yield response of +0.1 to –0.5 t/ha compared to control. In 2004 it was treatment 2, the single application at Z30 with the same total amount of

Moddus©, that increased yield by an average of 9%, that is, 0.2, 0.8 and 1.1 t/ha for H45, Drysdale and Chara, respectively. Change in crop height of –9, –3 and +3 cm for H45, Drysdale and Chara, respectively, was then inversely related to yield response. However, treatment 2 had the same average yield as control in 2003 (Table 6).

These and similar results of other recent trials in the Southern Region add to the complexity of PGR use in our environment. There's not a single treatment that shows consistency. The new product, for example, seems to create nil or negative results when plants experience stress at application time, such as frost or water stress. The dependency on specific outcomes for varieties and seasonal factors seem to make the use of PGR unwarranted.

Fungicides

Green leaf area duration is important for high yields and protection by fungicides can be profitable when properly timed. A trial with H45 and Chara was conducted in 2003 and 2004 at Griffith to evaluate five products. One H45 treatment was protected from leaf disease, by applications of Tilt followed by Amistar Xtra©, and lodging, by shoots growing through raised mesh-wire. The Amistar treatments were applied just after Z39 to protect the flag leaf. Other treatment sprays were applied when stripe rust first became visible on more leaves on some plants (*eg*. 'hot spot'). All other trials at Griffith were protectively sprayed with Tilt.

Stripe rust was severe in 2003 and started on H45 in mid-September and on Chara a month later with Z65 occurring on 30 September for H45 and 11 October for Chara. A single application on 26 September significantly increased yield for Chara from 7.5 to 8.1 t/ha and for H45 from 6.0 to 7.5 t/ha. However, these H45 treatments lodged 67% while the disease and lodging protected treatment yielded 9.6 t/ha.

In 2004 stripe rust appeared only by mid-October on H45 and three weeks later on Chara with Z65 occurring on 26 September for H45 and 3 October for Chara. Single fungicide treatments increased yields by 0 to 0.6 t/ha with no treatment significantly different from non-sprayed control of 8.6 t/ha for H45 and 9.6 t/ha for Chara. The application of 400ml Amistar Xtra © kept the yield for H45 at 8.6 t/ha as lodging prevented the use of the extended green leaf area duration. However, the lodging protected treatment sprayed with Amistar Xtra© yielded 9.8 t/ha. Yield for Chara increased from 9.6 to 10.2 t/ha with Amistar Xtra©.

Grain quality

Grain testing of project samples by Dr Helen Allen and Jennifer Pumpa at the NSW DPI ARI Wagga Wagga gave results of genotypes in the core trial across different environments and of varieties across different management practices. A summary for leading varieties used in this studies' core trial was shown in Table 2. The 9-trial average protein for many prime hard and durum varieties was above 11%.and 12%, respectively. Topdressing before flowering in these trials may have achieved more prime hard (>12%) and ADR1 (>13%) results.

Growing conditions under irrigation seem conducive to Late Maturity Alpha-Amylase (LMAA) development and the resulting low Falling Number (FN). Problems with low FN were very variable in 2004 between trial replicates at the Griffith (core) and Benerembah (core and NSW DPI) genotype evaluation trials with 46% and 22% of entries below the 350 seconds standard, respectively, with no apparent weather damage events caused by rain. This increased to 85% with rain-induced weather damage at Deniliquin for the same set of 54 core trial genotypes.

Dough quality tests were done for Chara samples with a range in FN from 150 to 500, selected from various experiments and trial sites[12]. Milling the Chara samples was not effective in removing the alpha-amylase as FN remained low in the flour of those with LMAA. However, samples with LMAA and appropriate protein did not appear to show any detrimental effect on the dough quality parameters measured. Only those Chara samples with low FN caused by weather damage had quality defects. Given these results, careful thought needs to be given to LMAA testing at silos because of its extreme variability and inconclusive impact on

[12] H.M.Allen, J.K.Pumpa, and M.Stapper, 2005, *LMAA and wheat quality*. 55th Cereal Chemistry Conf., Sydney

dough quality when it is not caused by weather damage. Generally FN was higher and more stable for more and later N application.

Conclusions

The core trial was done at three representative sites covering three years (2002 hot, 2003 average, 2004 'cool'). Using a well-aerated soil with good organic carbon content is the required foundation for consistent achievement of high-yielding wheat crops. A mean water use efficiency (WUE), the return of grain per mm rainfall and irrigation, of 17 kg/ha/mm was achieved with cultivars growing maximum yields across all site-years. Top yields for non-lodging and disease protected crops of Chara (10.2 t/ha) and H45 (9.6, 9.8 t/ha) again show the yields that are attainable with full irrigation. Varieties have not improved since the eighties and breeding for high-yielding irrigation is required to increase yields with, for example, a better adaptation to lodging conditions through improved stem and anchorage strength. Results with plant growth regulators were not consistent between years and varieties, and thus did not seem feasible as a management tool. Very low sowing rates or wider row spacing and deeper sowing may be used in management to lower lodging risk and achieve consistently high yields. The results show that a timely single fungicide spray can give good returns. Knowledge of crop development is important for effective and profitable management of high-yielding crops. Crop monitoring and growth stages for wheat are featured in another document.

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How does this plant develop Maarten **?**

See ICF website: ***Crop Monitoring and Growth Stages for Wheat***

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Appendix 1. Crop Growth Stages for Cereals

Adapted Zadoks Decimal Code – **Zxx** (also DCxx, Dxx or GSxx)

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0 Emergence

00 Dry seed sown
01 Seed absorbs water
03 Germination, seed swollen
05 Radicle emerged from seed
07 Coleoptile emerged from seed
09 Leaf at coleoptile tip
10 First leaf through coleoptile and tip visible

1 Seedling growth

11 1st leaf more then half visible
12 2nd leaf more then half visible
13 3rd leaf more then half visible
14 4th leaf more then half visible
19 6th leaf more then half visible
17 7th leaf more then half visible
18 8th leaf more then half visible
19 9 or more leaves visible and stem not elongating.

2 Tillering

20 Main shoot only
21 Main shoot and 1 tiller
22 Main shoot and 2 tillers
23 Main shoot and 3 tillers
24 Main shoot and 4 tillers
25 Main shoot and 5 tillers
26 Main shoot and 6 tillers
27 Main shoot and 7 tillers
28 Main shoot and 8 tillers
29 Main shoot and 9 or more tillers

3 Stem elongation

30 stem starts to elongate, 'spike at 1cm'
31 swelling 1st node detectable
32 swelling 2nd node detectable
33 swelling 3rd node detectable
34 swelling 4th node detectable
35 swelling 5th node detectable
36 swelling 6th node detectable

4 Flag leaf to Booting

37 Flag leaf tip visible
38 Flag leaf half visible
39 Flag leaf ligule just visible
41 Early boot, flag sheath extending
43 Mid-boot, boot opposite ligule of 2nd last leaf
45 Full-boot, boot above ligule of 2nd last leaf
47 Flag leaf sheath opening
49 First awns visible

5 Heading

51 10% of spikes visible (ear peep)
52
53 30% of spikes visible
54
55 50% of spikes visible
56
57 70% of spikes visible
58
59 90% of spikes visible
60 Whole spike visible, no yellow anthers

6 Flowering (anthesis)

61 Early– 20% of spikes with anthers
62
63 30% of spikes with yellow anthers
64
65 Mid– half of spikes with anthers
66
67 70% of spikes with anthers
68
69 Late– 90% of spikes with anthers

7 Kernel and Milk development

70.2 Kernels middle spike extended 20%
70.5 Kernels middle spike half formed
70.8 Kernels middle spike extended 80%
71 Watery ripe, clear liquid
73 Early milk, liquid off-white
75 Medium milk, contents milky liquid
77 Late milk, more solids in milk
79 Very-late milk, half solids in milk

8 Dough development

81-85 spikes turn colour from light-green to yellow-green to yellow
81 Very early dough, more solids and slides when crushed
83 Early dough, soft, elastic and almost dry, shiny
85 Soft dough, firm, crumbles but fingernail impression not held
87 Hard dough, fingernail impression held, spike yellow-brown
89 Late hard-dough, difficult to dent

9 Ripening

91 Kernels hard, difficult to divide by thumb-nail
92 Harvest ripe, kernels can no longer be divided by thumb-nail and straw still firm
93 Kernels loosening in daytime
94 Over-ripe, straw brittle

APPENDIX 2. Weather data for CSIRO Griffith N.S.W. with long-term mean for 1962 to 2006

	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	May-Oct.[A]
					Maximum temperature (^oC)					
Mean	23.4	18.6	15.3	14.5	16.4	19.4	23.1	26.9	29.9	17.9
1983	20.3	17.9	13.6	13.1	16.4	20.0	23.6	26.2	31.0	17.4
1984	23.0	19.4	17.2	13.4	16.0	16.7	22.8	27.3	28.6	17.6
1985	22.9	18.9	14.7	15.0	15.4	18.2	22.9	26.0	26.8	17.5
2002	25.8	19.2	15.9	16.5	18.1	21.3	24.5	29.7	31.4	19.3
2003	24.1	19.9	15.5	15.4	15.4	19.4	20.5	28.3	32.0	17.7
2004	24.6	18.0	15.2	13.8	16.8	19.6	24.9	27.4	29.7	18.0
					Minimum temperature (^oC)					
Mean	9.1	6.3	4.0	3.0	3.8	5.7	8.6	11.6	14.2	5.2
1983	8.1	8.0	3.5	2.7	4.8	6.2	8.4	11.4	15.2	5.6
1984	9.1	4.4	1.7	3.7	5.4	4.9	7.8	12.5	12.9	4.7
1985	10.2	6.3	2.7	1.2	4.4	4.2	9.9	12.5	13.4	4.8
2002	10.8	5.5	4.3	1.9	2.1	5.7	7.8	12.3	14.2	4.6
2003	9.8	6.0	5.2	3.2	3.2	4.7	6.5	11.0	15.9	4.8
2004	9.0	3.7	4.7	2.3	3.8	5.1	8.5	10.8	13.6	4.7
					Mean temperature (^oC)					
Mean	14.7	10.1	8.1	8.7	11.9	16.2	20.8	25.0	27.0	12.6
1983	13.6	9.6	7.6	8.8	11.3	17.0	18.7	24.0	26.1	12.2
1984	13.9	11.2	8.9	7.7	11.7	14.9	22.8	27.5	30.3	12.9
1985	17.4	11.2	9.7	10.6	11.9	18.2	21.2	25.6	25.6	13.8
2002	15.8	10.5	8.4	10.0	13.9	17.3	23.3	24.8	25.8	13.9
2003	14.4	10.5	7.7	9.3	11.7	16.8	20.0	24.9	26.1	12.7
2004	14.8	10.7	8.0	8.1	11.6	15.7	21.7	24.0	25.6	12.6
					Rainfall (mm)					
Mean	31	37	36	34	37	37	42	29	29	223
1983	75	46	23	45	56	25	22	39	131	216
1984	60	1	0	83	36	32	33	37	6	185
1985	47	28	23	14	62	29	65	43	65	222
2002	8	27	22	6	5	27	0	5	20	87
2003	10	21	29	58	62	16	45	27	47	231
2004	18	25	32	18	29	13	12	44	21	129
					Potential evapotranspiration (mm/d)					
Mean	3.8	2.1	1.5	1.6	2.5	3.8	5.6	7.6	8.9	526
1983	2.9	1.7	1.0	1.3	2.0	3.6	4.5	6.4	7.9	423
1984	3.2	1.9	1.6	1.4	2.4	3.0	5.1	7.3	8.6	462
1985	3.4	2.1	1.2	1.6	1.9	3.4	5.5	6.7	6.8	471
2002	4.7	2.4	1.9	2.6	3.5	5.6	7.8	9.3	10.1	729
2003	4.3	2.5	1.9	1.9	2.6	4.3	5.2	8.0	9.2	562
2004	4.5	2.5	1.7	1.7	3.0	3.9	6.8	7.7	8.9	602
					Wind run (km/d)					
Mean	141	135	145	148	168	181	189	197	201	161
1983	108	105	100	120	118	154	123	153	171	120
1984	99	79	97	128	162	142	145	165	180	126
1985	114	94	83	103	126	130	184	152	143	120
2002	172	159	194	195	197	253	259	235	246	209
2003	189	148	202	187	221	237	213	186	198	201
2004	162	149	209	162	191	177	205	202	226	182
					Frosts (minimum screen temperature <2^oC)					
Mean	1	6	10	14	11	5	1	0	0	47
1983	0	1	8	14	6	2	2	0	0	33
1984	0	9	16	9	3	5	2	0	0	44
1985	0	6	12	19	7	8	0	0	0	52
2002	0	4	9	12	19	4	0	0	0	48
2003	0	5	5	12	14	8	1	1	0	45
2004	0	8	7	12	8	7	0	0	0	42
					Maximum temperatures above 30^oC					
Mean	0	0	0	0	0	0	2	5	10	2
1983	0	0	0	0	0	0	2	8	17	2
1984	1	0	0	0	0	0	2	7	9	2
1985	2	0	0	0	0	0	2	4	6	2
2002	3	0	0	0	0	0	5	15	18	5
2003	0	0	0	0	0	2	2	13	23	4
2004	3	0	0	0	0	0	3	9	15	3

[A] Seasonal total or average