How much does seed rate (changing from 50 to 400 plants/m^2) influence barley's performance?

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Key messages

- Sowing barley to establish 50 plants/m^2 (20 to 30 kg/ha) came with a yield penalty. In this study the yield penalty was at least 10% compared to sowing more than 100 plants/m^2 (seed rate of >45 kg/ha).
- Increasing the seed rate of barley by 10 kg/ha (~20 plants/m^2) or even 20 kg/ha (~40 plants/m^2) above current practice may increase grain yield but will not significantly influence grain quality.
- The grain yield response of varieties to increasing seed rate was generally similar; however the target density for each variety did differ when the effect of seed rate on grain quality was considered.
- The optimum plant population for grain yield in this study was 137 ± 9 plants/m^2, which is in line with the suggested target density for barley in Western Australia of 120 to 150 plants/m^2.
- A target density of 150 plants/m^2 is proposed for Bass, Flinders, Hindmarsh and La Trobe and 120 plants/m^2 for Baudin, Commander, Granger and Scope CL (= Buloke) in weed free or low weed burden situations with a yield potential above 1 t/ha.
- Feed barley should be sown to achieve more than 150 plants/m^2 to maximise yield and weed competitiveness.

Aims

Before the 1990s target plant populations of up to 100 plants/m^2 were commonly recommended when growing barley in Australia (Sparrow and Doolette 1975; Young 1995). Current recommendations suggest sowing barley to achieve an establishment between 100 to 180 plants/m^2 with different recommendations nationally and due to expected rainfall (Paynter and Fettell 2011).

A survey of 90 growers in 2013 indicated that the average seeding rate for barley in Western Australia was 64 ± 7 kg/ha (Paynter, unpublished), but only 15% of growers counted how many plants were actually established. Assuming 80% establishment and 98% germination, a seed rate of 64 kg/ha is equivalent to a plant establishment of 100, 112, 125 and 143 plants/m^2 for seed weights of 50, 45, 40 and 35 mg respectively (based on Table 1). The resulting establishment could therefore be at or below the current recommendation for barley in Western Australia, which is to target an establishment density of 120 to 150 plants/m^2 (Paynter *et al*. 1999; Russell *et al*. 2008 and 2009).

When questioned about what influenced their seeding rate decisions only one in five growers felt grain weight was important and only two in five felt germination per cent and variety had a strong influence on their seed rate decision. When questioned about the impact of seed rate, two thirds felt increasing their seeding rate by 20% would have no impact on their grain yield but would increase their screenings by 5 to 10%. There was a perceived nervousness about sowing barley at high seeding rates. Grower's reasoning was often that sowing barley light "*as it can stool better than wheat*" was better than sowing it heavy "*because grain yields go backwards and your grain quality is not suitable for delivery as malt barley if you do that*".

The aim of this study was to:

1. assess whether there is a yield penalty from sowing barley at low or high rates,
2. quantify the effect seed rate has on grain quality, particularly at high rates,
3. determine if varieties differ in their responsiveness to increasing seed rate, and
4. quantify the optimum plant population for sowing barley in Western Australia.

Table 1. Conversion of plant density to seed rate and vice versa.

	Target plant density (plants/m^2)					
	50	100	120	150	200	400
1000 seed weight	Seeding rate (kg/ha)					
35 g	21	45	54	67	89	204
40 g	24	51	61	77	102	233
45 g	27	57	69	86	115	262
50 g	30	64	77	96	128	292
germination per cent	98%	98%	98%	98%	98%	98%
establishment per cent	85%	80%	80%	80%	80%	70%

$$\text{Seeding rate} = \frac{(\text{1000 seed weight} \times \text{target density})}{(\text{germination \%} \times \text{establishment \%})}$$

Table 2. Trials details for the 24 barley agronomy variety by seed rate (V x SR) trials.

Site	Location	Sown (date)	May-Oct rainfall (mm)	Site mean yield (t/ha)	pH_{Ca} (0-10cm)	Soil type
12WH24	Wongan Hills	06-Jun-12	217	2.50	5.9	sand overlying lateritic gravel
12WH24	Wongan Hills	28-Jun-12	217	1.82	5.9	sand overlying lateritic gravel
12MR13	Merredin	09-Jun-12	136	0.69	5.7	red shallow loamy duplex
12NO24	Cunderdin	09-Jun-12	136	1.46	5.4	red loamy earth
12NO22	York	05-Jun-12	205	2.72	4.5	red shallow sandy duplex
12NO22	York	25-Jun-12	205	1.56	4.5	red shallow sandy duplex
12GS30	Katanning	25-May-12	274	4.20	5.0	brown shallow sandy duplex
12GS30	Katanning	28-Jun-12	274	3.21	5.0	brown shallow sandy duplex
12GS31	Kojonup-W	25-Jun-12	328	1.95	4.4	yellow-brown sand
12ED17	Grass Patch	09-Jun-12	117	2.66	8.2	alkaline shallow loamy duplex
12ED16	Wittenoom Hills	18-May-12	136	2.79	6.3	alkaline grey shallow sandy duplex
12ED16	Wittenoom Hills	18-Jun-12	136	1.68	6.3	alkaline grey shallow sandy duplex
13WH15	Wongan Hills	21-May-13	303	4.29	5.5	brown deep sand
13WH15	Wongan Hills	12-Jun-13	303	3.89	5.5	brown deep sand
13MR12	Merredin	22-May-13	224	3.25	4.8	red deep sandy duplex
13NO33	Cunderdin	29-May-13	263	4.80	5.3	yellow sandy earth
13NO31	York	15-May-13	261	5.50	5.5	brown loamy earth
13NO31	York	12-Jun-13	261	5.53	5.5	brown loamy earth
13GS32	Katanning	13-May-13	353	5.31	4.6	brown duplex sandy gravel
13GS32	Katanning	05-Jun-13	353	5.36	4.6	brown duplex sandy gravel
13GS33	Kojonup-W	04-Jun-13	401	4.62	4.8	brown duplex sandy gravel
13ED21	Grass Patch	02-May-13	224	2.89	7.1	alkaline shallow loamy duplex
13ED20	Wittenoom Hills	07-May-13	264	4.46	6.2	alkaline grey shallow sandy duplex
13ED20	Wittenoom Hills	28-May-13	264	4.53	6.2	alkaline grey shallow sandy duplex

Table 3. Average (± s.e.) plant height, lodging score, grain yield and grain quality for each variety.

Trait Variety	Plant height (cm)	Lodging (9-0)	Grain yield (t/ha)	Kernel weight (mg, db)	Hectolitre weight (kg/hL)	Screenings (%<2.5 mm)	Grain protein (%, db)	Grain brightness ('L*')
Bass	52 ± 3	8.5 ± 0.1	3.34 ± 0.30	39.1 ± 1.1	72.3 ± 0.4	16 ± 4	12.4 ± 0.6	60.9 ± 0.4
Baudin	49 ± 2	8.5 ± 0.1	3.29 ± 0.30	36.0 ± 1.0	71.0 ± 0.4	23 ± 5	11.9 ± 0.5	61.7 ± 0.4
Buloke	65 ± 3	7.2 ± 0.3	3.30 ± 0.31	40.1 ± 0.9	70.8 ± 0.4	24 ± 4	11.8 ± 0.5	61.0 ± 0.5
Commander	57 ± 3	7.5 ± 0.3	3.40 ± 0.29	36.9 ± 0.8	69.9 ± 0.5	20 ± 3	11.5 ± 0.5	61.9 ± 0.6
Flinders	50 ± 2	8.6 ± 0.1	3.54 ± 0.31	36.8 ± 0.8	71.9 ± 0.4	18 ± 3	12.0 ± 0.6	61.0 ± 0.4
Granger	57 ± 3	8.3 ± 0.2	3.35 ± 0.32	37.9 ± 1.0	71.4 ± 0.4	21 ± 4	12.2 ± 0.7	59.9 ± 0.4
Hindmarsh	56 ± 2	7.8 ± 0.3	3.63 ± 0.27	37.1 ± 0.7	71.4 ± 0.5	19 ± 4	11.6 ± 0.5	60.3 ± 0.6
La Trobe	53 ± 2	8.0 ± 0.2	3.59 ± 0.28	37.3 ± 0.8	71.5 ± 0.5	20 ± 4	11.4 ± 0.5	60.6 ± 0.6
Vlamingh	64 ± 3	8.2 ± 0.2	3.22 ± 0.30	36.3 ± 0.9	71.5 ± 0.5	17 ± 4	12.2 ± 0.6	61.6 ± 0.4
Wimmera	53 ± 2	8.1 ± 0.2	3.38 ± 0.32	37.3 ± 0.8	71.4 ± 0.4	22 ± 4	12.3 ± 0.7	61.6 ± 0.3

Method

This study was undertaken in 2012 and 2013. In each year a core set of 12 'malt' or food barley varieties were evaluated at eight locations (Wongan Hills, Merredin, Cunderdin, York, Katanning, Kojonup-W, Wittenoom Hills and Grass Patch) (Table 2). At four of those locations (Wongan Hills, York, Katanning and Wittenoom Hills) a seed rate trial was established at two different dates of seeding. The 12 varieties sown were evaluated for their response to four different seed rates (50, 100, 200 and 400 plants/m^2) at one level of nitrogen (N) application over three replicates. Trials were sown as a split plot cyclic design with variety as whole plots and seed rate randomised as subplots.

Nine malt barley varieties Bass, Baudin, Buloke, Commander, Flinders, Granger, La Trobe, Vlamingh and Wimmera and one food barley variety Hindmarsh were sown in all 24 trials. Compass (under malt evaluation), Henley (accredited malt variety) and Skipper (withdrawn from accreditation) were also sown, but not in all trials, and data on those three varieties is not presented in this paper.

Trials were established into predominantly canola stubble, but some sites were sown into fallow or lupin stubble, with small plot seeding equipment and harvested with small plot research equipment. An NPK compound fertiliser was banded below the seed and the trials were topdressed at sowing (in front of the seeder) with an additional NPK compound fertiliser supplying a total of 20 to 30 kg N/ha to low rainfall sites (Merredin and Grass Patch) and 50 kg N/ha to the medium to high rainfall sites. The seed rate (kg/ha) to establish the target densities of 50, 100, 200 or 400 plants/m^2 varied for each variety and year and was adjusted based on their kernel weight and germination per cent. A seed rate of 50 plants/m^2 = 20 to 30 kg/ha, 100 plants/m^2 = 45 to 65 kg/ha, 200 plants/m^2 = 90 to 130 kg/ha and 400 plants/m^2 = 205 to 295 kg/ha (Table 1).

Results are graphed against the measured establishment (determined 2 to 4 weeks after seeding, WAS) rather than against the target densities. Measurements included plant establishment (plants/m^2), NDVI score at 6 WAS, plant height (cm, base of ear), lodging score (9-0) close to harvest, grain yield (t/ha), kernel weight (mg, db), hectolitre weight (kg/hL), screenings (% < 2.5 mm), grain protein concentration (%, db) and grain brightness (Minolta ‘L*’).

Data was analysed within Genstat (VSN International 2013) with a block structure of (rep+colrep)/variety/seed rate and a treatment structure of variety x seed rate. The optimum plant population for grain yield was calculated for each site as per Paynter (2016) with the point of inflection at 1.5 kg/ha of grain for each extra established plant/m^2.

Table 4. Likelihood of variety, seed rate and their interaction being significantly different across the 24 seed rate trials. Significance: rarely = occurrence in ≤20% trials, occasionally = 20 to 40% trials, 50% chance = 40 to 60% trials, often = 60 to 80% trials and consistently = ≥80% trials significant.

Trait Variety	Plant height (cm)	Lodging (9-0)	Grain yield (t/ha)	Kernel weight (mg, db)	Hectolitre weight (kg/hL)	Screenings (%<2.5 mm)	Grain protein (%, db)	Grain brightness ('L*')
Variety (V)	consistently	often	50% chance	consistently	consistently	consistently	50% chance	consistently
Seed rate (SR)	consistently	50% chance	consistently	consistently	consistently	consistently	often	often
V x SR	occasionally	occasionally	rarely	50% chance	50% chance	50% chance	rarely	occasionally

Results

Site and variety

Growing season rainfall (May-Oct) ranged between 117 mm to 401 mm at each site (Table 2). The site mean grain yield ranged from 0.69 t/ha (Merredin 2012) to 5.53 t/ha (York 2013) with an average yield of 3.40 ± 0.30 t/ha. Grain quality was within the GIWA Barley Malt 1 limits for hectolitre weight ≥64 kg/hL and grain brightness ≥56 ‘L*’ and within Malt 2 limits for screenings ≤35% and grain protein between 9.0 to 12.8% with a few exceptions. High screenings (site average >35%) was present at Cunderdin 2012, Kojonup-W 2012 and Wittenoom Hills 2012. Low grain protein (site average <9%) was observed at Grass Patch 2013 and high grain protein (site average >12.8%) at Wongan Hills 2012, Merredin 2012, Cunderdin 2012, York 2012, Kojonup-W 2012 and Wittenoom Hills 2012.

Varieties differed in their plant height, lodging scores, grain yield and grain quality (Tables 3 and 4). Hindmarsh and La Trobe had the highest average grain yield across sites, closely followed by Flinders, with Vlamingh the lowest yield. Bass and Buloke had a higher average kernel weight than Baudin and Vlamingh (39 to 40 mg vs 36 mg). Bass had the highest average hectolitre weight and Commander the lowest (72 vs 70 kg/hL). Bass and Vlamingh had plumper grain than Baudin and Buloke (16 to 17% vs 23 to 24%). Commander had the brightest grain and Granger the darkest (62 vs 60 ‘L*’). These differences in grain quality influenced the success of each variety in meeting the GIWA Barley Malt 1 and Malt 2 standards (data not shown).

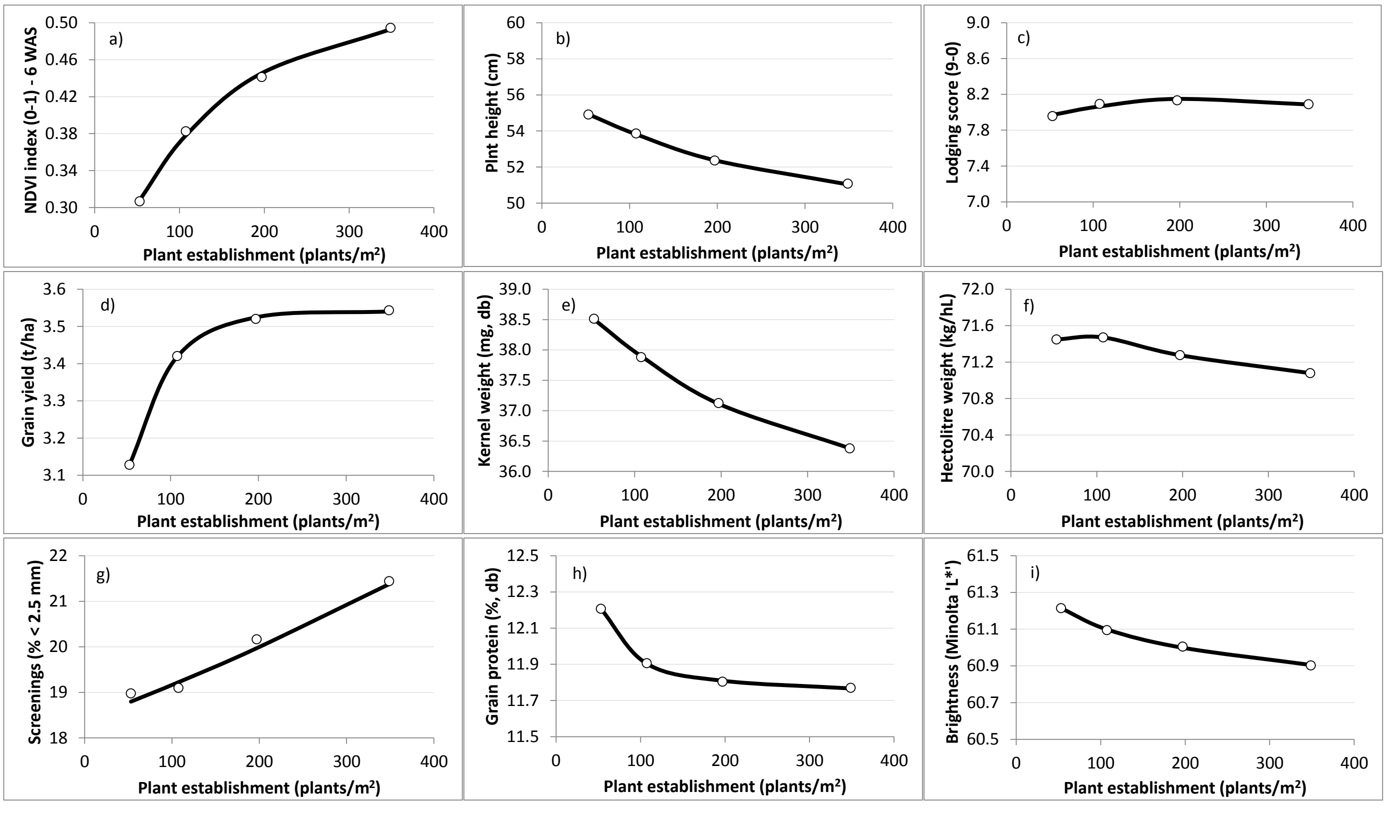

Figure 1. Average response of 10 barley varieties over 24 trials to increasing seed rate, a) NDVI – 6 WAS, b) plant height, c) lodging score, d) grain yield, e) kernel weight, f) hectolitre weight, g) screenings, h) grain protein concentration and i) grain brightness.

Seed rate

Seed rate consistently (in at least four out of every five trials) influenced early biomass, plant height, grain yield, kernel weight, hectolitre weight and screenings, but less frequently for grain protein and grain brightness (only two out of every three trials) and straw strength (only one in every two trials) (Table 4). Increasing seed rate (difference between 50 and 400 plants/m^2 treatments averaged across trials):

1. increased biomass at six weeks after seeding by 60% (Figure 1a),
2. decreased plant height by 4 cm with reductions of 5 to 7 cm in nearly 50% of trials (Figures 1b and 2b),
3. had no overall effect on straw strength or lodging resistance but occasionally improved it (Figures 1c and 2c),
4. increased grain yield by 15% before plateauing after 200 plants/m^2 (Figure 1d). The improvement in grain yield ranged from 0.2 to 1.4 t/ha, with a third of the observations between 0.2 to 0.4 t/ha (Figure 2d),
5. decreased kernel weight by just over 2 mg per grain with most reductions in kernel weight of 2 to 4 mg (Figures 1e and 2e),
6. decreased hectolitre weight by on average of 0.4 kg/hL with increases also noted in four trials (Figures 1f and 2f),
7. increased screenings on average by 2.5%. In one trial screenings increased by 11% and in another it decreased by 10% (Figures 1g and 2g),
8. decreased grain protein concentration before plateauing after 200 plants/m^2 (Figure 1h). In half the trials the decrease in grain protein ranged between 0.2 to 0.8% (Figure 2h), and
9. reduced grain brightness by just 0.3 Minolta 'L*' units across all trials but brightness did increase in three trials (Figures 1i and 2i).

The optimum plant population for grain yield ranged between 48 plants/m^2 (Merredin 2012) to 252 plants/m^2 (Kojonup-W 2013) with an average of 137 ± 9 plants/m^2. The optimum plant population for grain yield was not correlated with the site mean yield (data not shown).

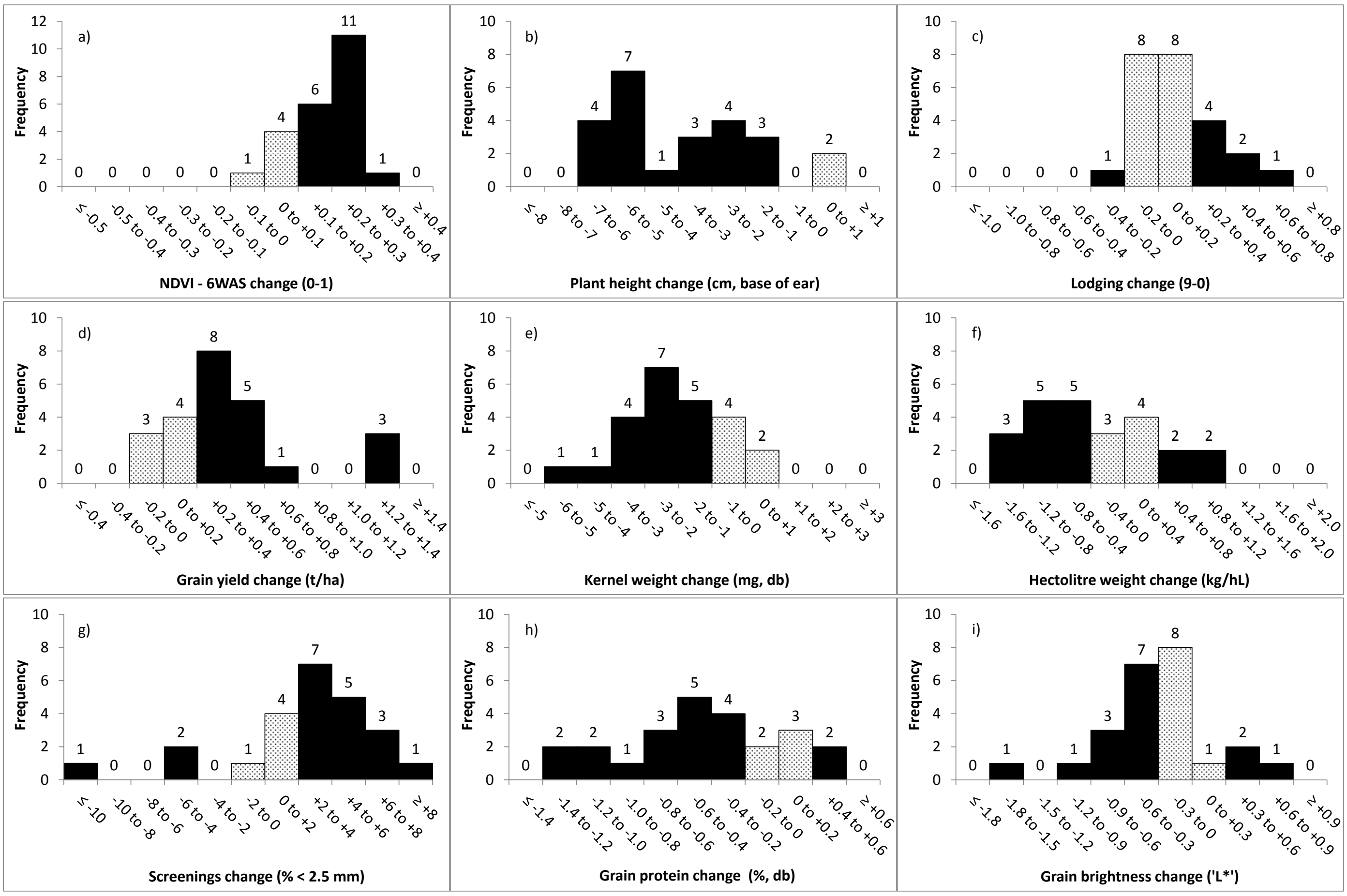

Figure 2. Change in the absolute value of a trait at 50 plants/m^2 versus 400 plants/m^2 averaged over the 10 barley varieties and expressed as a frequency of occurrence across sites, a) NDVI – 6 WAS, b) plant height, c) lodging score, d) grain yield, e) kernel weight, f) hectolitre weight, g) screenings, h) grain protein concentration and i) grain brightness. Bars adjacent to 0 (little or no difference) are highlighted.

Varietal interactions with seed rate

Despite differences in the plant type of the 10 barley varieties tested and their consistent response to seed rate, their plant height, lodging score, grain yield, grain protein and grain brightness responses were regularly the same (Table

4). That is, we observed V x SR interactions in less than one in four trials for plant height, lodging, grain yield, grain protein and less than two in five trials for grain brightness.

For NDVI at 6 WAS, kernel weight, hectolitre weight and screenings, however, we observed V x SR interactions in one in every two trials (Table 4 and Figure 3). Whilst there was a significant interaction the actual differences between varieties were small, except for screenings. Apart from NDVI at 6 WAS, genetic variation was larger than the management induced variation when averaged across sites.

For early biomass varieties with a more erect leaf structure (Hindmarsh, La Trobe and Vlamingh) showed a smaller increase in biomass (as measured by NDVI) with increasing seed rate than those with either a floppy leaf structure (Buloke and Commander) or a semi-dwarf habit (Bass, Baudin, Flinders, Granger and Wimmera).

For kernel weight, Flinders had the smallest change with increasing seed rate whilst Granger and Wimmera had the largest change (-1.6 mg vs -2.7 mg). For hectolitre weight, Bass and Flinders were the least sensitive and Vlamingh and Wimmera the most sensitive (-0.1 vs -0.9 kg/hL). For screenings, Bass and Flinders had the smallest change with increasing seed rate whilst Granger and Wimmera had the largest change (+0.4% vs +4.5%).

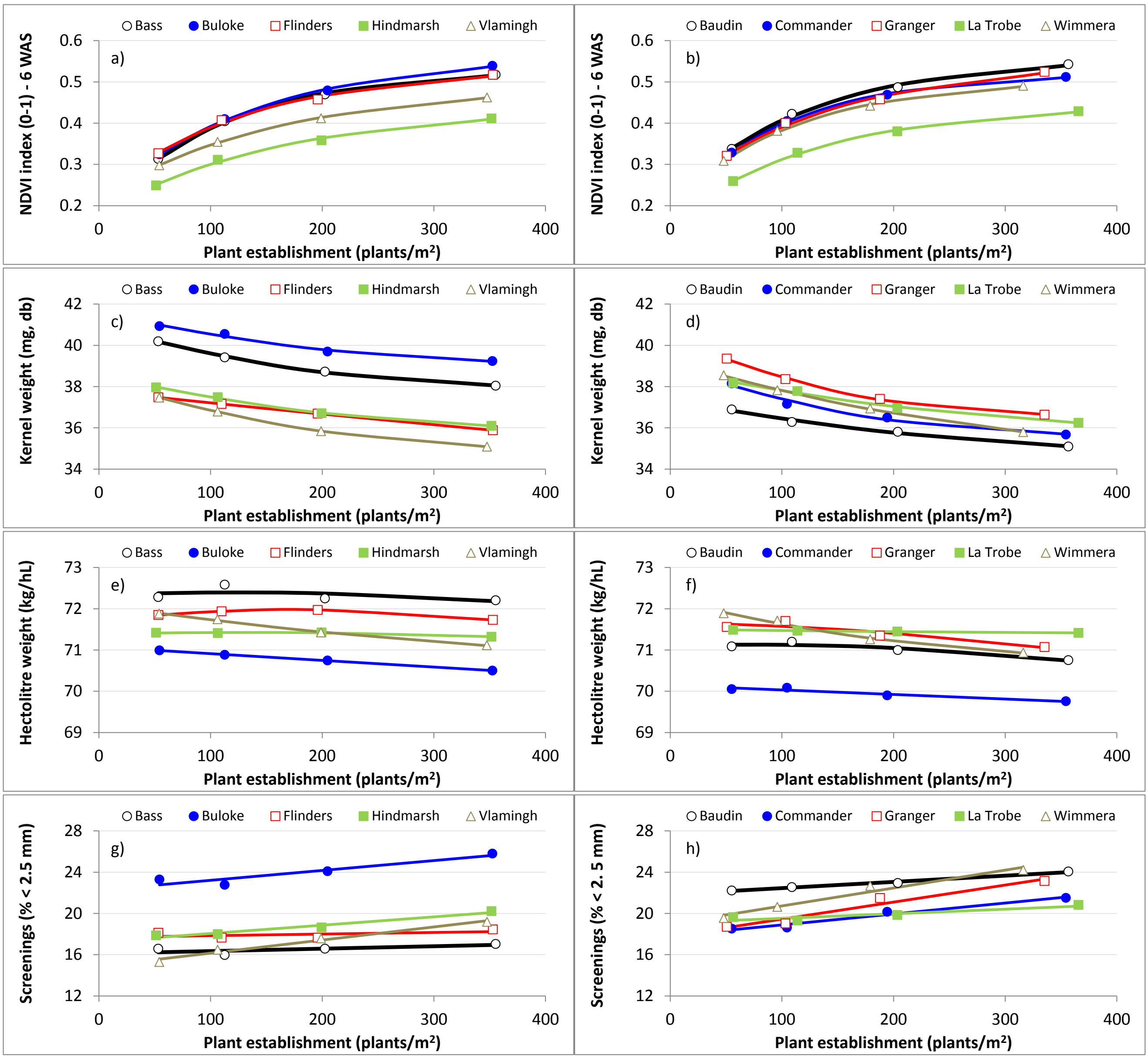

Figure 3. Interaction between variety and seed rate for NDVI at 6 WAS (a and b); kernel weight (c and d); hectolitre weight (e and f); and screenings (h and i) averaged across all 24 trials.

Economic analysis

An economic analysis calculating return (yield by price minus costs) was done for each variety, seed rate and site using the assumptions in Table 5 and the current GIWA Barley receival standards for Western Australia. The average return relative to 50 plants/m^2 ($/ha) across all 24 sites is presented in Figure 4, with varietal response separated into three groups. It should be noted that a single rate of N was used and as such was not necessarily the rate that optimised grain protein concentration for each site, year or sowing date. Grain protein (low or high) was therefore the main reason for downgrading to feed not seed rate (Table 6).

Table 5. Assumptions used in the economic analysis of 24 seed rate trials.

Variety	Indicative cash price ($/t)			EPR – malt or food / feed ($/t)	1000 seed weight (g)	Seed rate (kg/ha) to achieve			
	Malt 1 / Food 1	Malt 2 / Food 2	Feed			50 plants /m^2	100 plants /m^2	200 plants /m^2	400 plants /m^2
Bass	$265	$240	$230	$3.50 / $3.50	45	27	57	115	262
Baudin	$270	$240	$230	$3.00 / $1.00	42	25	54	107	245
Buloke	$260	$240	$230	$2.00 / $2.00	45	27	57	115	262
Commander	$260	$240	$230	$3.80 / $3.80	42	25	54	107	245
Flinders	$260	$240	$230	$3.80 / $3.80	42	25	54	107	245
Granger	$260	$240	$230	$2.95 / $2.95	45	27	57	115	262
Hindmarsh	$255	$240	$230	$1.50 / $1.50	42	25	54	107	245
La Trobe	$260	$240	$230	$4.00 / $4.00	42	25	54	107	245
Vlamingh	$255	$240	$230	$3.50 / $1.50	42	25	54	107	245
Wimmera	$260	$240	$230	$3.00 / $3.00	42	25	54	107	245
Establishment per cent						85%	80%	80%	70%

Barley receival + BAMA	$12.50	$/t	
Freight: farm to port	$22.50	$/t	farm to bin + bin to natural port
Seed cost	$350	$/t	
Seed dressing cost	$61	$/t	
Germination per cent	98	%	
Operating costs	$180	$/ha	low rainfall – fuel, fertiliser, weed control, foliar fungicides
Operating costs	$240	$/ha	medium and high rainfall – fuel, fertiliser, weed control, foliar fungicides
R&D levy	1.02%	farm gate value	

Note: cash price for Granger and Wimmera assumed to be similar to Buloke as no cash price has been posted in Western Australia.

Whilst there was a general decrease in grain quality with increasing seed rate (Figures 1, 2 and 3), there was no effect of seed rate on the per cent of samples meeting the GIWA Barley hectolitre weight and grain brightness receival standards in this study, with a slight decrease in samples meeting screening specifications and a slight increase in samples meeting grain protein specifications. Overall however, there was no effect of seed rate on the proportion of samples meeting the GIWA Barley malt or food barley receival standards.

The seed rate that maximised grain yield was not the same as the seed rate that maximised the return per hectare (Figure 1 and 4). Varietal response to increasing seed rate could be broken into three groups, based on their returns per hectare relative to 50 plants/m^2 (Figure 4). The maximum return for varieties in group 1 (Bass, Flinders, Hindmarsh, La Trobe and Wimmera) was between the target seed rates of 100 and 200 plants/m^2. The maximum return for varieties in group 2 (Baudin, Buloke, Commander and Granger) was just above 100 plants/m^2 and in group 3 (Vlamingh) around 200 plants/m^2.

Table 6. Per cent of barley samples meeting GIWA Barley receival standards for each quality trait and overall as either Malt (grades 1 and 2) or Food (grades 1 and 2) barley.

	Per cent of samples meeting specification			
	Target seed rate (plants/m^2)			
Quality trait	50	100	200	400
Hectolitre weight	100%	100%	100%	100%
Screenings	83%	83%	81%	79%
Grain protein concentration	62%	61%	61%	65%
Grain brightness	100%	99%	99%	99%
Received as Malt / Food	**61%**	**60%**	**60%**	**61%**

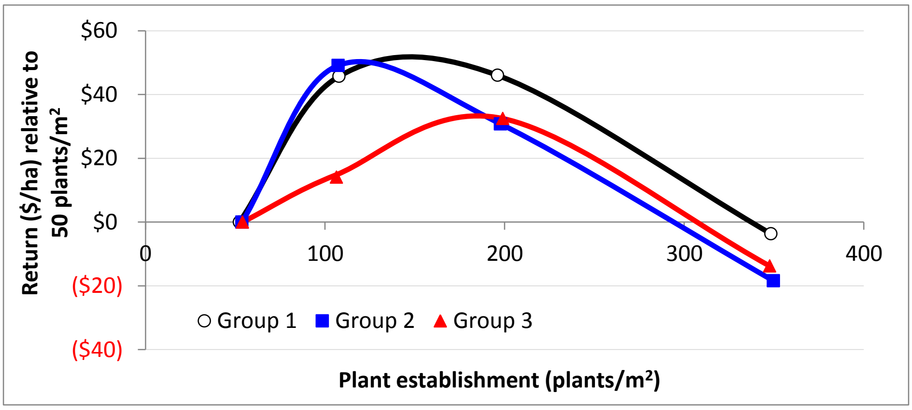

Figure 4. Return (yield by price minus costs, $/ha) with increasing seed rate relative to the return at 50 plants/m^2 grouped into three varietal response groups: Group 1 = Bass, Flinders, Hindmarsh, La Trobe and Wimmera; Group 2 = Baudin, Buloke, Commander and Granger and Group 3 = Vlamingh.

Conclusion

Sowing more than 300 plants/m^2 did not cause a grain yield penalty in any trial in this study (Figure 1). Merredin 2012 was the only site with no increase in grain yield when the seed rate was increased above 50 plants/m^2. On average increasing the seed rate from:

- 50 plants/m^2 (20 to 30 kg/ha) to 100 plants/m^2 (45 to 65 kg/ha) increased grain yield by 10 ± 1%.
- 100 plants/m^2 to 200 plants/m^2 (90 to 130 kg/ha) increased it by a further 4 ± 1%, and
- 200 plants/m^2 to 400 plants/m^2 (seed rate of 205 to 295 kg/ha) resulted in another 1 ± 1% yield gain.

Variety did not influence this response.

These observations are similar in scale to those of Paynter and Hills (2009), Paynter (2016) and Paynter *et al*. (2016a). In Paynter and Hills (2009) there was a 16% yield difference between the lowest seed rate (75 plants/m^2) and the highest seed rate (300 plants/m^2) in the absence of weeds. In Paynter (2016) there was a 19% yield difference between the lowest seed rate (25 plants/m^2) and the highest seed rate (400 plants/m^2), plateauing after 200 plants/m^2. In Paynter *et al*. (2016a) there was a 10% yield difference between the lowest seed rate (75 plants/m^2) and the highest seed rate (300 plants/m^2), with grain yield increasing to 300 plants/m^2.

Over four separate studies (Table 4, Paynter and Hills 2009, Paynter *et al*. 2016a, unpublished data) only 25% of seed rate trials (total of 71 trials) have shown a V x SR interaction. There is, therefore, not enough evidence to support recommending different target plant densities for individual varieties in the range of 100 to 200 plants/m^2 based on grain yield alone.

In this study the optimum plant population for grain yield across sites was 137 ± 9 plants/m^2, being similar to that observed by Paynter (2016) and Paynter *et al*. (2016a and 2016b). It is also in line with the target establishment densities of 120 to 150 plants/m^2 suggested for sowing barley in Western Australia.

Whilst there was a reduction in kernel weight, hectolitre weight, grain protein and grain brightness and an increase in screenings with increasing seed rate, the absolute change was relatively small given the wide range of seed rates – 50 to 400 plants/m^2 – used in this study (Figures 1 and 2). For two of the receival quality traits, the average reduction in hectolitre weight was less than 0.5 kg/hL and the average increase in screenings less than 3%. Similar observations were found by Paynter and Hills (2009) where the reduction in hectolitre weight was less than 1 kg/hL and screenings less than 5% over a range of seed rates from 75 to 300 plants/m^2 and in 32 seed rate trials (Blakely Paynter, unpublished). When assessed against the current GIWA Barley receival standards, there was no effect of seed rate on the proportion of samples that met the malt or food barley receival standards (Table 4). Increasing the seed rate also did not increase the lodging risk, if anything lodging risk was slightly reduced, but it did result in a slightly shorter crop (Figures 2 and 3). This may be of benefit in higher rainfall environments. From a practical perspective therefore increasing on-farm seed rates by 10 kg/ha (~20 plants/m^2) or even 20 kg/ha (~40 plants/m^2) above current practice will not change the receival risk and may enhance grain yield.

Is there a need to change the target plant density for a variety based on grain quality? The answer depends on which aspect of grain quality is looked at. For grain protein and grain brightness fewer than 25% of trials have shown a V x SR interaction indicating that variety responses based on those changes only occur occasionally. We did observe in 50% of trials, however, an interaction between V x SR for hectolitre weight and screenings (Table 4). In Paynter and Hills (2009) and other seed rate studies (Blakely Paynter, unpublished) V x SR interactions for hectolitre weight were observed in 24% of trials and for screenings in 48% of trials (37 trials). Hence there is a need to consider variety when choosing a target plant density if growing a variety with a malt classification.

When the return ($/ha) was determined for every site, variety and seed rate we were able to demonstrate that varieties differed in their sensitivity to increasing the seed rate, largely between 100 and 200 plants/m^2. Bass, Flinders, Hindmarsh and La Trobe and Wimmera were able to maintain their profitability over the target densities from 100 to 200 plants/m^2. Buloke, Commander and Granger were more sensitive, with their returns decreasing above 100 plants/m^2, whilst the maximum return in Vlamingh was not observed till around 200 plants/m^2. These observations are consistent with Paynter *et al*. (2016a), who similarly suggested that the management package for Bass and La Trobe is different to that of Buloke, Commander and Granger.

Therefore decisions on what seed rate to use should be based on achieving the suggested target plant population and modifying this target by the variety sown. For Bass, Flinders, Hindmarsh, La Trobe and Wimmera a target density of 150 plants/m^2 is proposed. For Baudin, Buloke (= Scope CL), Commander and Granger a target density of 120 plants/m^2 is proposed in weed free or low weed burden situations with a potential above 1 t/ha. A similar target density is proposed for Buloke and Scope CL based on their similarity in National Variety Trials and barley agronomy trials in Western Australia (Paynter *et al*. 2015), even though Scope CL was not evaluated in this study. This is supported by the fact that Hindmarsh and La Trobe had a similar reaction to seed rate in this study and like Buloke and Scope CL perform similarly in Western Australia (Paynter *et al*. 2015).

This study, Paynter and Hills (2009), Paynter (2016) and Paynter *et al*. (2016a and 2016b) have shown that increasing the seed rate of barley has a negligible risk of reducing grain yield in Western Australia when the yield potential is above 1 t/ha. One of the benefits of increasing the current seed rate is increased competitiveness with weeds and reduced weed seeds returning to the weed seed bank (Paynter and Hills 2008). The challenge to growers and consultants is therefore to increase the seed rate of barley sown in Western Australia. Increasing it by 10 kg/ha will add ~20 plants/m^2, increase grain yield by 1 to 3% and provide system benefits. The negative impact feared by growers is not supported by research in more than 1 t/ha environments. It can happen but it is a rare occurrence (three out of 71 seed rate trials). Two of the three observations with yield reductions occurred in trials with a site mean yield below 1 t/ha. Narrow grain varieties or those with a low hectolitre weight or darker kernels will always be at a higher risk of not meeting receival standards regardless of seed rate.

Feed barley growers should be looking to establish more than 150 plants/m^2 and in paddocks with a high weed burden, target establishment densities above 200 plants/m^2 (90 to 130 kg/ha) depending on seed weight and germination per cent. High densities result in more ground cover at 6 WAS (Figure 1 and Paynter 2016), an important component in increasing the early season competitiveness of crops like barley against weeds.

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Key words

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