SOURCES OF SCREENINGS IN MALTING BARLEY IN RELATION TO THE PATTERN OF TILLERING

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ABSTRACT

Triumph barley was sown in the field at densities of 125, 250 and 500 plants/m², and given either no-N, early-N (tillering), or late-N (anthesis) in factorial combination. The treatments produced crops with screening rates varying between 1 and 11 %.

Variations in screening rate were better related to both the number of grains/m² and mean kernel weight than to any other individual variable. High screening rates were observed in crops producing more than 18,000 grains/m² and where mean kernel weight was less than 45 mg. Screening rate was more related to ear and grain populations than to plant population. Early-N increased the screening rate mainly by producing more higher order tillers. Late-N decreased the screening rate and increased the kernel weight in all ears with similar magnitude, suggesting the importance of current dry matter production and partitioning to grains during grain filling.

Among the ears produced by the crops the mainstem was the least and tiller 3 the most likely to produce screenings. Tillers 1 and 2 had intermediate values. In all ears screenings were generally produced by the terminal spikelets, but in tiller 3, which only survived where early N was applied, screenings were also produced from basal spikelets.

***Additional Keywords:** Sowing density; Nitrogen; Growth potential; DM partitioning;* Hordeum vulgare.

INTRODUCTION

The production of many undersized grains, known as screenings, is undesirable in barley crops. Undersized grains give poor malting quality and also tend to reduce nutrient availability in the feed (Smart, 1983). Quality standards for malt and feed barley, therefore, often impose a limit on grain size with the intention of excluding poorly filled grains.

Grain size is directly related to kernel weight, the latter being an important component of yield. However, there is very little information on screening rate in relation to grain weight and yield despite the existence of vast literature reporting barley crop responses to agronomic treatments.

Grain growth is often characterized by a supply of carbohydrate to the growing grains and competition among grains for this resource (Walpole & Morgan, 1970). Overall dry matter (DM) production by a crop is known to be important in determining final kernel weight, as well as DM partitioning to individual kernels (Biscoe & Gallagher, 1978). The position of a grain within an ear is also known to affect its weight and size (Kirby, 1977), which suggests that some specific grains may have a disadvantage over the others in accumulating DM.

It is likely that conditions leading to a high grain population and/or poor grain filling after anthesis will result in a decrease in mean kernel weight and an increase in screenings. Tillering behaviour of a crop may have some effect on the determination of the screening rate by influencing DM partitioning among ears and grains, along with its effect on DM production. However, it is not known how environmental and agronomic factors affect screening rate by altering tillering, grain set and grain growth. The present study was undertaken to provide this information.

MATERIALS AND METHODS

The two-row spring barley cultivar, Triumph, was used in this experiment. It is widely accepted as a stable malting cultivar in New Zealand. The field trial was conducted at the Lincoln College research area on a Templeton silt-loam soil. The area was dressed with 2 t/ha of lime and 200 kg/ha of superphosphate before sowing.

The experiment was laid out in a factorial randomised complete block design with 5 replications, each plot measured 3 m x 28 m. Sowing rates of 125, 250 and 500 plants/m^2, were chosen as one factor to provide a wide range of yield, kernel weights and screening rates. Nitrogen fertiliser treatments at different phases of plant development were incorporated as the other factor to differentiate the effect of nitrogen on tillering, grain set and grain filling. They were:

1) Control (no nitrogen),
2) Early-N (50 kg N/ha at Zadoks' growth stage 25 (Zadoks *et al.*, 1974)), aiming to alter tillering and grain production of the crop,
3) Late-N (50 kg N/ha around anthesis), to enhance grain filling without modifying grain set.

The crop was sown using an Oyjord drill on 22 October 1986 in 15 cm rows. Each plot consisted of 20 rows oriented north-south. The average number plant/m^2 counted 12 days after sowing were 115, 235 and 430 for the low, medium and high density crops respectively. Early-N was applied as Calcium ammonium nitrate on November 19 for all densities and Late-N around anthesis which occurred on 26 and 29 December 1986 and 2 January 1987 for the high, medium and low density respectively. Due to the closed flowering of most plants, anthesis was assumed to occur 3 days after ear emergence.

Weather during the cropping period was dry with only 129 mm of rain, compared with the long-term mean of 170 mm. Evapotranspiration by Penman formula was 402 mm and the cumulative water deficit of 259 mm was double the long-term mean of 131 mm during the growing period. Apart from the drought, most climatic variables such as temperature and solar radiation were considered favourable for growth, development and yield of the crop. During the experiment, irrigation, disease and pest control were given to eliminate undue moisture stress or damage from pests and diseases.

Estimates of total green area, which comprised green leaves, stems and ears, were made at anthesis from a 1 m^2 random sample per plot using an area meter (Licor, model 3100). Solar radiation captured by the crop canopy was measured about weekly using tube solarimeters (Model TSM, Delta-T Devices). Grain yield and yield components were measured on 4 February, when all plants had lost visible green parts on their stems, leaves and ears. Five 0.2 m^2 samples were cut to ground level per plot and bulked for the plot. The numbers of ears and grains were counted and shoots were weighed. Dry weight (DW) of the grain and shoot was calculated after adjusting the moisture content by taking sub-samples and drying them at 80 °C for 48 hours. Grain weight and yield were expressed as weight at 14 % moisture content, except where otherwise noted. Grains were graded into 6 groups by their depth using a Westrup seed cleaner with sieves of 1.75, 2.00, 2.40, 2.80 and 3.25 mm.

Throughout this paper a screening is defined as a grain that was small enough to pass through the 2.40 mm sieve. The shortest dimension of a barley grain is also defined as depth which is the farthest distance between the palea and lemma. Grain width is the dimension at right angles to the depth, whereas grain length is the longest linear dimension of the grain. By convention the screening rate was calculated as the percentage by weight of screening as a proportion of the total grain weight. The screening rate in weight terms showed a high correlation with the screening rate in number terms in this experiment (Table 1). For observations of tillering behaviour and DM partitioning among ears and grains, two 0.15 m^2 quadrats were marked in each plot and thinned to match the established populations for each treatment. Tillers of 10 plants per quadrat were tagged with coloured loops for later identification using the numbering sequence described by Kirby & Appleyard (1981). The occurrence of tillers per quadrat and the formation of ears for each tiller type were recorded weekly.

To match the position of the terminal spikelets of ears from the high density crops, ears having the median spikelet number were chosen to analyse the distribution of kernel weights with the ear. The median spikelet numbers observed were 24, 20, 20 and 16 for MS, 1st tiller (T1), 2nd tiller (T2) and 3rd tiller (T3) ears respectively. Grains on even-numbered spikelet nodes were detached and dried at 80° for 48 hours before weighing. Whenever a sterile even-node grain was encountered, a substitute was taken from an adjacent node.

RESULTS

Screenings and related plant variables: The size-weight relationship between 20 randomly chosen grains from 6 depth grades is presented in Fig. 1. There was a direct linear relationship between the two variables as Weight (mg, adjusted for 14 % moisture content) =

Table 1: **Correlation coefficients (r) between screening rate and yield components (n=45).**

	DW of shoot /m^2	No.of ears /m^2	No.of grains /ear	No.of grains /m^2	1000 grain weight	Grain yield /m^2	Screening rate (%)
No. of ears/m^2	0.590						
No. of grains/ear	0.029	-0.752					
No. of grains/m^2	0.851	0.896	-0.387				
1000 grain weight	-0.329	-0.874	0.708	-0.751			
Grain yield/m^2	0.972	0.628	-0.042	0.862	-0.320		
Screening rate (%)	0.414	0.408	-0.032	0.535	-0.567	0.275	
Screening rate (no. %)	0.376	0.316	0.045	0.456	-0.485	0.224	0.991

** The 5 % and 1 % two-tailed significance levels of r are 0.288 and 0.372 (Snedecor & Cochran, 1980).

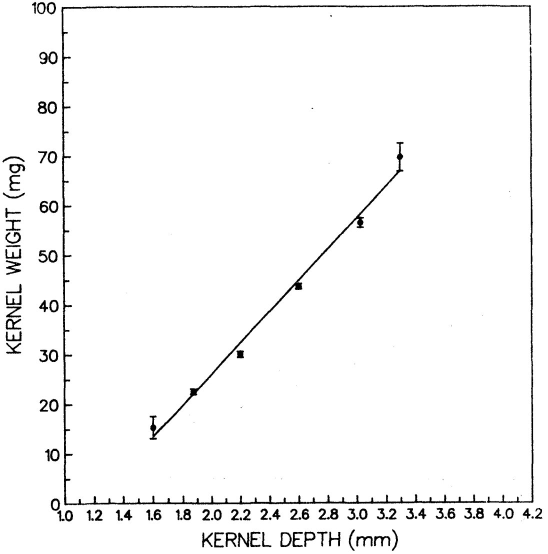

Figure 1. **The relationship between the weight and the depth of barley kernels: the linear regression equation plotted is:**

Weight = - 36.8 + 31.4 Depth (R^2 = 0.99) where the weight is adjusted to 14 % moisture content. (The vertical bars represent a standard deviation (n = 45)).

-36.8 + 31.4 Depth (mm). The weight of a marginal grain for screening was 38.6 mg with 14 % moisture and 33.8 mg in terms of dry weight under this relationship.

Correlation analysis between screening rate and yield characteristics is presented in Table 1. The variables highly correlated with screening rate were the number of grains/m^2 and 1000 grain weight with correlation coefficients of +0.535 and -0.567 respectively, while grain yield did not show any clear relationship with screening rate in spite of its strong linear relation to the number of grains/m^2. Other plant variables like the shoot DW and ear number/m^2 also showed high correlations with screening rate. Even thought grain number/m^2 was derived from the multiplication of the ear number/m^2 and the grain number per ear, grain population was more explanatory for the variations of yield and screening than each variable alone, as shown by its higher coefficient.

In spite of the significant correlation coefficients of both the number of grains/m^2 and mean grain weight with screening rate, the linearity of their individual relationships was poor as shown in Fig. 2. Screening rate was not responsive up to certain levels of grain number and mean kernel weight. The high screening rates were observed only in cases of grain numbers above 18,000/m^2 and below 45 g of 1000 grain weight.

As screening rate might be determined by the function of both grain number (Gr) and mean grain weight (Wt), further correlation analysis was done for screening rate using parameters derived from the two variables. The results showed that the parameter Gr.Wt had a higher correlation with screening rate (r = +0.626)

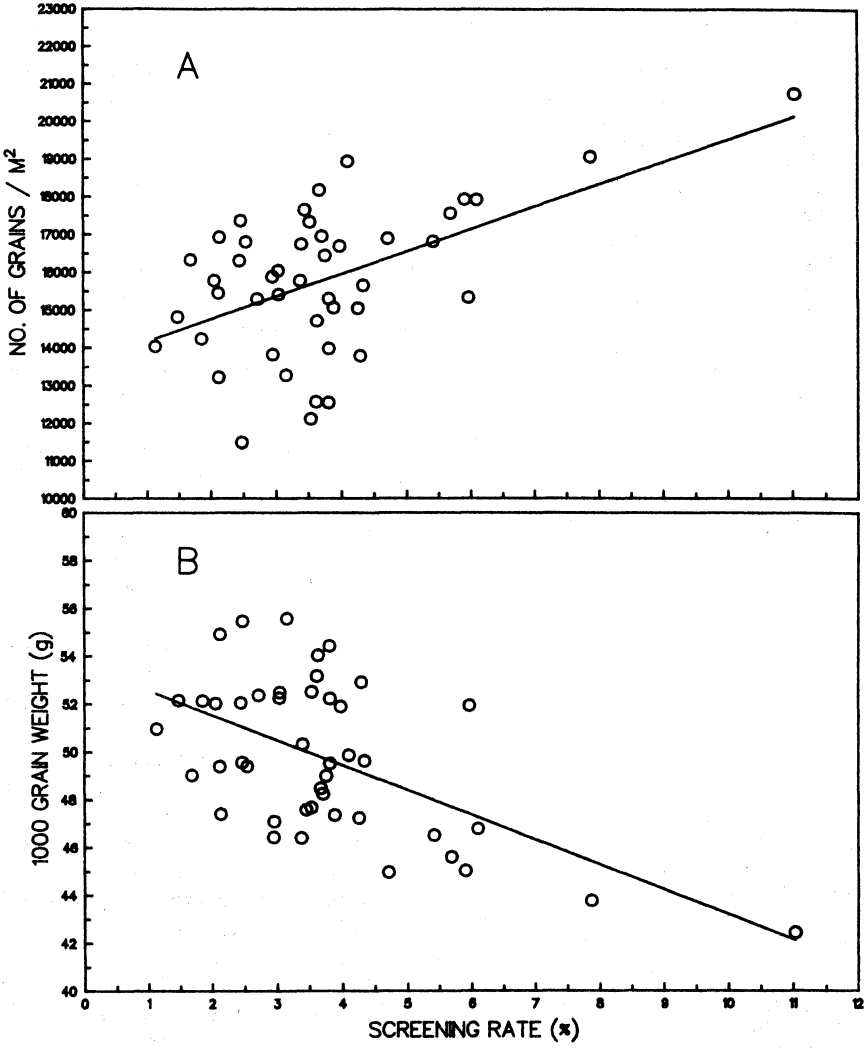

Figure 2. The relationship between screening rate and (A) the number of grains per m^2 and (B) 1,000 grain weight adjusted to 14 % moisture content. The linear regressions are:
(A) Number of grains/m^2 = 13,564 + 596 screening rate (%) ($R^2 = 0.29$)
(B) 1,000 grain weight + 53.6 - 1.04 screening rate (%) ($R^2 = 0.32$)

than each variable alone. Though the reciprocal of mean grain weight (1/wt) also showed a higher coefficient (r = +0.606) than each variable did, parameters comprising both the grain number/m^2 and mean grain weight gave better coefficients.

Density and nitrogen effect: The main effects of sowing density and nitrogen fertiliser on screening rate, shoot DW and grain yield components are shown in Table 2. There were no interactions. The screening rate

Table 2: **Effect of sowing density and nitrogen fertiliser on yield components and screening rate.**

	DW of shoot/m² (g)	No.of ears/m²	No.of grains/ear	No.of grains/ m²	1000 grain weight (g)	Grain yield/m² (g)	Screening rate (%)	Harvest index (%)
Density								
125	1,294	637	22.2	14,174	53.2	753	3.4	58.3
250	1,348	814	19.8	16,107	49.3	794	3.5	58.9
500	1,346	907	18.8	17,047	46.8	796	4.2	59.2
N-fertilizer								
none	1,263	771	20.0	15,186	48.9	739	3.9	58.6
early	1,435	840	20.5	17,101	48.8	831	4.8	58.0
late	1,290	747	20.3	15,041	51.6	772	2.4	59.9
Significance								
Density	NS	**	**	**	**	*	NS	*
N-fertilizer	**	**	NS	**	**	**	**	**
SEM	11.5	7.0	0.11	147.8	0.16	6.8	0.19	0.20

ranged from 2.4 - 4.8 % as the means for each treatment and 1 - 11 % in overall dispersion (Fig. 2).

Nitrogen had a marked effect on screening rate. Early-N increased the screening rate and its effect was related to the increased numbers of ears and grains per m². Late-N decreased the screening rate by increasing mean grain weight. The 12.4 % grain yield increase produced by early-N was higher than that of 4.4 % produced by late-N compared with the control. The effect of sowing density on screening rate was not statistically significant in spite of more undersized grains being produced in higher densities (Fig. 3a).

Fig. 3 shows the effects of the treatments on grain size distribution. The proportion of well filled grains (over 2.8 mm in depth) as well as that of poorly filled grains (below 2.8 mm in depth) was affected by density and nitrogen treatment. With higher sowing density, the proportion of well filled grains decreased, while that of poorly filled grains increased. Late-N increased the proportion of well filled grains while decreasing the proportion of poorly filled grains. Early-N only increased the poorly filled portion of grains compared with the control. As the area under the graphs in Fig. 3 represents the grain yield for a treatment it can be seen that early-N increased grain yield mainly by increasing the proportion of poorly filled grains.

Dry matter production and ear formation: Under the stable harvest index of this experiment, the level of DM production determined the grain yield and mean grain weight for a given grain number. Total green area and the fraction of the incident radiation absorbed by the crop canopy are shown in Table 3 as the parameters closely related with total DM production and grain yield. The effects of density and early-N on green area and average light interception rate were similar to those on grain yield components (Table 2), indicating again the close relationship between green area, light interception and DM production. Higher sowing density and early-N increased the fraction of intercepted light throughout the season, as a result of their pronounced effects on increased green area, and higher tiller and ear production.

Higher sowing density and Early-N increased the number of ears produced. In ear formation sowing density had a marked effect and showed no interaction with N in all ears. The frequency of ear formation by different tillers is shown in Table 4. Ears from the primary tillers even up to the fourth tiller (T4) as well as the coleoptile tiller (TC) and some secondary tillers (TC-P, T1-P, T1-1, T2-P, etc.) were observed in the low plant density, while few T4 and secondary tiller ears formed in higher plant populations.

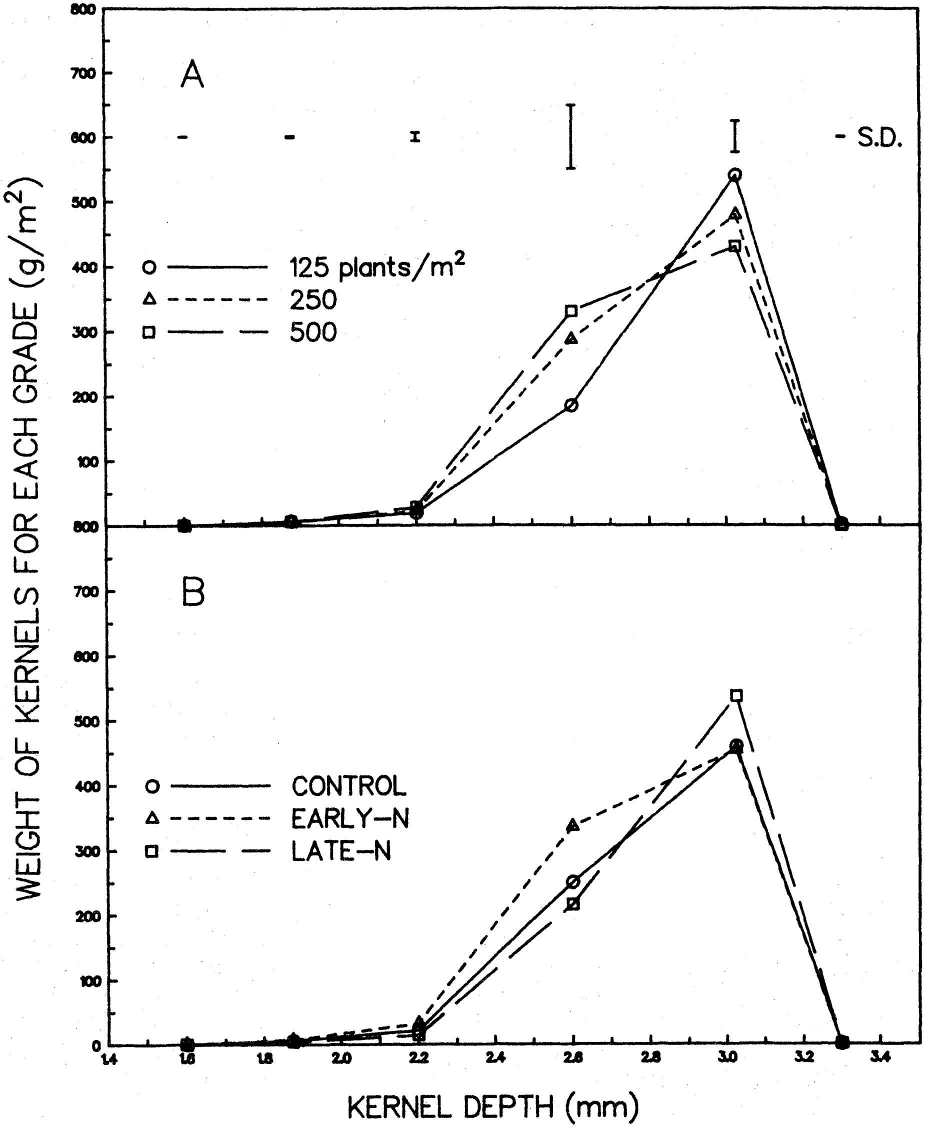

Figure 3. **Effect of (A) plant population and (B) nitrogen fertilizer applied at Zadoks' growth stage 25 (Early-N) and around anthesis (Late-N) on kernel distribution.**

Early-N enhanced ear formation for all tillers, resulting in a significant increase in ear number per plant and m^2. Despite this effect in ear production, ANOVA analysis for the frequency of occurrence of each ear showed only the formation of TC and T3 ears was significantly affected by early-N. The occurrence of secondary tiller ears was much more variable, as indicated by the higher CV values in Table 4.

Dry matter partitioning among ears and grains: Plants from the high sowing density were selected to study patterns of DM partitioning among ears and grains within an ear as these showed the biggest variation in screening rate. The results for DM partitioning among

Table 4: **The effects of sowing density and nitrogen fertiliser at tillering stage on the frequency (%) of ear formation observed from quadrat samples.**

	Density			N-fertiliser		Significance		SEM	CV
	114	235	427	0	50	Density	N-fert.		(%)
MS	100	100	100	100	100				
TC	10.0	2.0	1.0	3.2	6.7	**	*	0.59	91.1
TC-P	1.3	0.6	0	0.5	1.0	NS	NS	0.26	262.2
T1	90.7	78.0	53.3	71.3	79.3	**	NS	1.89	17.2
T1-P	48.7	14.7	2.3	20.2	25.3	**	NS	1.69	51.8
T1-1	14.3	0	0	4.0	6.3	**	NS	1.02	143.6
T2	94.0	84.0	66.7	79.2	86.3	**	NS	1.79	14.7
T2-P	61.0	4.3	0.3	19.0	27.0	*	NS	1.67	51.2
T3	93.7	51.7	6.0	47.3	56.7	**	*	1.76	23.3
T3-P	42.3	0	0	13.5	15.3	**	NS	1.18	58.4
T4	10.0	0	0	2.1	5.7	**	NS	1.18	238.3
Ears/plant	5.7	3.4	2.3	3.6	4.1	**	**	0.06	11.3
Ears/m²	656	809	965	776	877	**	**	7.5	6.2

ears are presented in Table 5. The data indicated a strong hierarchy among MS and tillers where the MS was always superior to the tillers in acquisition of total shoot DW and grain yield. Among the tillers, T1 and T2 were superior to T3 which was only produced where early-N was applied. There was no difference between T1 and T2. Early-N increased the grain yield by maintaining it in the MS, T1 and T2 ears, while producing an additional ear on T3. Unlike early-N treatment, late-N maintained the contribution rates by each tiller and increased the grain yield in all ears.

The weight of grains in different spikelet positions is shown in Fig. 4 together with the threshold screening line derived from Fig. 1. The order of ears in the gradient positions was MS > T1 H T2 > T3, again indicating the hierarchy among ears observed in Table 5. Within an ear the heaviest grains were always found in the lower middle part of the ear, around the 8th or 10th spikelet node, grains in both basal and terminal directions being progressively smaller. The terminal grains were the smallest and those were most likely to become screenings. The hierarchy among grains in different spikelet positions was also maintained in all ears regardless of the diverse levels of DM accumulation produced by the nitrogen treatments.

Late-N increased the weight of all grains. As a consequence, screenings were found only at the terminal spikelets with late-N, while both the basal and terminal grains tended to become screenings without it. The effect of early-N was to decrease slightly the weight of all grains in MS ears with similar magnitude, but the weight of grains in T1 and T2 was not affected. The weight loss in MS was compensated by the production of grains by T3. However, grains produced by T3 had low kernel weights and more than half of them were screenings.

DISCUSSION

The observation of a close relationship between barley grain size and weight reflects the pattern of barley grain growth described by Briggs (1978). Increase in depth is obtained in parallel with an increase

Table 5: **Dry matter partitioning among main stem and tillers by different nitrogen fertiliser treatments.**

	MS		T1		T2		T3	
	shoot (g)	grain (mg)	shoot (g)	grain (mg)	shoot (g)	grain (mg)	shoot (g)	grain (mg)
Control	1.60	843 (41.2)	1.20	621 (30.3)	1.13	583 (28.5)	-	-
Early-Nitrogen	1.63	849 (33.2)	1.19	593 (23.2)	1.21	622 (24.3)	1.03	497 (19.4)
Late-Nitrogen	1.68	903 (41.4)	1.21	649 (29.8)	1.18	628 (28.8)	-	-
SEM	0.08	47.4	0.13	71.8	0.13	76.2	0.07	43.0

** The values inside the parenthesis are the percentage of yield contribution by each ear to the cumulative grain yield per plant.

Table 3: **Effects of sowing density and nitrogen fertiliser application at tillering stage on the total green area at anthesis and the average light interception by the crop canopy throughout the growing period.**

	Green area/m^2 (m^2)	Average light interception (%)
Density		
125 (plants/m^2)	5.1	76.2
250	6.3	80.7
500	6.8	82.7
N-fertilizer		
0	5.6	78.0
50 (kg N/ha)	7.1	83.6
Significance		
Density	**	**
N-fertilizer	**	**
Interaction	NS	NS
SEM	0.15	0.32

in endosperm volume caused by carbohydrate accumulation during the later part of grain growth. On the other hand, husk size and weight are known to be fixed at an early stage in grain growth, usually before the vigorous carbohydrate accumulation by the grain (Porter *et al.*, 1950). It is unlikely that husk size and weight are the determinants of final grain weight, though some researchers (Scott *et al.*, 1983; Sadeque, 1985) related them to final grain weight. Findings of heavier husks in heavier grains, as can be seen in median grains compared with lateral grains observed by Scott *et al.* (1983), may be related to the hierarchy in the grain growth potential among grains while the actual level of final grain size and weight are determined by the degree of grain filling. A further study to clarify whether husk size physically determines final grain weight may be warranted in conjunction with an investigation of patterns of grain and husk growth under several levels of assimilate supply.

For a single grain, the level of grain filling and subsequent grain weight (Fig. 1) appeared to be the most important factor in generating a screening. The screening rate was shown to be closely related to the mean grain weight and the grain number per unit area, while the grain number per unit area was the single most important determinant of grain yield. Mean kernel weight in this experiment ranged from 42 to 56 mg, though Gallagher *et al.* (1975) considered mean kernel weight quite stable over a wide range of field conditions and cultivars. They supported their view with two physiological observations; (1) the post-anthesis mobilisation of pre-anthesis assimilate from stem and leaves to growing grains, particularly when post-

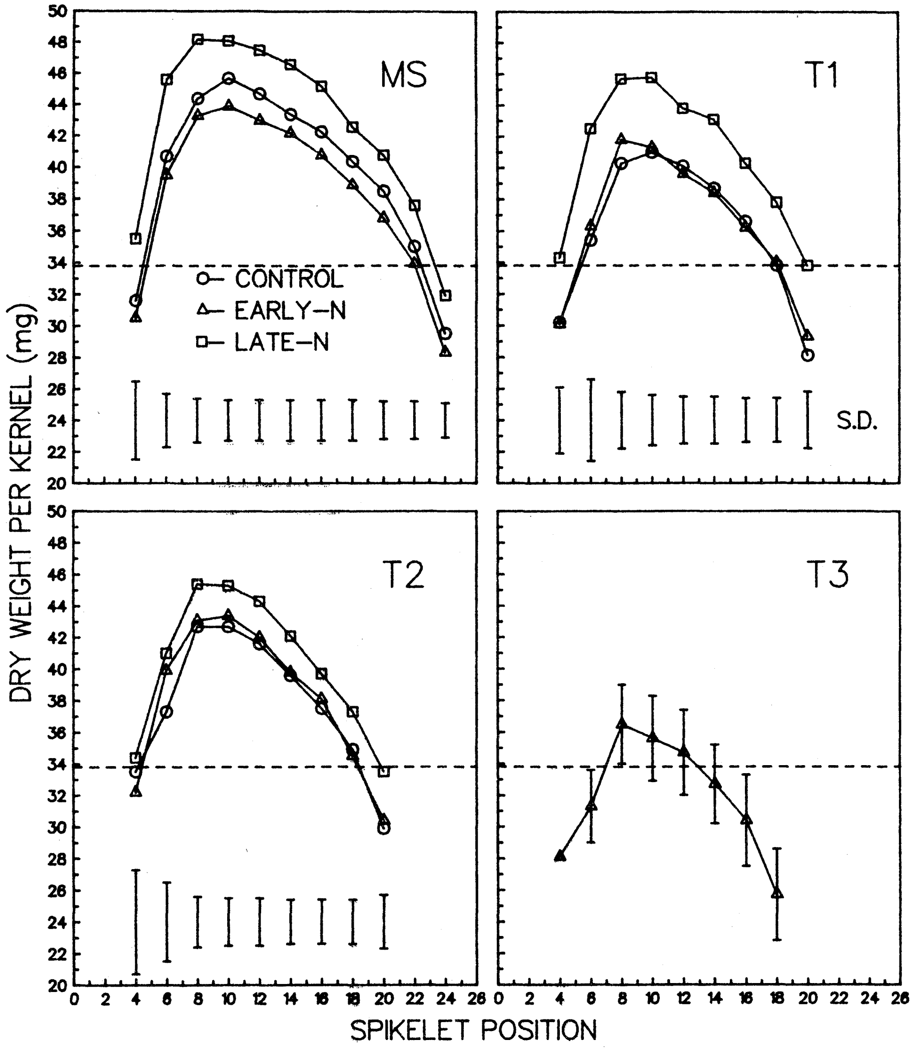

Figure 4. **The gradient of kernel dry weight in different ears with nitrogen fertilizer treatment in a crop sown at 500 plants/m^2: early-N, N applied at Zadoks' growth stage 25; Late-N, N applied around anthesis. grains below the dotted line are screenings.**

anthesis assimilation was severely hampered, and (2) the close linear relationship between grain yield and number of grains per unit area.

The post-anthesis translocation of pre-anthesis assimilate has been reported by many others (e.g. Thorne, 1966; Holliday & Willey, 1969; Yosida, 1972). However, they also reported that the maximum possible contribution to grain yield by pre-anthesis reserves ranged from less than 20 % (Thorne, 1966; Holliday & Willey, 1969) to 40 % (Yosida, 1972). They all suggested that under normal field conditions such translocation did not significantly contribute to grain yield. It is likely that the grain in stability of mean kernel weight by this mechanism is minimal under most field conditions. The observation of a linear relationship between grain yield and number is also open to misinterpretation. The yield components presented by Gallagher *et al.* (1975) were from crops in which the grain number ranged from 5,000 to 18,000 grains per m^2. Over a wider range of grain number situations as produced by more extreme treatments, the relationship may be asymptotic rather than linear as suggested. Another point worth noting is that the wide variation in the linear relationship presented by Gallagher *et al.* (1975) in Fig. 2 and Fig. 6 was overlooked, though they correctly remarked that the scatter of points about the lines reflected the differences of mean kernel weight. The graphs showed a wide variation in grain yields for a given grain population and in an extreme case shown in Fig. 6 (a) the variation of mean kernel weight for the grain population of 11,000 grains/m^2 was estimated to range from 32 mg to 48 mg, which can hardly be considered as a stable component. It is suggested therefore that the linear relationship between grain yield and grain number does not necessarily imply a stable mean kernel weight.

Substantial variations in mean kernel weight may be further disguised by rough harvesting methods. Conventional combine harvesters tend to blow away small grains, thus increasing mean kernel weight, and decreasing screening rate. This effect would be more likely in high grain number situations than low grain number situations, as the former are likely to produce more small grains. Thus, the higher grain number situations might be arbitrarily interpreted as linearly responsive to grain yield. In short, wide differences may exist in mean kernel weights of barley depending on the cropping condition and treatment, though mean kernel weight is relatively more stable than any of the other grain yield components, a phenomenon that also occurs in wheat (Scott, 1981).

In this experiment, the high screening rates were observed at grain populations above 18,000 per m^2 and below 45 g of 1000 grain weight. When it is considered that the yield level of this experiment was about double the New Zealand average yield (New Zealand Ministry of Agriculture & Fisheries, 1987), the above levels would not be applicable in lower yielding crops, especially where environments were unfavourable for grain filling. In these cases, a higher screening rate could be produced even at much lower grain numbers and mean kernel weights.

Nitrogen fertiliser had a marked effect on screening rate, while the effects of sowing density were less consistent. The increased yield produced by early-N resulted mostly from the production of more grains. It has less effect on the number of grains per ear than the ears per plant or unit area. Thus, the higher grain number produced by early-N was related to grain production by higher order tillers, this being partly responsible for increased portion of poorly filled grains and higher screening rate (Fig. 3, 4). Wauchop & Field-Dodgson (1978) also found that nitrogen fertiliser applied before or around tillering increased grain number more than grain yield, consequently reducing mean kernel weight and increasing screening rate. On the other hand, late-N did not affect grain number, but increased total DM, grain yield and mean kernel weight, resulting in a decreased screening rate. It is perhaps ironical that the late-N treatment which produced the lower screening rate could have adverse effect on malting quality by increasing the protein content of the grains (Smart, 1983).

The major portion of screenings came from higher order tillers and from terminal spikelets within an ear. The findings of this experiment in the competitive ability of ears and the hierarchy of grain growth potentials conform with other reports: the superiority of MS over tillers (Fletcher & Dale, 1977), the similarity in growth for primary tillers (Metivier, 1976), the reduced size of main stem ears by competition with tillers (Kirby & Jones, 1977), the bigger grains in MS ears and the bigger median grains in an ear (Kirby, 1977).

The differences of ears in competitive ability was postulated by Fletcher & Dale (1974, 1977) to be related to differences in the initial size of the apical dome and tiller bud meristems and to their structural association with the basal frusta (nodes + internodes). For the competing grains, Kirby (1977) suggested the difference in floret initiation time caused the grain weight gradient in an ear. Michael & Beringer (1980) argued the case for hormonally controlled interactions within and between spikelets which lead to a suppression of growth of young wheat grains by hormones produced in older ones. Such factors may well explain competitive ability of ears and grains to draw and utilize assimilates from the available supply. However, it is not clear whether such a difference in potentials caused by different floret initiation time is related to the duration of floret development or to the duration of grain growth. Further research in relation to the initiation, development and growth of ears and grains is needed to clarify the reasons for relative difference in their competitive ability.

The persistence of a hierarchy in grain weight despite several levels of assimilate supply indicates that the difference in grain growth potential is established at an early stage of grain growth. Scott *et al.* (1983) observed that relative differences in carpel weight were established before meiosis and there was a similarity in the relative growth rates of all the carpels from the time of meiosis until near grain maturity. The results of the present experiment also supports the existence of the early fixation and persistence of a hierarchy during grain growth. Within a barley crop certain grains have growth potentials that are well below average and, therefore, even under optimum conditions during grain filling, these grains still remain small and close to the screening line (33.8 mg D.Wt.). It follows that under sub-optimum conditions during grain filling these grains with low growth potential are the first to become screenings. Under such circumstances, the modification in the hierarchy would be possible only by manipulating tillering and ear formation. Early-N was a pre-anthesis treatment that manipulated potentials by altering the pattern of tillering and ear formation. Even though optimum ear population for grain yield and quality has never been defined, the findings that the MS, T1 and T2 produced kernels with higher weights than T3 (Fig. 4) and they are relatively insensitive to stress environments (Jones & Kirby, 1977) suggest that agronomic practices and/or plant breeding should aim to produce plants with no more than 2 tillers if screenings are to be kept to a minimum.

The higher production and partitioning of DM to the grains, as produced with late-N, decreased the screening rate with increased mean kernel weight and yield. While the growth potential of a grain is under the influence of a number of factors operating before or around anthesis, the extent to which this potential is not realized and manifests itself as a screening is determined during grain filling.

REFERENCES

Biscoe, P.V. & Gallagher, J.N. 1978. A physiological analysis of cereal yield. 1. Production of dry matter. *Agricultural Progress 53,* 34-50.

Briggs, D.E. 1978. *Barley.* Wiley, New York. 612 pp.

Fletcher, G.M. & Dale, J.E. 1974. Growth of tiller buds in barley: Effects of shade treatment and mineral nutrition. *Annals of Botany 38,* 63-76.

Fletcher, G.M. & Dale, J.E. 1977. A comparison of mainstem and tiller growth in barley: apical development and leaf unfolding rates. *Annals of Botany 41,* 109-116.

Gallagher, J.N., Biscoe, P.V. & Scott, R.K. 1975. Barley and its environment. V. Stability of grain weight. *Journal of Applied Ecology 12,* 319-336.

Holliday, R. & Willey, R.W. 1969. Varietal potential in cereals and its improvement. *Agricultural Progress 44,* 56-57

Jones, H.G. & Kirby, E.J.M. 1977. Effects of manipulation of tillers and water supply on grain yield in barley. *Journal of Agricultural Science, Cambridge 88,* 391-397.

Kirby, E.J.M. 1977. The growth of shoot apex and apical dome of barley during ear initiation. *Annals of Botany 41,* 1297-1308.

Kirby, E.J.M. & Appleyard, M. 1981. *Cereal development guide.* NAC Cereal Unit, Stoneleigh.

Kirby, E.J.M. & Jones, H.G. 1977. The relations between the mainshoot and tillers in barley plants. *Journal of Agricultural Science, Cambridge 88.* 381-389.

Metivier, J.R. 1976. Studies on the growth and photosynthesis of barley as affected by grain nitrogen and exogenously supplied nitrate. Ph.D. thesis, University of Edinburgh.

Michael, G. & Beringer, H. 1980. The role of hormones in yield formation. Physiological aspects of crop productivity. *Proceedings 15th Collegium International Potash Institute, Bern,* 85-116.

New Zealand Ministry of Agriculture and Fisheries. 1987. New Zealand Agricultural Statistics.

Porter, H.K., Pal, N. & Martin, R.V. 1950. Physiological studies of plant nutrition. 15. Assimilation of carbon by the ear of barley and its relation to the accumulation of dry matter in the grain. *Annals of Botany 14,* 55-68.

Sadeque, M.A. 1985. A study of grain filling in barley. Ph.D. thesis, Lincoln College, University of Canterbury.

Scott, W.R. 1981. Improving wheat quality by agronomic management. *Proceedings of the Agronomy Society of New Zealand 11,* 91-97.

Scott, W.R., Appleyard, M., Fellowes, G. & Kirby, E.J.M. 1983. Effects of genotype and position in the ear on carpel and grain growth and mature grain weight of spring barley. *Journal of Agricultural Science, Cambridge 100,* 383-391.

Smart, J.G. 1983. Malting Quality - What is it? In 'Barley: Production and Marketing'. *Special Publication No. 2. Agronomy Society of New Zealand,* 109-112.

Snedecor, G.W. & Cochran, W.G. 1980. *Statistical Methods.* Iowa State University Press, Ames.

Thorne, G.N. 1966. Physiological aspects of grain yield in cereals. In *The growth of cereals and glasses.* (ed. F.L. Milthorpe and J.D. Ivins.). pp 88-105. Butterworth, London.

Walpole, P.R. & Morgan, D.S. 1970. A quantitative study of grain filling in *Triticum aestivum*, L. cv. Maris Widgen. *Annals of Botany 34*, 309-318.

Wauchop, P. & Field-Dodgson, J. 1978. Response of malting barley cultivars to different levels of P with and without N supplement in the southern North Island. *Proceedings of the Agronomy Society of New Zealand 8*, 11-13.

Yosida, S. 1972. Physiological aspects of grain yield. *Annual Review of Plant Physiology 23*, 437-464.

Zadoks, J.C., Chang, T.T. & Konzak, C.F. 1974. A decimal code for the growth stages of cereals. *Weed Research 14*, 415-421.