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Effect of Nitrogen Rate and Planting Density on Early Growth in Wheat

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ABSTRACT

This experiment was conducted with nine wheat genotypes to choose the wheat which has excellent early vigour. 'Vigour 18' and 'ZL 59A' are excellent in the long coleoptile genotype, while 'Amery' and 'Janz' are excellent in the short coleoptile genotype. Responding to the growth stage and nitrogen level, Vigour 18 is predominant in the long coleoptile genogype, while Janz in the short coleoptile genotype. Responding to sowing density and nitrogen level, the higher the sowing density was, the shorter the leaf area of Vigour 18 and Janz. Also the leaf area turned out to larger in the plot fertilized with high nitrogen than in the plot fertilized with low nitrogen. This is true of leaf weight and root weight. Concerning specific leaf area (SLA) and leaf area ratio (LAR), the higher the sowing density was, the SLA tended to grow larger, while the SLA grew larger in the plot fertilized with low nitrogen, as were found in Vigour 18 and Janz. Thê roots of long coleoptile genotype, Vigour 18, turned out to grow longest on the plot sown with 3 seeds. While the roots of short coleoptile genotype, Janz, grew longest on the plot sown with 2 seeds. The relative growth rate (RGR) was the same at low N rates and high N rates. The RGR was 0.071 and 0.072 g $g^{-1}d^{-1}$ at low N rates and high N rates. The partitioning of RGR into net assimilation rate (NAR) and LAR showed that the average LAR at low N rates was similar to the LAR at high N rates. Variation within each cultivar in the LAR and NAR was small relative to the difference between them at low N rates and high N rates. Above ground mass was 8.2 mg greater at high N rates than low N rates, whereas leaf area was 0.05 m^2kg^{-1} greater at high N rates than low N rates. The NAR was similar at low N rates and high N rates, whereas LAR was greater at high N rates (0.05 m^2 kg^{-1}); variation in SLA was responsible for the variation in NAR and LAR both at low N rates and high N rates. NAR was more closely associated with the reciprocal of SLA.

Key words : wheat, coleoptile, early vigour, nitrogen level, growth stage, specific leaf area (SLA), leaf area ratio (LAR), net assimilation rate (NAR), relative growth rate (RGR).

In crop cultivation, the superiority of early growth results from the advantage of competition against weeds on the levels of nutrient, light and moisture. Therefore, this leads to an increase in the harvest yields of crops. Especially, it is desirable to take advantage of moisture at the early growth stage of crops in the dry region. Accordingly, it is necessary that crops should grow actively in the early stage and have plenty of leaf area.

The favorable conditions which crops could grow vigorously and have plenty of leaf area are applicable to do several cultivation methods, for example, moving up the seeding date by several days, raising the quality of nitrogen fertilizer and improving the varieties which can grow predominantly in the early stage.

This experiment was carried out to obtain the basic data to breed crops, which might not be damaged at the early growth stage. We reported cultivars which showed predominant growth in the early stage. The effects of nitrogen on plant growth during different growth stages of several cultivars of wheat were also investigated.

MATERIALS AND METHODS

Selection of predominant cultivar (Experiment 1)

Wheat cultivars were separated by coleoptile length. The long coleoptile type which were considered as high vigour cultivars included 'Jing Hong', 'Kharchia', 'Vigour 18', 'ZL 38', and 'ZL 59A', and the short coleoptile type included 'Hartog', 'Amery', 'Janz' and 'Stiletto'. These were sown at two N rates in pots under natural conditions in Canberra, Australia (147 °E, 35 °S).

The mean grain weight of seeds was 45~50 mg. Five seeds per pot were sown at a depth of 2.5 cm on 17 May, 1996. The pot was prepared from 15.4 cm inside diameter and 45 cm long polyvinyl chloride pipe. Pots were filled with equal volumes of river sand and loam. Phosphorus was incorporated on the upper 10 cm of soil at planting as single surperphosphate. The N rates were 30 kg/ha and 100 kg/ha with urea in low and high N treatments. A completely randomized design with 4 blocks was used, and all pots were thinned to 3 healthy seedlings per pot at 17 days after sowing (at about the 1.0 leaf stage).

The plant height, leaf length and leaf diameter of each plant were measured at the 1st leaf stage (20 days after sowing) and the 3rd leaf stage (42 days after sowing). One replicate (one pot) of each treatment was harvested at the 5th leaf stage (58 days after sowing). The number of tillers were measured after harvesting, and the below ground developments such as the root length and

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root weight were measured after washing. Plant materials were dried in the dryer at 70℃ for 48 hrs before weighting. The leaf area of each plant was measured using an area meter (Model VM-900E/K, Delta-T devices Ltd., Cambridge, England).

Growth stage and response to nitrogen rates (Experiment 2)

Four cultivars which were vigourous in early growing stage were selected in the lst experiment. They were Vigour 18, ZL 59A (long coleoptile type) and Amery, Janz (short coleoptile type). These cultivars were sown at the same natural conditions as described in the 1st experiment in Canberra, Australia (147E, 35S).

The mean grain weight of seeds was 47~50 mg. Two seeds were vernalized for 7 days in the dark at 2℃ and were sown at a depth of 2.5 cm on 17 October 1996. Pot diameter was 8.5 cm and pots contained a river sand soil. Aquasol was sprayed and the N rates with urea were 20 kg/ha and 50 kg/ha. A split plot design with four blocks was used. The mainplots consisted the growth stage and the subplots consisted of the two N rates and the cultivars. There were four replicates within each subplot.

One replicate (one pot) of each treatment was harvested at the 1st, 2nd, 3rd and 4th leaf stage, respectively, and the leaf area, leaf weight, root weight and root system were measured by the methods of the 1st experiment after every harvest.

Planting densities and nitrogen rates (Experiment 3)

Two cultivars, Vigour 18 (long coleoptile type)and Janz (short coleoptile type), were selected in the 2nd experiment, and were sown at the same natural conditions of the 2nd experiment in Canberra, Australia (147E, 35S). Seeds were vernalized for 7 days in the dark at 2℃ and were sown at a depth of 2.5 cm on 17 October 1996. Pots were constructed from polyvinyl chloride pipe with 8.5 cm inside diameter and 50 cm long. Pots contained river sand and were sprayed by Aquasol. The N rates were 20 kg/ha and 50 kg/ha. The sowing densities were 1, 2, 3 and 4 grains per pot. A split plot design with four blocks was used. The main plots consisted of the two N rates and the subplots consisted of the cultivars. There were four replicates within each subplot.

The leaf length and leaf diameter were measured using a ruler at the 1st (11 days after sowing) and 2nd leaf stage (19 days after sowing). One replicate of each treatment was harvested at the 3rd leaf stage (27 days after sowing) and then, the leaf area, root weight, root length and dried plant weight were measured. The leaf area was calculated using the following equation: leaf length × leaf diameter × 0.8=leaf area.

Relative growth rate (RGR) and its components, net assimilation rate (NAR) and leaf area ratio (LAR), were calculated according to Hunt (1982). Specific leaf area (SLA) was calculated using the leaf area divided by the dried leaf weight. Leaf area ratio (LAR) was calculated using the leaf area divided by the sum of dried leaf weight and dried stem weight and the other traits were measured by the methods of the 2nd experiment. Analyses of variance were computed after each harvest for each variable in each experiment.

RESULTS AND DISCUSSION

Selection of predominant cultivar

Summary of the analysis of variance for the leaf area

Table 1. Variation of leaf area for nitrogen and harvest date.

Nitrogen level	Low			High		
Cultivar / Days after sowing	20	42	58	20	42	58
Long coleoptile						
Jing Hong	2.90†	17.99	39.83	3.43	18.41	49.05
Kharchia	1.87	14.32	30.28	3.43	20.60	47.98
Vigour 18	3.13	18.95	38.18	3.69	22.23	52.36
ZL 38	2.50	15.79	34.43	3.39	21.05	52.01
ZL 59A	3.15	18.09	37.49	3.78	27.26	65.20
Mean	2.71	17.03	36.04	3.54	21.91	53.32
Short coleoptile						
Amery	1.35	12.11	27.95	2.68	15.27	35.06
Hartog	2.08	13.13	26.08	2.23	14.58	32.91
Stiletto	1.83	12.75	24.69	2.12	14.01	29.05
Janz	2.38	13.13	32.24	2.50	13.17	34.86
Mean	1.91	12.78	27.74	2.38	14.26	32.97
LSD (0.05) cultivars	1.44	5.18	8.59	1.27	5.76	10.51

†Values are square centimeter per plant.

Table 2. Dry mass of leaf, stem, below stem, root, and total for long coleoptile and short coleoptile wheat cultivars at the last harvest.

Nitrogen level	Cultivar	Leaf dry mass (mg)	Stem dry mass (mg)	Below stem dry mass (mg)	Root dry mass (mg)	Total dry mass (mg)
Low	Long coleoptile					
	Jing Hong	184†	54	74	195	507
	Kharchia	135	33	51	137	356
	Vigour 18	174	58	74	184	490
	ZL 38	161	36	66	200	463
	ZL 59A	173	48	66	193	480
	Mean	165	46	66	182	459
	Short coleoptile					
	Amery	133	30	63	141	367
	Hartog	129	19	54	141	343
	Stiletto	135	22	66	144	367
	Janz	160	28	52	140	387
	Mean	139	25	59	142	366
	LSD (0.05) cultivars	17	6	7	15	16
High	Long coleoptile					
	Jing Hong	216	64	83	232	595
	Kharchia	208	62	72	184	526
	Vigour 18	226	81	86	192	585
	ZL 38	232	56	96	229	613
	ZL 59A	283	96	112	200	691
	Mean	233	72	90	207	602
	Short coleoptile					
	Amery	161	37	74	165	437
	Hartog	161	30	69	165	425
	Stiletto	157	30	72	139	398
	JanZ	173	37	64	148	422
	Mean	163	34	70	154	421
	LSD (0.05) cultivars	17	8	9	15	30

† Values are per plant.

measured at N rates is described in Table 1. There were significant growth effects for the long and short coleoptile wheat cultivars with the increasing N rate. In the long coleoptile cultivar, the leaf area was increased 2.71 cm^2 (20 days after sowing [DAS]) to 36.04 cm^2 (58 DAS) at the low N rate, and was increased 3.54 cm^2 (20 DAS) to 53.32 cm^2 (58 DAS) at the high N rate. And in the short coleoptile cultivar, the leaf area was increased 1.91 cm^2 (20 DAS) to 27.74 cm^2 at the low N rate, and was increased 2.38 cm^2 (20 DAS) to 32.97 cm^2 (58 DAS) at the high N rate.

The cultivar with the widest leaf area was Jing Hong (long coleoptile) and janz (short coleoptile) at the low N rate, and the significance of the other cultivars was in the following order: Vigour 18, ZL 59A, ZL 38, and Kharchia (long coleoptile), and Amery, Hartog, and Stiletto (short coleoptile). On the other hand, ZL 59A (long coleoptile) and Amery (short coleoptile) were the widest leaf area cultivars at te high N rate.

The dry masses of leaf, stem, below stem, root, and total are shown in Table 2. At the low N rate, the main value of leaf dry mass for the long coleoptile cultivars was 165 mg but was 139 mg in the case of the short coleoptile cultivars, the latter was decreased. The interaction between cultivar and low N rate was highly significance in Jing Hong (long coleoptile) and Janz (short coleoptile) at the low N rate, respectively. And at the high N rate, the main values of leaf dry mass for the long and short coleoptile cultivars were 233 mg and 163 mg, respectively. Of all the long coleoptile cultivars the root dry mass of ZL 58 was significantly affected by the low N rate. There was no significant interaction by the low N rate in the short coleoptile cultivars. At the high N rate, the magnitude of significance for the root dry mass was in the following order: Jing Hong, ZL 38, ZL 59A, Vigour 18 and Kharchia (long coleoptile), ; Amery, Hartog, Janz, and Stiletto (short coleoptile).

The early stage growth was favorable in Vigour 18, ZL

Table 3. Mean values and analysis of variance of agronomic characteristics in the experiment by growth stage.

Nitrogen level (A)	Cultivar (B)	Leaf stage (C)	Leaf area / plant (cm²)	Leaf wt. / plant (mg)	Stem wt. / plant (mg)	Root wt. / plant (mg)	Total wt. (mg)
Low	Amery	1st (11 DAS†)	0.58	8.9	4.6	14.8	28.3
		2nd (19 DAS)	1.21	16.6	8.4	27.7	52.7
		3rd (27 DAS)	2.96	21.8	12.4	57.4	91.5
		4th (34 DAS)	4.03	36.0	28.2	77.2	141.4
	Janz	1st (11 DAS)	0.63	9.1	5.2	14.2	28.4
		2nd (19 DAS)	1.11	16.8	7.8	26.8	51.4
		3rd (27 DAS)	2.84	24.7	12.3	61.5	98.5
		4th (34 DAS)	4.31	39.3	22.2	84.6	146.1
	ZL 59A	1st (11 DAS)	2.38	12.7	6.0	20.7	39.4
		2nd (19 DAS)	3.43	23.2	9.9	39.0	72.0
		3rd (27 DAS)	5.81	30.2	16.1	77.9	124.1
		4th (34 DAS)	9.04	51.2	45.3	113.3	209.9
	Vigour 18	1st (11 DAS)	3.24	14.5	6.0	21.1	41.6
		2nd (19 DAS)	5.25	29.9	13.0	44.3	87.3
		3rd (27 DAS)	7.80	36.0	22.9	85.7	144.5
		4th (34 DAS)	9.55	59.0	49.5	107.8	216.3
High	Amery	1st (11 DAS)	1.01	10.6	5.1	17.2	32.9
		2nd (19 DAS)	1.73	18.1	8.9	30.7	57.7
		3rd (27 DAS)	3.58	27.6	14.4	66.6	108.7
		4th (34 DAS)	5.33	41.6	36.1	80.7	158.5
	Janz	1st (11 DAS)	0.88	10.9	6.1	15.9	33.0
		2nd (19 DAS)	1.49	18.4	8.7	33.0	60.1
		3rd (27 DAS)	3.21	27.1	14.0	68.7	109.8
		4th (34 DAS)	5.01	43.2	23.8	93.9	160.8
	ZL 59A	1st (11 DAS)	2.80	14.7	7.6	21.9	44.2
		2nd (19 DAS)	4.09	28.4	12.0	43.7	84.0
		3rd (27 DAS)	6.95	36.3	20.3	87.2	143.9
		4th (34 DAS)	11.10	57.8	57.6	123.2	238.6
	Vigour 18	1st (11 DAS)	3.65	16.2	6.2	23.6	46.0
		2nd (19 DAS)	6.16	31.8	14.1	50.9	96.8
		3rd (27 DAS)	8.15	47.3	29.3	105.7	182.3
		4th (34 DAS)	10.48	66.3	62.6	126.6	255.5
	ANOVA						
	Main (A)		**	**	**	**	**
	Subplot (B)		**	**	**	**	**
	A*B		NS	NS	*	NS	*
	Sub-subplot (C)		**	**	**	**	**
	A*C		*	**	**	**	**
	B*C		**	**	**	**	**
	A*B*C		NS	NS	NS	NS	NS

† DAS : Days after sowing.
*, ** Significant at 5 and 1% probability levels, respectively; NS Not significant.

59A (long coleoptile) and Amery, Janz (short coleoptile) as shown in Tables 1 and 2.

Growth stage and response to nitrogen rates

The results of response to growth stage and N rates in four cultivars selected in the 1st experiment, long (Vigour 18, ZL 59A) and short (Amery, Janz) coleoptile, are given in Tables 3 and 4.

Table 4. Mean values and analysis of variance of agronomic characteristics in the experiment by growth stage.

Nitrogen level (A)	Cultivar (B)	Leaf stage (C)	Root /shoot ratio	Number of root	Root length / plant (mm)	Longest root length (mm)
Low	Amery	1st (11 DAS+)	1.09	4.6	537	181
		2nd (19 DAS)	1.10	5.4	860	257
		3rd (27 DAS)	1.68	6.5	1518	439
		4th (34 DAS)	1.22	8.0	1857	544
	Janz	1st (11 DAS)	0.99	4.5	574	160
		2nd (19 DAS)	1.09	5.4	966	263
		3rd (27 DAS)	1.66	7.4	1494	354
		4th (34 DAS)	1.38	9.0	2142	502
	ZL 59A	1st (11 DAS)	1.10	5.0	678	169
		2nd (19 DAS)	1.17	5.3	1182	280
		3rd (27 DAS)	1.69	6.4	1637	368
		4th (34 DAS)	1.18	8.0	2368	573
	Vigour 18	1st (11 DAS)	1.02	5.1	695	170
		2nd (19 DAS)	1.03	7.4	1123	265
		3rd (27 DAS)	14.7	8.6	2066	466
		4th (34 DAS)	1.00	10.3	2513	528
High	Amery	1st (11 DAS)	1.10	5.1	641	177
		2nd (19 DAS)	1.14	5.9	961	287
		3rd (27 DAS)	1.58	7.0	1663	489
		4th (34 DAS)	1.05	8.4	2050	583
	Janz	1st (11 DAS)	0.94	5.0	675	184
		2nd (19 DAS)	1.22	6.4	1053	291
		3rd (27 DAS)	1.67	8.0	1798	404
		4th (34 DAS)	1.41	9.5	2274	565
	ZL 59A	1st (11 DAS)	0.98	5.1	727	181
		2nd (19 DAS)	1.08	6.0	1260	305
		3rd (27 DAS)	1.55	6.9	1912	485
		4th (34 DAS)	1.07	9.0	2569	599
	Vigour 18	1st (11 DAS)	1.05	6.0	908	197
		2nd (19 DAS)	1.11	8.1	1408	325
		3rd (27 DAS)	1.38	9.0	2254	541
		4th (34 DAS)	0.99	10.6	2961	667
	ANOVA					
	Main (A)		NS	**	**	**
	Subplot (B)		**	**	**	**
	A*B		NS	NS	NS	NS
	Sub-subplot (C)		**	**	**	**
	A*C		NS	NS	NS	*
	B*C		**	**	**	*
	A*B*C		NS	NS	NS	NS

+ DAS : Days after sowing.
*, ** Significant at 5 and 1% probability levels, respectively; NS : Not significant.

The leaf area had very high significance with increasing N rate, cultivars, and harvesting period at the last harvest as in the following: Amery 4.03 cm^2 (low N rate; L) to 5.33 cm^2 (high N rate; H), Janz 4.31 cm^2 (L) to 5.01 cm^2 (H), Zl 59A 9.04 cm^2 (L) to 11.10 cm^2 (H), and Vigour 18 9.55 cm^2 (L) to 10.48 cm^2 (H), respectively. The values of leaf and stem weight of all cultivars were increased with increasing N rate and there was a difference between long and short coleoptile cultivars. The root weight and total weight significantly increased with increasing N rate and the early growth of long coleoptile cultivars was more favorable than that of short coleoptile cultivars.

In the R/S (Root/Shoot) ratio, the development below ground was greater at the low N treatment, but there was shown to be similar growth below ground and above ground, and these tendencies were presented at the high N treatment. Moreover, the number of roots and root length were apparently significant with increasing N rate. The early growth of long coleoptile cultivars, especially Vigour 18, was favorable at the low and high N treatment, and in the case of the short coleoptile cultivars, Janz.

Sowing densities and nitrogen rates

The analysis of variance of leaf area and traits of Vigour 18 (long coleoptile) and Janz (short coleoptile), which were selected as the result of the 2nd experiment, are presented in Tables 5 and 6.

The leaf area and stem weight of Vigour 18 and Janz were apt to be decreased by the increasing plant density at the low and high N rates, and were significantly affected by increasing the N rate. The leaf weight of Vigour 18 decreased form 33.7 mg to 28.4 mg and that of Janz decreased form 27.4 mg to 21.4 mg at the low N rate. It is said that these results come from extreme competitions against nutrient, moisture, CO_2, and light between inter-plants (Hong, 1983). Therefore, the stem elongation was thought to be inhibited. Jeon et al. (1992) also reported that increasing plant density decreased growth traits. It was thought that there were occurrences of nutrient and moisture competitions and decreasing photosynthetic capacity. As a result, the poor growth was also presented by plant density in this experiment.

The root weight of Vigour 18 was reduced from 84.6 mg to 69.0 mg and from 62.1 mg to 50.9 mg for Janz at the low N rate by the increasing plant density, respectively. At the high N rate, the root weights of the two cultivars, of course, decreased as the same tendency, the density effect was highly presented at the high N rate as development of the root system. Miller (1916) reported that root system development was significantly influenced by soil and climate conditions and management of crops. There were similar results at the increasing N rate of this study, but the poor root system development was observed at the high plant density. The total weight at the high N rate increased more than at the low N rate.

The R/S ratio of Vigour 18 and Janz were increased from the plot sown 1 seed to 3 seeds, while were decreased at 4 seeds at the low and high N rates. At increasing N rate, the below ground system was greaster than the above ground because of the early growth stage. The root length of long coleoptile, Vigour 18, increased 390 mm (1 seed plot) to 431 mm (3 seeds plot), but decreased 420 mm (4 seed plot) at the low and high N rates. On the other hand, the root length of short coleoptile, Janz, was the greatest at the 2 seed plot at the low and high N rates. Hoshikawa (1989) reported that the fertilizer condition and the depth of cultivation incluenced the root system in barley, therefore the root system of healthy plants was deeper and grew faster than that of unhealthy plants. In this study, it was presented to be a similar tendency as described by Hoshikawa, while, the high density planting resulted in the unhealthy plants formed due to the competitions for nutrient and moisture.

Table 7 shows RGR, NAR, LAR, and SLA in the experiment by nitrogen rates and density. The RGR was the same at low N rate and high N rate. The RGR was 0.071 and 0.072 g g^{-1} d^{-1} at low N rate and high N rate. The partitioning of RGR into NAR and LAR showed that average LAR at low N rate was similar to that of high N rate. Variaiton within each cultivar in LAR and NAR was small relative to the difference between them at low N rate and high N rate. These results were similar in both low N rate and high N rate experiments.

Table 5. Mean values and analysis of variance of leaf area in the experiment by density.

Nitrogen level (A)	Cultivar (B)	Density (C)†	Days after sowign (DAS) 11 DAS	19 DAS	27 DAS
Low	Vigour 18	1	3.4‡	6.5	9.8
		2	3.2	6.1	9.7
		3	3.2	5.9	9.5
		4	3.0	5.7	8.4
	Janz	1	2.2	4.3	7.2
		2	2.0	4.0	6.7
		3	1.8	3.6	6.2
		4	1.8	3.4	5.7
High	Vigour 18	1	3.8	7.1	12.2
		2	3.7	7.1	12.2
		3	3.6	7.1	11.8
		4	3.5	6.5	10.4
	Janz	1	2.5	4.8	8.3
		2	2.5	4.7	7.9
		3	2.3	4.1	7.5
		4	2.2	4.0	6.6
	ANOVA				
	Main (A)		**	**	**
	Subplot (B)		**	**	**
	A*B		NS	NS	**
	Sub-subplot (C)		NS	**	**
	A*C		NS	NS	NS
	B*C		NS	NS	NS
	A*B*C		NS	NS	NS

† Density : Number of plant per pot

‡ Values are square centimeter per plant.

** Significant at 5 and 1% probability levels, respectively; NS : Not significant.

Table 6. Mean values and analysis of variance of agronomic characteristics in the experiment by density.

Nitrogen level (A)	Cultivar (B)	Density (C)†	Leaf wt. (mg)/plant	Stem wt. (mg)/plant	Root wt. (mg)/plant	Total wt. (mg)	Root/shoot ratio	Longest root length (mm)
Low	Vigour 18	1	33.7	24.8	84.6	143.1	1.45	390
		2	32.1	21.6	82.0	135.7	1.53	418
		3	30.6	20.7	81.7	133.1	1.59	431
		4	28.4	20.4	69.0	117.8	1.42	420
	Janz	1	27.4	14.0	62.1	103.5	1.50	375
		2	24.3	11.9	56.9	93.1	1.57	461
		3	22.3	11.0	52.9	86.1	1.59	425
		4	21.4	10.7	50.9	83.1	1.58	409
High	Vigour 18	1	41.4	26.9	92.7	160.9	1.36	450
		2	39.5	26.7	92.6	158.7	1.40	459
		3	36.7	24.9	92.0	153.6	1.49	545
		4	35.8	23.5	84.3	143.6	1.42	532
	Janz	1	30.8	16.2	72.2	119.2	1.54	466
		2	28.5	14.2	66.6	109.3	1.56	531
		3	27.1	11.9	61.1	100.0	1.57	479
		4	25.5	11.3	56.6	93.4	1.54	475
	ANOVA							
	Main (A)		**	**	**	**	NS	**
	Subplot (B)		**	**	**	**	*	NS
	A*B		**	NS	NS	NS	*	NS
	Sub-subplot (C)		**	**	**	**	*	*
	A*C		NS	NS	NS	NS	*	NS
	B*C		NS	NS	NS	NS	NS	NS
	A*B*C		NS	NS	NS	NS	NS	NS

† Density : Number of plant per pot

*,** Significant at 5 and 1% probability levels, respectively; NS : Not significant.

The greater the sowing density the larger the SLA and LAR tended to grow, and then in the low N rate, SLA was the larger of the two. The values of SLA and LAR of Janz were greater than Vigour 18.

The greater plant mass, leaf area, and leaf appearance rate of wheat previously found in field-grown plant (Lopez-Castaneda and Richards, 1994a). The magnitude of the differences between cultivars for plant mass and leaf area in these experiments was also similar.

Above ground mass was 8.2 mg greater at high N rate than low N rate, whereas leaf area was 0.05 m^2 kg^{-1} greater at high N rate than low N rate.

The RGR is the product of NAR and LAR, and it was found that at low N rate and high N rate had similar RGR but for different reasons. The NAR was similar at low N rate and high N rate, whereas LAR was greater at high N rate (0.05 m^2 kg^{-1}); variation in SLA was responsible for the variation in NAR and LAR both at low N rate and high N rate. NAR was more closely associated with the reciprocal of SLA.

Greater growth after sowing is advantageous in winter-grown spring cereals not only because it results in a greater water use by plants at expense of water lost by evaporation from the soil surface but also because of greater ratio of assimilation to transpiration during the winter compared with if growth was delayed until spring (Tanner & Sinclair, 1983). The advantage will arise from a higher transpiration efficiency because of more growth when it is cool and reduction in water lost from the soli surface, which can translate to more water use by the crop (Lopez-Castaneda & Richards, 1994b). There are additional advantages from early vigour in reducing weed biomass and herbicide use. This study identifies the interval between germination and the appearance of the first four seedling leaves as being responsible for the substantially greater vigour of long coleoptile culivar compared with short coleoptile cultivar.

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Table 7. Relative growth rates (RGR) for the duration of each experiment. Net assimilation rate (NAR), leaf area ratio (LAR) and specific leaf area (SLA) for wheat cultivars.

Nitrogen level (A)	Cultivar (B)	Density (C)	RGR	NAR	LAR	SLA
			$g\ g^{-1}d^{-1}$	$g\ m^{-2}d^{-1}$	$-m^2kg^{-1}-$	
Low	Vigour 18	1	0.066	0.039	1.67	2.90
		2	0.069	0.038	1.80	3.02
		3	0.068	0.037	1.85	3.10
		4	0.064	0.037	1.72	2.95
	Jnaz	1	0.074	0.043	1.73	2.62
		2	0.075	0.041	1.85	2.75
		3	0.077	0.041	1.86	2.78
		4	0.072	0.040	1.77	2.66
High	Vigour 18	1	0.073	0.041	1.78	2.94
		2	0.075	0.040	1.84	3.08
		3	0.074	0.038	1.93	3.21
		4	0.068	0.038	1.75	2.90
	Janz	1	0.075	0.042	1.76	2.69
		2	0.072	0.038	1.85	2.77
		3	0.074	0.039	1.92	2.76
		4	0.068	0.038	1.79	2.58
	ANOVA					
	Main (A)		*	NS	*	NS
	Subplot (B)		**	**	**	**
	A*B		**	**	**	**
	Sub-subplot (C)		**	**	**	**
	A*C		**	NS	**	**
	B*C		**	NS	**	**
	A*B*C		NS	NS	**	**

*,** Significant at 5 and 1% probability levels, respectively
NS : Not Significant

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