The effect of sowing date on growth and yield of two cultivars of oats

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Abstract

Oats cvs. Cashel and Drummond were sown at Lincoln on 16 September, 2 November, and 21 December 1994; and on 7 February, 3 April, and 16 May 1995 in order to compare the effect of sowing date on their growth and yield. Biomass and leaf area were measured at one to four-week intervals from the end of tillering. Crops grew for periods ranging from just over 100 days to nearly 300 days. The crop sown in February died before maturity, and the one sown in April was affected by frost. Biomass production was much higher for the April sowing (over 20 t/ha) than the 7.5-15 t/ha for the other sowings, and was higher for Drummond than for Cashel at all sowing dates. Leaf area indices did not exceed 4.5 except for the February and April sowings of Drummond. There was a strong linear relationship between cumulative biomass production and intercepted radiation for all sowing dates, with the same rate of increase in biomass with radiation increase for both cultivars. Grain yields estimated from quadrat samples were higher than header yields for all sowings, but especially for the April sowing in which grain weights and harvest indices were lower than for the other sowings. Fifty-seven percent of grain yield came from post anthesis photosynthesis and 43% from remobilization from other plant parts. Oat yield is dependent on the amount of radiation intercepted by the crop and harvest index. Changes in conversion of radiation to biomass were not significantly affected by the range of conditions experienced by the crops in this study.

Additional key words: *leaf area, radiation interception, kernel weight*

Introduction

As well as being grown widely for greenfeed, oats (*Avena sativa* L.) rank sixth in world cereal grain production following wheat, maize, rice, barley and sorghum. However, compared with these five crops, relatively little research has been undertaken on the growth and development of the oat crop. Thus our ability to predict the performance of this crop in different environments is limited.

The objective of Crop & Food Research's oat physiology programme is to gather sufficient information to be able to adapt crop growth and development models, such as those for wild oats (Weavers *et al.*, 1993) and other cereals (e.g., Jamieson *et al.*, 1996), to the cultivated oat crop.

In order to adapt existing models to oats, it is necessary to evaluate how the oat crop responds to different environmental conditions by changing light interception, growth duration or efficiency, or partitioning of dry matter to economic yield.

Following the approach of Charles-Edwards (1982), the accumulation of biomass (B) by a crop can be described as the integral of the crop growth rate (C), which is the product of the amount of radiation intercepted (Q) and the radiation use efficiency (A):

$$B = \int(C.dt) = \int(A.Q.dt) \quad (1)$$

Q can be calculated from measurements of incident radiation (Qo) and leaf area index (LAI) using Beer's Law:

$$Q/Qo = 1\text{-}exp(-k.LAI) \quad (2)$$

where k is an extinction coefficient that depends on canopy geometry, and for temperate cereals is about 0.45 (Jamieson *et al.*, 1995).

The economic yield of the crop (Y) depends on the harvest index (HI):

$$Y = HI \times B \quad (3)$$

In unstressed crops, A is very stable (Monteith, 1977, Wilson and Jamieson 1984), and so biomass production depends mainly on the amount of radiation intercepted, and hence on the duration of growth. Under conditions of stress, such as drought, either Q or A or both can be reduced depending on when the stress is imposed (Jamieson *et al.*, 1995). HI is also affected by environmental conditions, and varies between cultivars (Donald and Hamblin, 1976).

Undertaking a field experiment in which sowings are spread throughout the year is an effective way of obtaining a suitable data set to use in the evaluation of crop models because it exposes cultivars to a wide range of temperature and photoperiod conditions, and hence produces contrasting responses in the rate and duration of growth. Such an experiment was carried out at Lincoln with two oat cultivars sown on six dates over a year. This paper reports on the biomass production, leaf area and grain yield results from the experiment.

Methods

The experiment was carried out on a Templeton Silt Loam at Crop & Food Research's Lincoln farm. The cultivars were Cashel, a tall, early-maturing forage and feed oat, and Drummond, a semi-dwarf, late-maturing milling oat. They were sown with an Oyjord drill at 169 kg/ha for Cashel and 167 kg/ha for Drummond, with the aim of establishing 300 plants/m^2. Sowing dates were 16 September, 2 November, and 21 December 1994; and 7 February, 3 April, and 16 May 1995. The experiment was a split plot design with sowing dates as main plot treatments, arranged in four randomized complete blocks, and cultivars as subplot treatments. Each subplot was 15 m long by 2.7 m wide. Herbicides, insecticides and fungicides were applied as required, but no fertilizer was applied. Irrigation was applied when soils were close to wilting point. Except for the first sowing of Cashel, plots were covered with netting soon after anthesis to prevent bird damage.

Emerging plants were counted in six 0.1 m^2 quadrats to determine when 50% of the plants had emerged. From mid tillering to maturity, at intervals varying from weekly in mid summer to monthly in winter, a 0.1 m^2 quadrat was harvested to ground level from each subplot for growth analysis. Measurements included biomass and leaf area index (LAI), and, at maturity, grain yield. If possible, the plots were then harvested with a Wintersteiger plot header to get a header grain yield. Four of the sowings were headed at maturity. The December sowing was not headed because of cold, damp conditions and severe lodging at maturity, and the February sowing did not mature. For the December sowing, two 1.5 m^2 quadrats were taken from each plot to obtain a yield estimate.

Daily LAI values were interpolated linearly between adjacent samplings, using means over replicates for each treatment, and daily incoming radiation data were obtained from the Lincoln Meteorological Station, about 300 m from the experiment. These data were then used to calculate radiation intercepted (Q) on a daily basis using equation (2) and accumulate it throughout the growth of each crop.

Total biomass and LAI data were log transformed prior to a joint analysis of variance of each measurement, treating sampling dates as a sub-subplot factor. Regression analysis on means over replicates were fitted to test for differences in radiation use efficiency. All statistical analyses were performed with the GENSTAT statistical package (Genstat 5 Committee, 1993). Where, when analysed as a split plot experiment, main plot variances were less than subplot variances, the experiment was reanalysed as a randomized complete block experiment.

Results

Meteorological data recorded during the experiment are presented in Table 1. In all but three of the 18 months of the experiment, rainfall was lower than the long term average; it was less than half in nine of the months. Mean temperatures were similar to the long term average, but solar radiation was generally higher, especially in the spring and summer of 1994/95.

The crops were generally free of diseases and pests. The April sowing showed symptoms of infestation by Barley Yellow Dwarf Virus (BYDV), and the May sowing was infected by Halo Blight and *Fusarium* root infection.

The September and May sowings took 16 days to reach 50% emergence, whereas the other four sowings took only 6-8 days. There was little difference in emergence between the two cultivars. Plant populations generally exceeded the target 300 plants/m^2, indicating that field emergence was higher than the 70% used in calculating sowing rates.

The duration of crop growth varied considerably among sowing dates (Figure 1), with time from emergence to maturity ranging from just over 100 days for the November and December sowings to nearly 300 days for the April sowing. The February sowing grew to

Table 1. Rainfall, mean temperature and solar radiation data from the Lincoln Meteorological Station.

	Rainfall (mm)			Mean temperature (°C)			Solar Radiation (MJ/m^2)		
Month	1994-5	1995-6	Mean	1994-5	1995-6	Mean	1994-5	1995-6	Mean
September	56.4	94.0	40.1	8.1	9.1	9.2	401	324	339
October	19.0	39.6	54.9	10.1	10.5	11.3	517	479	508
November	22.7	19.8	55.7	13.9	12.4	13.1	756	684	603
December	24.7	15.3	61.3	15.2	17.0	15.7	814	732	673
January	32.3	16.0	50.3	16.3	16.6	17.0	760	689	669
February	25.4	32.3	51.3	16.5	16.6	16.3	527	581	515
March	32.5	-	58.9	15.5	-	15.0	502	-	421
April	31.0	-	51.8	13.0	-	12.2	264	-	288
May	25.1	-	50.4	9.7	-	8.7	183	-	177
June	146.4	-	63.0	6.4	-	6.3	121	-	126
July	22.6	-	73.7	4.6	-	6.1	182	-	146
August	56.2	-	68.1	7.2	-	7.6	273	-	220

the ear emergence stage for Cashel and the booting stage for Drummond, but then growth stopped and the crops died during winter. In the April sowing, the reproductive apices on the main stems of Cashel were killed by frost, but development continued on tillers.

Growth of Cashel for the September sowing was reduced in the later stages because most of the grain was removed by birds at the milky ripe stage. So biomass production was only 7500 kg/ha in this cultivar compared to around 10000 kg/ha for Drummond. Biomass production for both cultivars reached around 10000 kg/ha for the November and December sowings (Fig. 1). It was only about 7500 kg/ha in the February sowing, and this was reached just after the ear had emerged in Cashel and at the boot stage in Drummond. In contrast, biomass production exceeded 20000 kg/ha in the April sowing and 12500 kg/ha in the May sowing. Production was higher for Drummond than for Cashel at all sowing dates.

LAIs were low in the September, November and December sowings; values for Cashel were slightly lower than for Drummond (Fig. 2). The low LAIs in these sowings may have been caused by dry conditions during the spring and summer of 1994/95. LAIs were also low in the May sowing, which was affected by BYDV. Values in the February and April sowings did not exceed 4.5 for Cashel, but were much higher for Drummond.

A (radiation use efficiency, g/MJ), the slope of the lines in Figure 3, was not significantly different between the two cultivars, indicating that total biological yield was solely a function of the amount of light intercepted during the growth of the crop. A was also not significantly different between sowing dates (Table 2).

Drummond produced a higher grain yield than Cashel for all sowings (Table 3). Drummond header yields were more consistent, ranging from 4.3 to 6.2 t/ha. Cashel yields were very variable, ranging from around 2 t/ha for the April and May sowings to 5 t/ha for the November sowing. Yields from the September sowing of Cashel were reduced by bird damage at the milky ripe stage. In subsequent sowings, all plots were covered with netting after panicle emergence.

Quadrat yields averaged 0.6 t/ha higher than header yields for the September and November sowings (Table 3). For the April and May sowings, quadrat yields were up to twice as high as header yields, a reflection of greater header losses of small grain in these two sowings.

Kernel weights for Cashel ranged from 29.8 to 40.9 mg (Table 3). Except for the April sowing, values for Drummond were 2 to 4 mg lower. Kernel weight was significantly lower for the April sowing for both cultivars, probably a reflection of the BYDV infection.

HI was lower for Cashel than for Drummond for all sowing dates (Table 3). The difference was greatest for

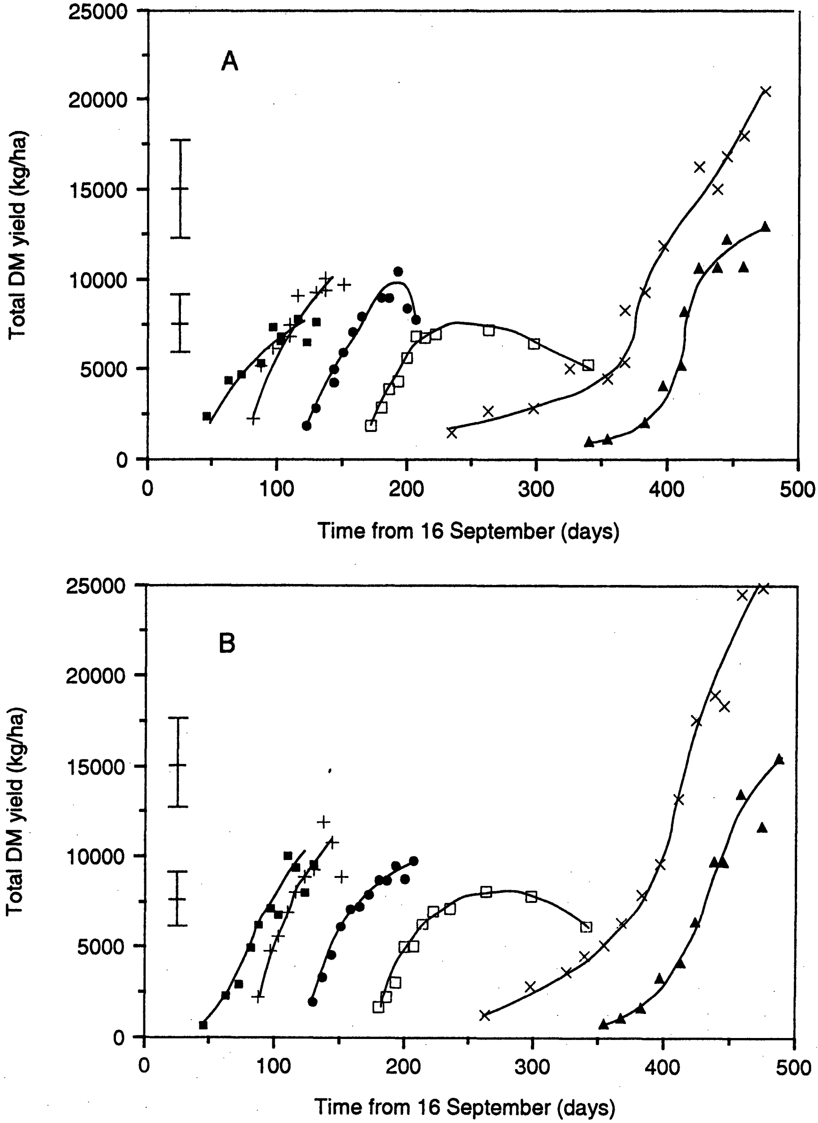
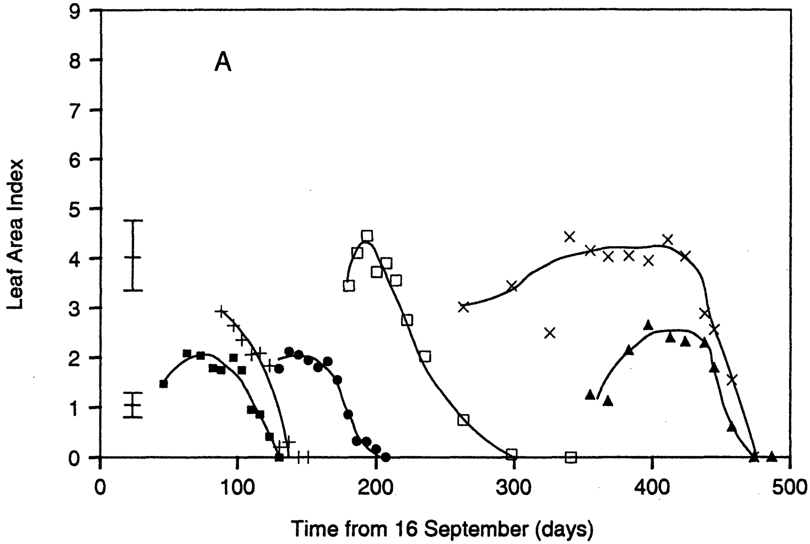


Figure 1. Total biomass production (t/ha) over time for (a) Cashel and (b) Drummond. Sowing dates: ■ = 16 September, + = 2 November, O = 21 December, □ = 7 February, x = 3 April, ▲ = 16 May. Curves fitted by eye. Vertical bars indicate 95% confidence intervals, calculated from $\log_{10}$ transformed data, for 7.5 and 15 t/ha.



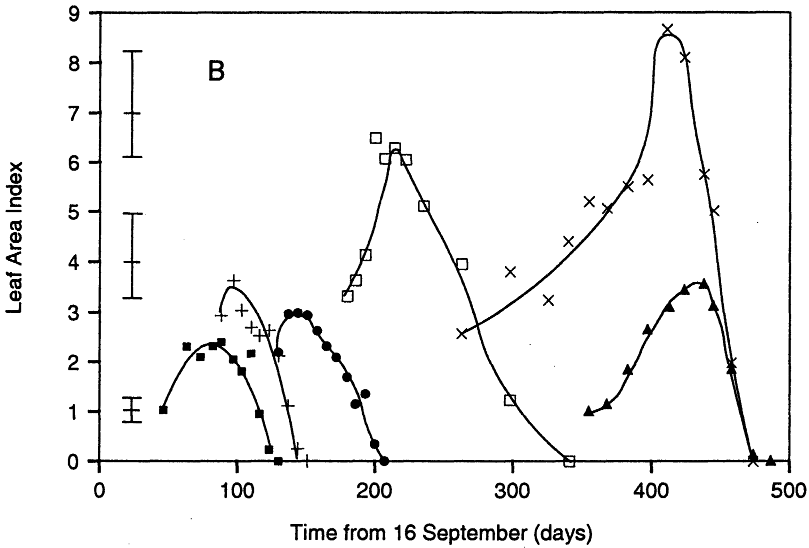
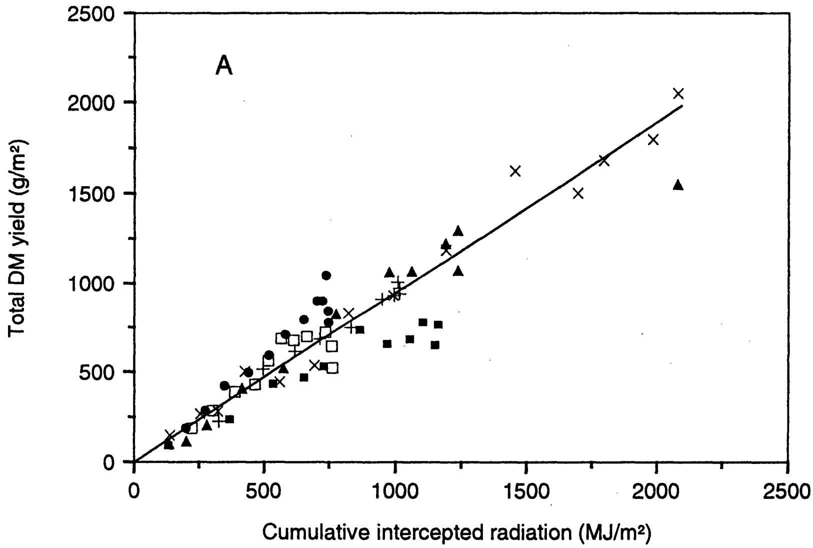


Figure 2. **Leaf area index over time for (a) Cashel and (b) Drummond. Sowing dates: ■ = 16 September, + = 2 November, O = 21 December, □ = 7 February, x = 3 April, ▲ = 16 May. Curves fitted by eye. Vertical bars indicate 95% confidence intervals, calculated from $\log_{10}$ transformed data, for LAI of 1, 4, and 7.**



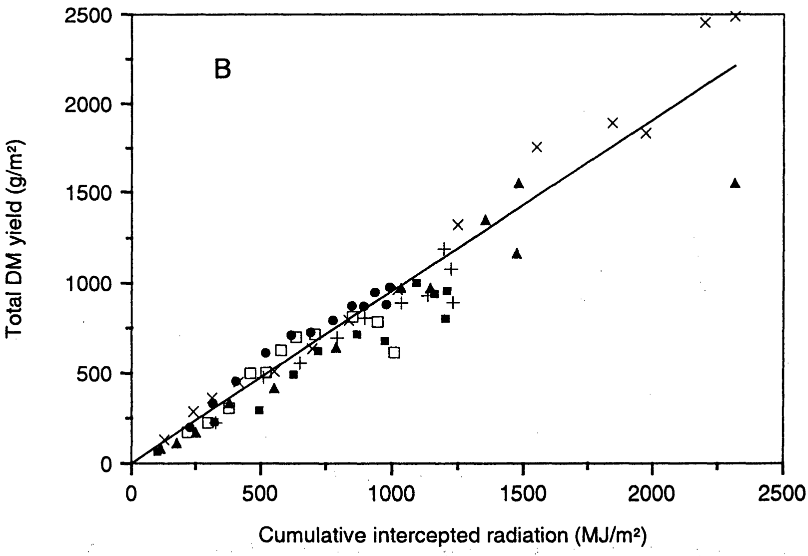


Figure 3. **The relationship between total biomass production (g/m^2) and cumulative amount of radiation intercepted (MJ/m^2) for (a) Cashel and (b) Drummond. Sowing dates: ■ = 16 September, + = 2 November, O = 21 December, □ = 7 February, x = 3 April, ▲ = 16 May. Slopes of the regression lines plotted through the origin are: Cashel: 0.94 (±0.019), r^2=0.893($P<0.001$); Drummond: 0.95 (±0.016), r^2=0.934($P<0.001$).**

Table 2. Values of A (Radiation Use Efficiency) (g/MJ) for Cashel and Drummond from six sowing dates.

	Cashel			Drummond		
Sowing date	A	Standard error	R squared	A	Standard error	R squared
16 Sep	0.68	0.246	0.902	0.78	0.275	0.936
2 Nov	0.95	0.155	0.974	0.86	0.279	0.917
21 Dec	1.20	0.344	0.931	1.01	0.216	0.953
7 Feb	1.05	0.314	0.939	1.00	0.323	0.946
3 Apr	0.96	0.213	0.978	1.04	0.205	0.984
16 May	0.99	0.277	0.972	0.91	0.340	0.959

Table 3. Plant population, grain yield, kernel weight and harvest index. Weight data are at 14% moisture content.

				Grain yield (t/ha)							
		Plant population ($plants/m^2$)		Header		Quadrat		Kernel weight (mg)		Harvest index	
Sowing date	Harvest date	Cashel	Drumm.	Cashel	Drumm.	Cashel	Drumm.	Cashel	Drumm.	Cashel	Drumm.
16 Sep	8 Feb	352	286	3.6	5.4	4.2	6.2	38.8	36.7	41.5	52.3
2 Nov	8 Feb	358	339	5.0	6.2	5.7	6.6	40.9	36.6	50.0	52.6
2 Dec	11 Apr[1]	421	375	3.5	4.3	4.4	5.7	39.6	36.5	42.5	50.0
7 Feb	July/Aug[2]	353	288	-	-	-	-	-	-	-	-
3 Apr	13 Feb	362	343	1.7	6.1	6.4	12.2	29.8	29.8	29.6	42.8
16 May	13 Feb	359	295	2.5	6.1	6.7	9.1	36.3	33.0	47.2	48.7
L.s.d.$_{0.05}$ Sowing dates within cultivars (d.f. = 25-31)		55*		0.70*		1.92*		3.60		3.65	
L.s.d.$_{0.05}$ Cultivar within sowing dates (d.f. = 15)								2.52		3.40	

[1] hand harvested; [2] crop died;
* L.s.d.(5%) for sowing date - cultivar interaction when analysed as randomized block.

the April sowing where HI was only 29.6% for Cashel compared with 42.8% for Drummond (Table 3). For all other sowing dates, Drummond averaged 49-53% HI. HIs were calculated from the original data, not the back transformed data in Figure 1.

If grain yield all came from post anthesis photosynthesis, then it would equal the increase in total biomass of the crop from anthesis to maturity. However, Figure 4 shows that the increase in grain yield for all sowings was more than the increase in biomass. The regression line indicates that 57% of grain yield was produced after anthesis and that the other 43% came from remobilization of dry matter from other plant parts.

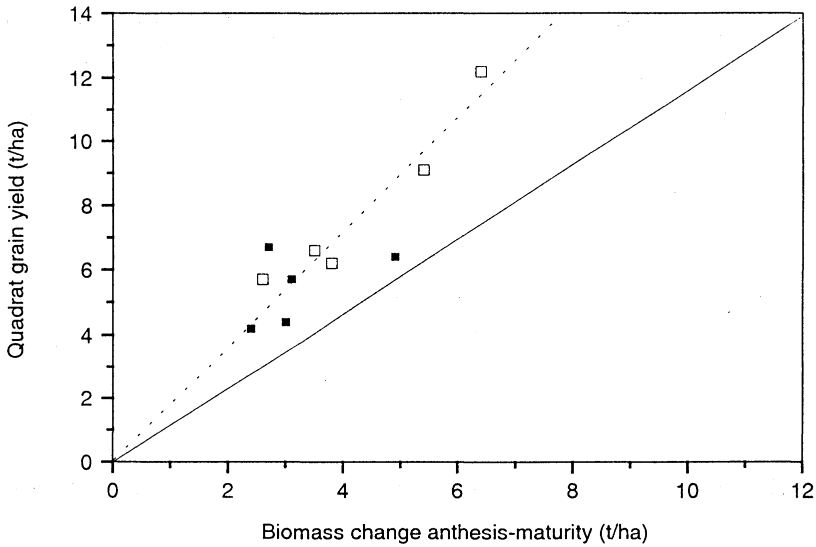


Figure 4. The relationship between quadrat grain yield (t/ha) and the increase in quadrat biomass from anthesis to maturity (t/ha) for the five sowing dates. □ = Cashel; ■ = Drummond. Solid line is the 1:1 ratio. Dotted line fitted through the origin: slope = 1.75 (±0.093), r^2 = 0.75(P<0.01).

Discussion

Radiation interception was not measured in this experiment. However, the extinction coefficient of 0.45 used to estimate the amount of radiation intercepted is the value measured in wheat (Thorne *et al.*, 1988) and barley (Jamieson *et al.*, 1995). It was assumed to be the same for oats, which has a similar canopy architecture to wheat and barley. Martin (1986) found that the amount of radiation intercepted changes little over a range of extinction coefficients.

The relationship between total biomass production and the amount of total radiation intercepted, with a slope of 0.94 g/MJ, was the same for both cultivars. For photosynthetically active radiation, which is 48% of total incoming solar radiation in New Zealand (McCree, 1966), the slope is 1.96 g/MJ. This is slightly lower than for other cereal crops at Lincoln (Wilson and Jamieson, 1984, Jamieson *et al.*, 1995). Analysis of the individual regression lines (Table 2) showed that the slopes did not vary significantly between sowing dates. This suggests that radiation use efficiency was quite robust to environmental factors - in this experiment moisture stress, frost damage and disease. In barley, Jamieson *et al.* (1995) found that A was only reduced when moisture stress was imposed early in growth, and that after this, biomass production was only limited by Q.

There may have been some overall restriction to growth from reduced availability of nitrogen. To reduce the risk of lodging, which would have made sampling very difficult, no nitrogen was applied to the crop and it was only irrigated when the soil neared wilting point. However, biomass production at equivalent sowing and harvest dates was similar to yields obtained elsewhere in New Zealand (Rhodes, 1977, Taylor and Hughes, 1979). Therefore, the results from the experiment were not atypical.

The very high total biomass production in the April sowing was offset by a low HI, especially in Cashel. A negative relationship between duration of vegetative growth and HI was reported for a number of oat cultivars by Peltonen-Sainio (1994), who attributed the negative relationship to a reduced ability to allocate photoassimilates to the grain in crops with high biomass. In this experiment, BYDV infection will have contributed to the reduction in grain size and yield in the April sowing. In Cashel this may have been exacerbated by the main stems being killed by frost, so that all of the grain yield was obtained from tillers. Drummond was much slower to reach reproductive development in this sowing, and so the young growing point was protected until the danger from frost was over.

The 43% contribution to grain yield from remobilization of material from other plant parts contrasts with the results of McMullen *et al.* (1988), which indicated that nearly all oat grain yield came from post anthesis production. However, the results from this experiment were very similar to those obtained previously with wheat (Martin, 1992). These ignore losses due to respiration, which can be considerable (Austin *et al.*, 1977).

This experiment has shown that, over a wide range of growth durations and various amounts of incoming radiation, oat biomass was a function of Q, the amount of radiation intercepted. The duration of growth and HI varied considerably according to time of sowing, but A was little affected by time of sowing and the environmental stresses experienced in this experiment.

References:

Austin, R.B., Edrich, J.A., Ford, M.A. and Blackwell, R.D. 1977. The fate of the dry matter, carbohydrates and ^{14}C lost from the leaves and stems during grain filling. *Annals of Botany* ***41***, 1309-1321.

Charles-Edwards, D.A. 1982. Physiological determinants of crop growth. Academic Press, Sydney. 161 pp.

Donald, C.M. and Hamblin, J. 1976. The biological yield and harvest index of cereals as agronomic and plant breeding criteria. *Advances in Agronomy* ***28***, 361-405.

Genstat 5 Committee 1993. Genstat 5 Release 3 Reference Manual. Oxford University Press, Oxford. 796 pp.

Jamieson, P.D., Martin, R.J., Francis, G.S. and Wilson, D.R. 1995. Drought effects on biomass production and radiation-use efficiency in barley. *Field Crops Research* ***43***, 77-86.

Jamieson, P.D., Semenov, M.A., Brooking, I.R. and Francis, G.S. 1996. Sirius: A mechanistic model of wheat response to environmental variation. Submitted to *Field Crops Research.*

Martin, R.J. 1986. Radiation interception and growth of sugar beet at different dates in Canterbury. New Zealand Journal of Agricultural Research 29, 381-390.

Martin, R.J. 1992. Dry matter and nitrogen redistribution in autumn and spring sown wheats. *Proceedings Agronomy Society of New Zealand* ***22***, 91-96.

McCree, K.J. 1966. A solarimeter for measuring photosynthetically active radiation. *Agricultural Meteorology* ***3***, 353-366.

McMullan, P.M., McVetty, P.B.E. and Urquhart, A.A. 1988. Dry matter and nitrogen accumulation and redistribution and their relationship to grain yield and grain protein in oats. *Canadian Journal of Plant Science* ***68***, 983-993.

Monteith, J.L. 1977. Climate and the efficiency of crop production in Britain. *Philosophical Transactions of the Royal Society, London Series B,* ***281***, 277-294.

Peltonen-Sainio, P. 1994. Growth duration and above-ground dry-matter partitioning in oats. *Agricultural Science in Finland* ***3***, 195-198.

Rhodes, P.J. 1977. The effect of harvest date and nitrogenous fertilizer on cool season forage yields of cereals and Tama ryegrass in Nelson and Marlborough. *Proceedings Agronomy Society of New Zealand* ***7***, 27-30.

Taylor, A.O. and Hughes, K.A. 1979. Effect of locality and sowing date on seasonal rates of dry matter accumulation of cereal forages. *Proceedings Agronomy Society of New Zealand* ***9***, 105-108.

Thorne, G.N., Pearman, I., Day, W. and Todd, A.D. 1988. Estimation of radiation interception by winter wheat from measurements of leaf area. *Journal of Agricultural Science, Cambridge* ***110***, 101-108.

Weavers, S.E., Kropff, M.J. and Cousens, R. 1993. A simulation model of *Avena fatua* L. (wild-oat) growth and development. *Annals Applied Biology* ***122***, 537-554.

Wilson, D.R. and Jamieson, P.D. 1984. Models of growth and water use of wheat in New Zealand. *In:* Wheat Growth and Modelling. (Eds. W. Day and R.K. Atkin), Plenum Press, New York, pp. 211-216.