Growth potential of spring forage cereals for silage

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Abstract

Cereals sown in the spring provide suitable supplements for grazing animals either as conserved feed or a standing crop. Comparisons were made between the growth responses of wheat, barley, oats and triticale cultivars over two seasons. The objective was to relate crop performance to key environment variables and to use the differences in crop responses (quantified as biomass accumulation and leaf growth) to discriminate among new cultivars and commercial standards. There were differences among cultivars in their biomass response to thermal time, particularly for early and late sown crops. There was more variation in radiation use efficiency among trials than for cultivars within trials. Growth response to temperature was a more useful indicator than radiation use efficiency for selecting cultivars with improved productivity. However, thermal time was not the sole factor determining growth. Timing of harvest was shown to be a predictable event because the change in moisture content progressed in a linear manner. Timing of harvest can, therefore, be adjusted by choosing cultivars with differing durations to maturity or by managing sowing dates.

Additional key words: *wheat, barley, oats, triticale, radiation use efficiency, crop development, thermal time*

Introduction

Good productivity with acceptable protein, fibre and soluble carbohydrate composition is the basis for increasing the use of whole crop cereals for supplementary feeding in dairy, beef and sheep production systems in New Zealand, (Eagles *et al.*, 1979; Hughes and Haslemore, 1984). While the use of cereals for grazing and silage is not a new concept (Burgess *et al.*, 1973), the introduction of cereal cultivars with improved yield and disease resistance (de Ruiter, 2000) and their relatively low production costs have resulted in renewed interest in them, particularly for dairy and beef feeding. Cereals provide flexible feed options (Jermyn *et al.*, 1993) when used as a standing winter feed crop or conserved as a single cut silage crop in late spring and summer. Shortages of pasture protein and fibre can readily be alleviated with whole crop cereal supplementation, especially during summer feed shortages (Kerr *et al.*, 1986).

Production patterns of cereals can be modified by selecting sowing dates and cultivars to match the requirements of dairy farm systems. Information is also required to manage crops for optimal quality of herbage for silage. For example, temporal changes in leaf and stem fractions, progression of dry matter (water content) and the accumulation of grain dry matter strongly influence the suitability of cereals for silage. Quick methods are also required for monitoring the progress of crop maturation in the field and defining the relationships between crop performance, crop development and crop quality. The pattern of production may be dependent on the efficiency of utilisation of resources during periods of active growth (Green, 1984; Gales, 1985). Factors such as biomass yield, seed yield, harvest index, canopy development and light capture, radiation use efficiency (RUE), water use efficiency and environmental effects on nutritional composition will determine the suitability of cultivar selections (Green, 1984; Green, 1987; Gallagher *et al.*, 1983; Bruckner and Raymer, 1990). Simple models using combinations of thermal time and radiation explain a significant amount of the yield variation of autumn oats grown in New Zealand (Hughes *et al.*, 1984). Deviations from generalised growth responses provide the best opportunity for screening and identifying potentially useful germplasm. However, there is a need to improve methods for predicting biomass and quality changes during development, and to include descriptions for existing commercial cultivars and new cultivars destined for the forage market.

The objective of the study was to derive patterns of leaf development and biomass accumulation and to relate these variables to environmental determinants. In addition, it was proposed to use these relationships to assist with species and/or cultivar selection on the basis of yield, and to determine optimum times for silage harvest.

Materials and Methods

Cultivar trials were conducted over two seasons at Lincoln, New Zealand (Lat. 43°39'S; Long. 173°30'E), on a Templeton silt loam (Typic Ustochrept, USDA soil taxonomy). In the first year (1999/2000), two trials were sown on sites 3 km apart. In year 2 (2000/01 season), two sowing dates were evaluated at a single site at Lincoln. Experimental numbered cereal lines, which showed good forage biomass productivity in small plot evaluations in previous seasons, were included for comparison with commercial cultivars.

Year 1

Two trials consisting of an early sowing date (ES1; 27 August 1999) with 4 entries and a late sowing (LS1; 2 November 1999) with six entries were sown in a randomised complete block design with three replicates (Table 1). Plots were 12.5 x 1.35 m. Soil tests in the ES1 trial were pH 6.3, Ca QT 8, Olsen P 18, K QT 4, SO_4 (ppm) 6, Mg QT 13, and Na QT 6. Similarly, soil tests for the LS1 trial were: pH 6.3, Ca QT 8, Olsen P 17, K QT 8, SO_4 (ppm) 3, Mg QT 11 and Na QT 5. Sowing rates were adjusted for seed viability and grain weight for target plant populations of 250 plants per m^2.

The ES1 trial required 3 irrigations of 25 mm each on 27/10, 18/11 and 20/12. Cropmaster 20 (200 kg/ha) was applied pre-planting, and nitrogen was applied as 150 and 100 kg urea on 2 September and 3 November, respectively. Trimec (3.5 L/ha)/Cougar 0.75 L/ha) and Puma S (0.75 L/ha) herbicides were applied on 20 October to control broadleaf weeds and annual grasses. In the LS1 trial, 50 kg N/ha urea and 200 kg/ha of 15% potassic superphosphate was applied pre-sowing and 50 kg N/ha urea was applied on 24 December. Trimec (3.5 L/ha) was applied on 7 December for weed control and the trial was irrigated on 1 Dec (50 mm).

Year 2

Two trials (ES2 and LS2) were sown on 8 September and 9 October 2000, respectively, using 12.5 x 1.35 m plots. The trials were sown as randomised complete block designs at Lincoln on the same soil type as for the trial in Year 1. Trial entries are shown in Table 1.

Soil tests prior to cultivation showed that levels of P and soluble sulphate were marginal. Corrections were subsequently made to balance these nutrients with the application of 334 kg/ha superphosphate on 28 August during pre-sowing cultivation. Test values for nutrients were as follows: pH 6.0, Ca QT 9, Olsen P 14, K QT 6, SO_4 (ppm) 4, Mg QT 12, Na QT 8. Urea was applied in three split applications of 50 kg N/ha on 17 October, 16 November, and 24 November for ES2 and on 16 November, 24 November and 13 December for LS2. Measurements of potentially mineralisable nitrogen on 21 August and 24 January for ES2 were 61 and

Table 1. Cereal cultivar entries in spring trials at Lincoln.

Species	Spring trial entries Year 1		
	Early sowing (ES1)	Late sowing (LS1)	Spring trial entries Year 2 [1]
Avena sativa L.	--	Hokonui	Hokonui
Avena sativa L.	--	Stampede	Stampede
Triticum aestivum L.	Sapphire	Sapphire	Sapphire
Hordeum vulgare L.	Omaka	Omaka	Omaka
Hordeum vulgare L.	1828.100	1828.100	--
Hordeum vulgare L.	--	--	1802.102.13
Triticum (x Triticosecale)	Rocket	Rocket	Rocket
Triticum (x Triticosecale)	--	--	Aranui

[1] entries were the same for both sowing dates in Year 2, e.g.,trials ES2 and LS2, respectively.

74 kg/ha, respectively. In LS2, potentially mineralisable nitrogen was 55 and 65 kg/ha on 23 November and 24 January, respectively. Levels of mineral N measured on these dates were 52 µg/ml and 5.3 µg/ml for ES1, and 44.8 and 7.1 for LS2. In ES2, herbicide (Duplosan Super at 2.5 L/ha) was mixed with insecticide (Pirmor at 250 g/ha) and fungicide (Opus at 1 l/ha), and applied on 20 October and again 1 month later but without the herbicide. The same chemicals were used for LS2 except that application was delayed by 30 days. Bird repellent (Avex) was applied twice for ES2 and once for LS2.

Measurements

Two 0.1 m^2 quadrats were cut at ground level from each plot at 4-day intervals from flowering until grain maturity. These were combined for biomass determination. Dry matter content of the whole crop was determined by drying for 24 hours at 80°C. Additional samples were taken for production/loss of leaf weight and leaf area by sub sampling 15 stems and separating leaf fractions that were green or senesced. Leaf area was determined using a dry weight correction following calibration for specific leaf area using a Delta-T image analysis system.

In year 1, leaf area was determined at two-weekly intervals using a LICOR LAI-2000 plant canopy analyser until canopy closure and thereafter by destructive harvest and leaf area measurement using a Delta-T digital image analysis system. In year 2, leaf area was measured using a planar LICOR 3100 leaf area meter. Radiation intercepted by the crops was measured weekly using a Decagon Sunfleck Ceptometer (Delta-T SF80) during the period from emergence to canopy closure.

The pattern of senescence of successive leaves (leaf area and leaf dry weight) on the main stem culms was determined on a single date (21 December) in LS2. Leaf area development (by destructive sampling) and specific leaf weights were also determined once only (at anthesis) for each trial location x sowing date.

Weather records

A mobile Campbell CR10 weather station was located adjacent to the trial site. Air temperature at screen (1.2 m) height was averaged from hourly mean measurements and daily observations reported as true means. Calculations of thermal time were on a 0°C base. Total short wave radiation flux ($MJ/m^2/day$) was recorded using a LICOR pyranometer.

Results and Discussion

Crop development

All cereal cultivars progressed quickly to flowering. The mean duration from emergence to flowering was 79 days in early-sown crops and 65 days for late-sown crops (Table 2). There was significant variation in the development rate for cultivars within trials. For example, barleys flowered earlier (mean 842 °C.d) than wheat (950 °C.d), oats (909 °C.d) or triticale (888 °C.d). Mean durations from emergence to flowering, expressed in thermal time, were influenced by sowing date (Table 2). In year 2, a delay in sowing of 31 days reduced the thermal time duration to flowering by 200 °C.d. It appeared that factors other than the accumulated temperature had significant effects on the development rate. The prediction of crop maturity or silage harvest dates would be more readily defined using a thermal time or calendar day duration following a key

Table 2. Developmental observations for cereal cultivars.

	Canopy closure		Anthesis	
Trial	Days after emergence	Degree days after emergence	Days after emergence	Degree days after emergence
Year 1				
Early spring sowing (ES 1)	47.5 (2.08) [1]	564 (28.2)	77.8 (9.4)	970 (125.1)
Late spring sowing (LS 1)	40.3 (1.37)	531 (16.5)	66.7 (6.4)	898 (103.9)
Year 2				
Early spring sowing (ES 2)	71.0 (2.94)	818 (41.3)	80.1 (3.3)	960 (57.6)
Late spring sowing (LS 2)	50.0 (4.40)	570 (56.1)	63.4 (3.0)	762 (46.8)

[1] Values in parentheses are standard errors.

developmental event such as ear emergence or anthesis.

Early sowing did not necessarily mean increased biomass production. To ensure maximum dry matter production, it was important to sow the crops early to allow maximum accumulation of biomass during the vegetative period. If crop duration in the field was to be minimised, then barleys were the best choice, although consideration should be given to potential yield loss with later sowing.

Temperature and biomass production

There were significant differences ($P<0.05$) among trial entries in pre-anthesis biomass production in all but the first harvest of spring-sown crops. Biomass accumulation in calendar days from emergence was not linear (data not shown), but, when related to thermal time (base 0°C), the mean response was linear (Fig. 1A and 1B) for the successive years. The production efficiency in the pre-anthesis phase ranged from 1.08 to 1.77 t/ha/100 °C.d.

Thermal time accumulation from emergence to canopy closure and emergence to anthesis was shorter in the late sowing compared with the early sowing. Differences in rate of biomass increase could in part be explained by site or soil characteristics in year 1. However, in year 2, the trials were conducted on the same site, yet the production efficiency differed for the two sowing dates. Factors other than temperature, e.g., the pattern of radiation interception or problems with crop establishment may cause deviations from the optimum response. For example, there was poor establishment of oats cv. Hokonui in LS2, and the production efficiency was correspondingly lower than in other cultivars (Fig. 1B).

Leaf growth

Leaf area index development followed a decreasing exponential response with increase in biomass (Fig. 2). In all cases, measurements were discontinued at anthesis. Leaf area index development before canopy closure may be a useful alternative to measurement of biomass for screening of genetic material with good early growth. Cultivars with a large leaf area index early in growth are also likely to have high relative nutritive value. If the relationship between LAI and biomass was stable, rapid selection of high performing cultivars could be made using remote measurements with the LICOR canopy analyser within a period between 20 and 35 days after emergence. However, deviations in fitted relationships among trials showed a degree of instability and confirmed that the method would not be useful in practice.

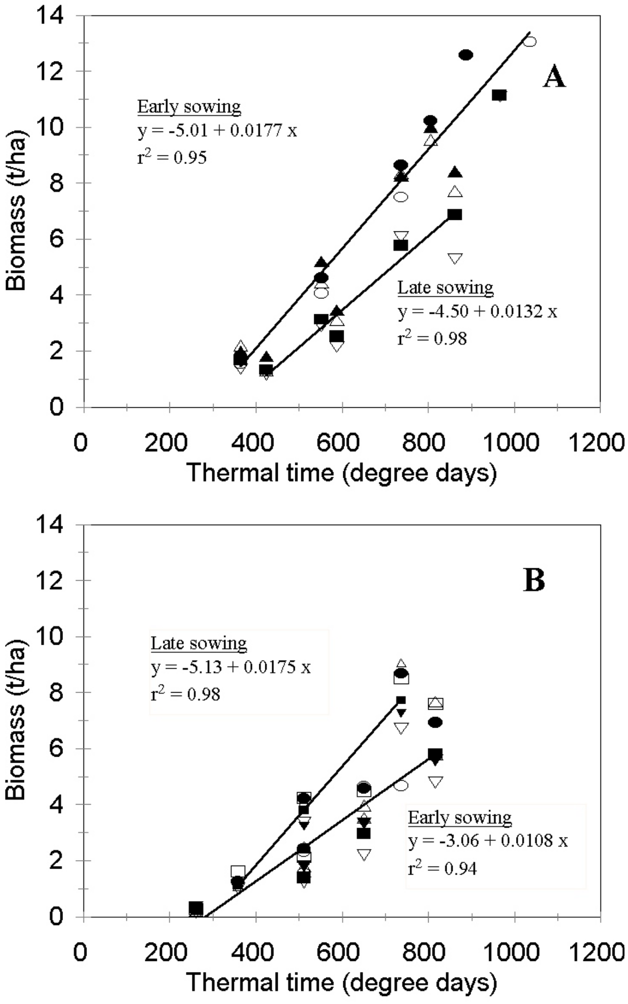

Figure 1. Relationships between pre-anthesis biomass accumulation and thermal time after emergence for trials in year 1 (A) and Year 2 (B); (○ Hokonui, ● Stampede, □ Aranui, ■ Rocket, Δ Omaka, ▼ 1802.102.13, ∇ Sapphire).

Leaf longevity, leaf size and leaf area duration are plant characteristics that could also be used to identify potential high performing forage selections. The pattern of green leaf area on main stem culms was determined for ES2 from a sample taken on 21 December (Fig. 3). There were strong cultivar differences in the relative weight of the first unexpanded leaf and for the three subtending fully expanded leaves on culms. The barleys (Omaka and 1802.102.13) had significantly lower leaf fractions relative to the culm weight. Conversely, oats (cv. Hokonui and Stampede) had the greatest fraction, while the triticales and wheats were intermediate. In the barleys, triticale cv. Rocket and oats cv. Stampede, the second and third leaves had the largest leaf weight (proportion of total leaf weight) whereas the two uppermost leaves of oat cv. Hokonui, wheat cv. Sapphire and triticale cv. Aranui were the largest contributors. The capacity for culms to maintain high green leaf area on lower leaves in the canopy is also dependent on the culm density. Within each trial the sowing rates had been adjusted to achieve comparable emergence. However, variation in establishment meant differences in tiller populations might have had an effect on the culm leaf proportions. Plant establishment varied greatly, e.g., there were 112, 38, 147, and 94 plants per m^2 in ES1, LS1, ES2 and LS2 trials respectively. However, these differences were not considered to have a significant effect on the biomass potential as the within trial variation in duration from emergence to canopy closure did not exceed 10 days.

Radiation use efficiency

Early canopy closure is hypothesised to improve the potential for biomass accumulation. However, while sowing density may advance closure of crop canopies, such crops are prone to lodging, especially in high fertility situations or during irrigation/rainfall. In this experiment, biomass production after canopy closure

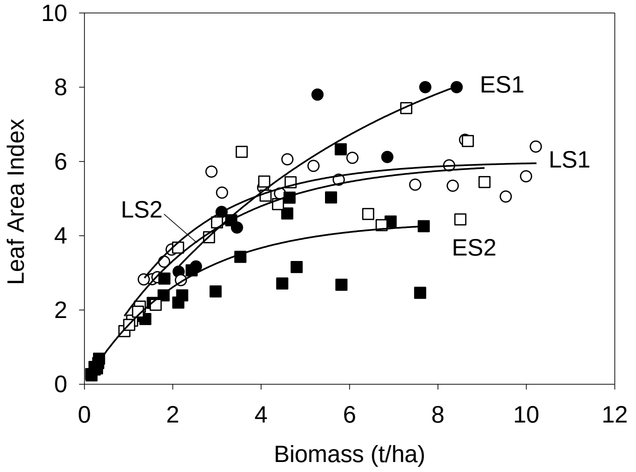

Figure 2. Relationship between leaf area index and biomass for spring trials conducted at Lincoln. ES1 (●) = early sowing year 1; LS1(○) = late sowing year 1; ES2 (■) = sowing 1, year 2; and LS2 (□) = sowing 2, year 2.

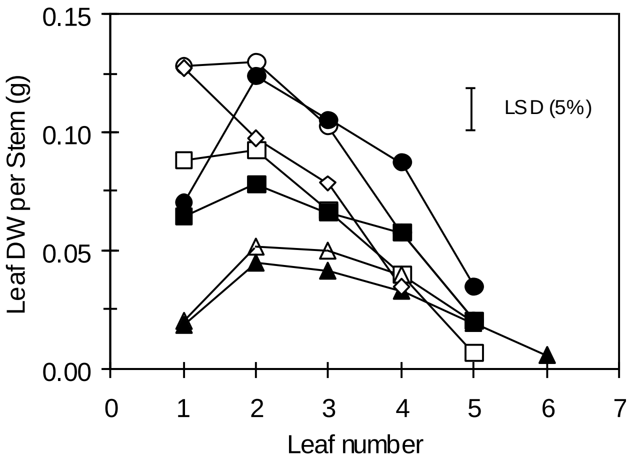

Figure 3. Leaf weight pattern (dry weight of successive leaves as a proportion of culm weight) on main stems of forage cereals harvested on 21 December (leaf number: 1 = last unexpanded leaf, 2= first liguled leaf, etc.; ○ Hokonui, ● Stampede, □ Aranui, ■ Rocket, Δ Omaka, ▲ 1802.102.13, ◊ Sapphire).

continued at rates determined by the level of canopy light interception. Full canopy cover occurred between 40 and 71 days after emergence, with early sown crops taking longer than late sown cultivars (Table 2). Similarly, the mean duration for 50% closure varied among trials, ranging from 22 to 34 days after emergence. Once the canopies reached 95% closure it was assumed that the efficiency of light capture also continued at the optimum rate. However, rapid stem elongation also occurred at this time along with leaf death in the lower canopy.

Production efficiency was related to the amount of light intercepted by the crops (Fig. 4). Relationships between biomass production and intercepted radiation were linear for the duration of crop growth until anthesis. In year 1, (data combined from two trials) the mean RUE was 1.08 g/MJ, compared with 0.77 and 1.07 g/MJ in the ES2 and LS2 trials respectively. In year 1, the early growth response to radiation was lower than the mean for the whole of the growth cycle. Lower temperature during this period possibly restricted the potential growth that could have been achieved from radiation-driven biomass production. There was also no apparent explanation for the reduced radiation use efficiency in year 2 because the crops were managed well for irrigation and available soil nutrients.

Post-anthesis growth

A comparison of the entries in ES2 showed that the biomass increase (Fig. 5A) occurred along with a rapid decline in leaf to stem ratio (Fig. 5C). A similar pattern was observed for LS2 (data not shown). The changes in leaf and stem fractions and the decline in green leaf area index (Fig. 5D) have significant effects on the quality of herbage. The decline in leaf fraction was different among the cultivars tested and has a bearing on the nutritive value of the crops as they mature. The effects on quality will be considered in a subsequent paper.

Dry matter content was monitored for all trial entries during the course of grain filling (Fig. 5B). It was significant that there was little cross over in the dry down patterns. This was expected, because the water loss from crops during grain filling is dependent on the environmental influences. The dry matter increase over time followed a near linear trend, although rainfall caused a general hydration of all cultivars during mid grain filling. The subsequent progress of dry down followed the pattern established before the rain event.

It is important for arable farmers or silage contractors to monitor the progress of crop dry down before harvest in order to gain an improved prediction date for

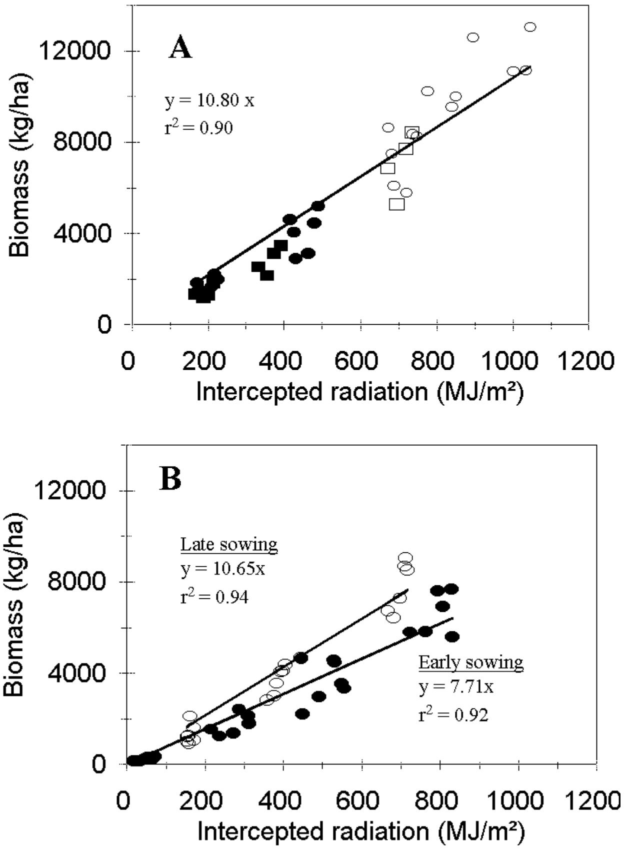

Figure 4. Efficiency of radiation use for forage trials in Year 1 (A: closed symbols are pre-canopy closure measurements and open symbols are pre-anthesis: squares = trial 1, and circles = trial 2) and Year 2 (B: all pre-canopy closure measurements; closed circles = sowing 1 (early), open circles = sowing 2 (late)).

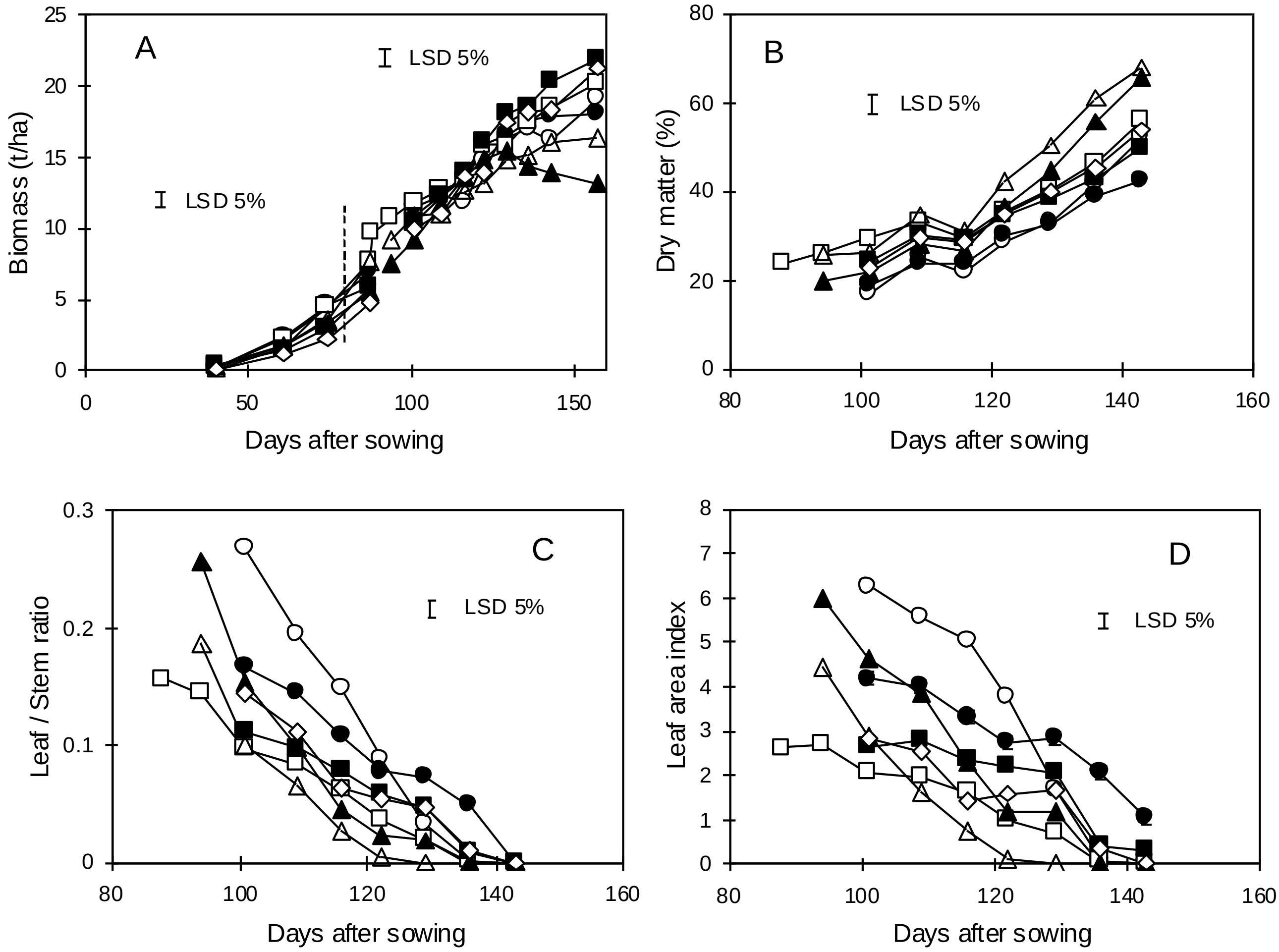

Figure 5. Progress of biomass production (A), dry matter content (B); leaf stem ratio (C) and leaf area index (D) for spring-sown cultivars (○ Hokonui, ● Stampede, □ Aranui, ■ Rocket, Δ Omaka, ▲ 1802.102.13, ◊ Sapphire) in the early sowing of year 2. Error bars are least significant differences (*P*<0.05) for comparing cultivar x harvest means. In A, the LSDs apply to data before and after the dotted line.

silage harvest, which is best defined by crops reaching 38% dry matter content. Production of high quality silage with the correct moisture content ensures good fermentation characteristics and good compaction. Harvesting for direct cut silage or harvesting followed by wilting to 35-40% DM before ensiling is recommended as a compromise between the need to restrict anaerobic fermentative and proteolytic losses in wet silages and the processes of oxidative fermentation in excessively dry silages (Ohshima and McDonald, 1978). It has been recommended (Kilcher and Troelsen, 1973) that oats should be harvested for silage around the milk stage, which is earlier than commonly recommended for other cereals. This is a compromise between the requirement for high yield and the reduction in fibre quality and digestibility as the crops approach physiological maturity. Early harvest will, however, reduce the potential for carbohydrate accumulation during grain fill and, therefore, the energy value of the herbage will be compromised. However, Fisher *et al.* (1974) reported improved intake and animal performance when oats are ensiled at the soft dough stage. A practical alternative is to cut herbage at higher moisture contents and allow the crop to desiccate in the field. Losses of nitrogen and carbohydrate fractions may increase and there is potential for field losses while the crop is on the ground. Nevertheless, a reduction in moisture content is known to limit fermentation (McDonald and Edwards, 1976) and therefore retain nutritive quality during ensiling. Wilting can also improve animal intake (Barry *et al.*, 1977).

The pattern of crop dry down is closely linked to the stage of crop development and the progress of total biomass accumulation. Alternative methods that can be used by growers in the field should be developed to provide more rigorous estimation of the crop moisture content. Grain moisture content, grain dry matter or soluble carbohydrate levels are possible indicators of the optimum time of harvest.

Conclusions

Determining the extent of differences in biomass produced by cultivars in response to environmental factors has assisted with the selection of improved material for grazing and silage. Cultivar choice should be made with consideration for the timing of production and the best developmental stage for utilisation.

Leaf development patterns differed among species. Barley developed rapidly and lost leaf area earlier than wheat, triticale or oats. There were significant differences among cultivars in the pattern of decline of leaf area index, and marked differences among cultivars in the timing of dry matter changes during maturation, although differences in the rate of change of dry matter were small.

Biomass in these spring-sown forages was best described by a thermal time model with production efficiency varying among trials from 1.08 to 1.77 t/ha/100 °C.d. Accumulated radiation intercepted also explained a high proportion of the variation in biomass with up to 20 t/ha of biomass achieved at crop maturity with good crop management. The differences observed in radiation use efficiency between cultivars could explain the improved biomass potential within and across species.

In spring-sown crops for silage, there were rapid changes in moisture content and green leaf fractions during grain filling. Research is continuing to define interrelationships between loss of nutritive value and gain of biomass with crop maturation. Further definition of the comparative yield and also quality differences among cultivars will ensure the best use of whole crop cereals from both farming system and nutritional perspectives.

Information on leaf proportions, progress of biomass and whole crop moisture content as well as quality indicators are required to optimise harvest dates for spring silage production. These data may also assist in the selection of species/cultivars that are easily managed or that show good silage characteristics during development.

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