Optimising harvest timing by predicting dry matter content of whole-crop cereals for silage

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Abstract

Timing of harvest is the single most important factor affecting the yield and quality of whole-crop cereals used for conserved feed. Changes in dry matter content (%DM) and relationships to herbage quality and maturation are presented for experiments conducted over three seasons beginning in 2001/02. Changes in crop characteristics such as ear moisture, ear fresh weight, ear dry weight and leaf fraction were monitored to determine whether growers could use other crop-based measurements in place of whole-crop %DM content to assist with decision making close to harvest. A preliminary model was established that defined the rate of crop maturation for a range of currently grown cultivars. Linear patterns of dry-down occurred with only small variation in drying rate for the duration of grain filling. A model with specific inputs for cultivar, date of awn tip appearance (GS49), and developmental response to thermal time was then used to form the basis of a decision support tool that enables growers and contractors to predict optimum harvest timing for whole-crop cereals.

Additional key words: silage maturity, supplements, forage, herbage quality

Introduction

Cereal forage for direct grazing or silage is traded primarily on the basis of crop weight determined on the standing crop, or from measurements made on the day of harvest. Currently there are no universal standards for sampling and drying to determine the moisture (or dry matter) content. Although commercial laboratories offer a service for dry matter content analysis the time taken from field sampling to reporting often precludes its use in harvest date prediction because crops mature rapidly. The variation in moisture content occurring within paddocks and during the course of harvest means that calculations of total crop yield are often inaccurate. In addition, harvest timing is important in maximising the quality of herbage for ensiling (Burgess *et al.,* 1973; de Ruiter *et al.,* 2002; Nishida and Nakano, 1979; Pettersson *et al.,* 1996) and in reducing the impact of poor stack compaction (Woolford 1984).

Yield and quality changes during crop development of whole crop cereals have previously been defined. Best quality is achieved by delaying harvest as long as possible (de Ruiter, *et al.,,* 2002). However, plant material for ensiling is best harvested when moisture content ensures that the resulting fermentation will cause least loss of dry matter (DM) and quality during storage (Woolford *et al.,* 1982). There is also potential for crop management practices such as fertiliser and irrigation applications, to influence crop maturation and herbage quality (Nishida and Nakano, 1982). The timing of whole-crop dry-down during maturation may also be related to the leaf senescence pattern (Juskiw *et al.*, 2000).

Methods used for determining crop maturation, other than phenological observations and remote sensing, invariably require measurements of dry herbage components. In this study, ear fresh weight (FW mean per ear) and mean ear dry weight (DW) were evaluated for their potential use as predictors of whole-crop %DM content. Ear weights could help growers optimise harvest timing if there are robust relationships between these variables and the whole-crop %DM. We also examined the potential for using the whole-crop %DM as the main driver for harvest timing, and aimed to define the cultivar parameters for dry-down of whole-crop cereals. Test crops of barley, wheat, triticale and oats were used to relate crop quality changes to other indicators of crop maturation, and determine the interaction between crop development and changes in %DM. Practical crop monitoring methods will assist with defining a harvest window that minimises losses and protects quality.

Methods

Field trials were established in successive seasons (2001/02 to 2003/04) on the Crop & Food Research farm at Lincoln (lat. 34 38' S, long. 172 E) on a sandy loam soil type (Udic Ustochrept, USDA soil taxonomy). These experiments comprised a range of crop cultivar entries, sowing dates, and rates of nitrogen fertiliser and irrigation treatments.

Year 1: 2001-02 trial

The trial area preparation comprised application of 300 kg/ha potassic super (15:10:10:8, NPKS) on 27 August and 3 t/ha lime on 1 September followed by deep grubbing, maxi-tilling and a final pass with a power harrow on 4 September. The trial had a split-split plot design. Whole plots comprised four replicated blocks, each randomly split into irrigated and non-irrigated main plots. Irrigated treatments received 31 mm water on 4 October followed by 32 mm on 20 November, 39 mm on 8 December and 35 mm on 17 December. Other treatments comprised factorial combinations of three cereals (Rocket triticale, Boss barley and Sapphire wheat) with four nitrogen (N) rates randomised within cultivar subplots. Nitrogen treatment, applied as urea, comprised (1) control; (2) 50 kg N /ha at emergence; (3) 50 kg at emergence + 50 kg at GS 23 + 50 kg at GS 29; (4) 50 kg at emergence + 50 kg at GS 23 + 50 kg at GS 29 + 50 kg at GS 32 (2nd node), and 50 kg at flag leaf ligule (GS 39). Total N applications for the respective treatments, in addition to the base dressing, were 0, 50, 150 and 250 kg N/ha. Plots, each 12 x 1.35 m wide, were sown with an Oyjord drill at an inter row spacing of 15 cm.

Year 2: 2002/03 trial

Six cultivars (Boss barley, Omaka barley, Rocket triticale, Sapphire wheat, Stampede oat, and CRTR22 triticale) were sown on 20 September in randomised complete blocks, with three replications, in 12 x 1.35 m plots with 15 cm row spacing. Pre-sowing fertiliser comprised 200 kg/ha CropMaster 20 (N:P:K:S; 20:10:0:13) on 20 September. Urea was applied in split applications of 80 kg/ha and 50 kg/ha of urea on 22 November and 2 December, respectively. Weeds were controlled with Duplosan super (a.i 130 g/litre mecoprop-P, 310 g/litre dichlorprop-P and 160 g/litre MCPA as dimethylamine salts in the form of a soluble concentrate) at 2.5 L/ha in 200 L water per ha. Fungicide was applied on 27 November and 11 December. Applications comprised Folicure (a.i. 430 g/litre tebuconazole) and Opus (a.i. 25 g/litre epoxiconazole) at 440 ml/ha and 1 L/ha respectively. The trial was irrigated on 30 December (30 mm) and 13 January (20 mm).

Year 3: 2003/04 trial

A randomised complete block (three replications) experiment with eighteen cultivar entries (listed in Table 1) was sown on 15 September with pre-sowing applications of 150 kg/ha Cropmaster 20, and 50 kg N/ha as urea. Additional applications of 50 kg N/ha were made on 29 October, 15 November and 6 December. Nine-row plots were 15 x 1.35 m with 15 cm row spacing. Weeds were controlled with Axall (a.i 75 g/litre bromoxynil, 75 g/litre ioxynil and 345 g/litre mecoprop) at 2.5 L/ha in 200 L water/ha. The crops received 500 ml/ha of Opus and 500 ml/ha of Amstar on 19 November and 3 December, respectively. The trial area was irrigated four times (15 November, 1 December, 15 December and 27 December) with 25 mm on each occasion except for 30 mm on 1 December.

Measurements

Whole plant %DM was determined at 3-4 day intervals on all experiments beginning at awn tip appearance (GS49), (Zadoks et al., 1974) and ceasing at approximately 65-70 %DM. Whole-crop %DM was determined on at least 300 g FW from each plot, dried at 100 °C for a minimum of 24 hours. Similar drying protocols were used for ear weight. In trial 1, ear sampling consisted of 20 random ears per plot per sampling date. Both whole-crop herbage and ears were sampled into sealed plastic bags in the field to minimise water loss during transit.

A key crop development event, awn tip appearance (GS49) was monitored for all treatments. This was chosen in preference to anthesis because it usually occurs over a short period. This event is easy for growers to observe and is less sensitive to environmental variation within and among cereal cultivars than was anthesis.

Selected replicate samples were taken from the 2002/03 experiment (year 2) for near infrared reflectance spectroscopy (NIRS) analysis of herbage quality by cutting approximately 200 g FW of whole stems to 5 cm above ground. These were frozen, freeze dried and finely ground using a Cyclotec sample mill. Samples were analysed by feedTECH (AgResearch, Palmerston North) for the following forage quality variables: neutral detergent fibre (NDF), acid detergent fibre (ADF), digestibility, total soluble sugars (starch + soluble sugars), lipid, metabolisable energy (ME), ash and protein.

Hourly air (1.2 m above ground) and soil temperatures (at depths of 5 and 10 cm) were recorded using a CR10 Campbell data logger located at the trial sites. Statistical analyses were performed using GenStat 6 (2002).

Table 1. Calibration statistics for whole-crop dry down in trials at Lincoln in 2001/02 (Year 1), 2002/03 (Year 2) and 2003/04 (Year 3). Whole crop %DM data were regressed against thermal time after awn tip appearance (GS49). Data for irrigated and dryland treatments in 2001/02 were combined.

Species Cultivar	Year	Slope (β_1)[1] (%DM/°C.d)	Intercept (β_0)[1]	Coefficient of determination (%)	Thermal time to 38%DM (°C.d from GS49)
Barley					
cv. Omaka	2	0.0604	13.16	93.9	411
cv. Cask	3	0.0335	23.04	98.3	447
cv. Dash	3	0.0759	5.76	99.6	425
cv. CRBA107	1	0.0484	12.96	96.0	517
cv. CRBA107	2	0.0452	17.99	98.9	443
cv. CRBA107	3	0.0436	19.12	99.6	433
cv. CFR 2387	3	0.0499	15.70	92.5	447
cv. CFR 2091	3	0.0621	12.36	93.6	413
Triticale					
cv. CRTR21	1	0.0311	15.83	99.2	713
cv. CRTR21	2	0.0295	20.34	94.5	599
cv. CRTR21	3	0.0276	25.49	89.1	453
cv. CRTR22	2	0.0294	18.57	95.3	661
cv. CRTR22	3	0.0276	24.63	86.8	484
cv. CRTR16	3	0.0319	22.29	93.3	492
cv. CRTR20	3	0.0334	25.35	99.2	379
cv. CRTR23	3	0.0276	27.28	86.7	389
cv. 'A'	3	0.0318	21.28	87.7	526
cv. 'B'	3	0.0328	20.62	89.7	530
Wheat					
cv. Sapphire	1	0.0424	15.36	97.9	534
cv. Sapphire	2	0.0368	20.89	97.5	465
cv. Sapphire	3	0.0344	19.24	98.3	545
cv. CRTR6	3	0.0256	24.18	89.4	540
Oat					
cv. Hokonui	3	0.0323	21.40	98.0	514
cv. Stampede	3	0.0411	17.68	91.2	494
cv. CROA131	3	0.0377	18.48	97.0	517
cv. CROA132	3	0.0484	15.37	92.4	468

[1] Model $y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$; where y_i = whole-crop dry matter (%) and X_i = thermal time from GS49 (°C.d, base 0°C), i = sample date.

Results

Ear FW and DW

In trial 1, ear biomass accumulation in relation to ear FW showed a consistent pattern within sample dates (Figure 1). There was little variation in ear moisture between the irrigation and nitrogen treatments within harvest dates. This supports the principle that the main driver for changes in ear FW during development is the progressive increase in biomass, primarily as grain starch, that occurs with the decline in ear moisture. The comparative rate of water loss was greater than the decline in the rate of DM deposition in grain. The usefulness of this relationship for approximating the whole-crop DM status was limited, despite the consistent relationship between ear FW and ear DW. Maximum ear FW occurred at close to 40% whole-crop DM for non-irrigated crops and at 35% for irrigated crops. Maximum ear FW occurred too late for it to be used as a signal for ideal harvest timing. Moreover, the differences in ear FW between the treatments was large, thus making it impractical to compare test samples with ear FW standards. The same would be true for ear DW

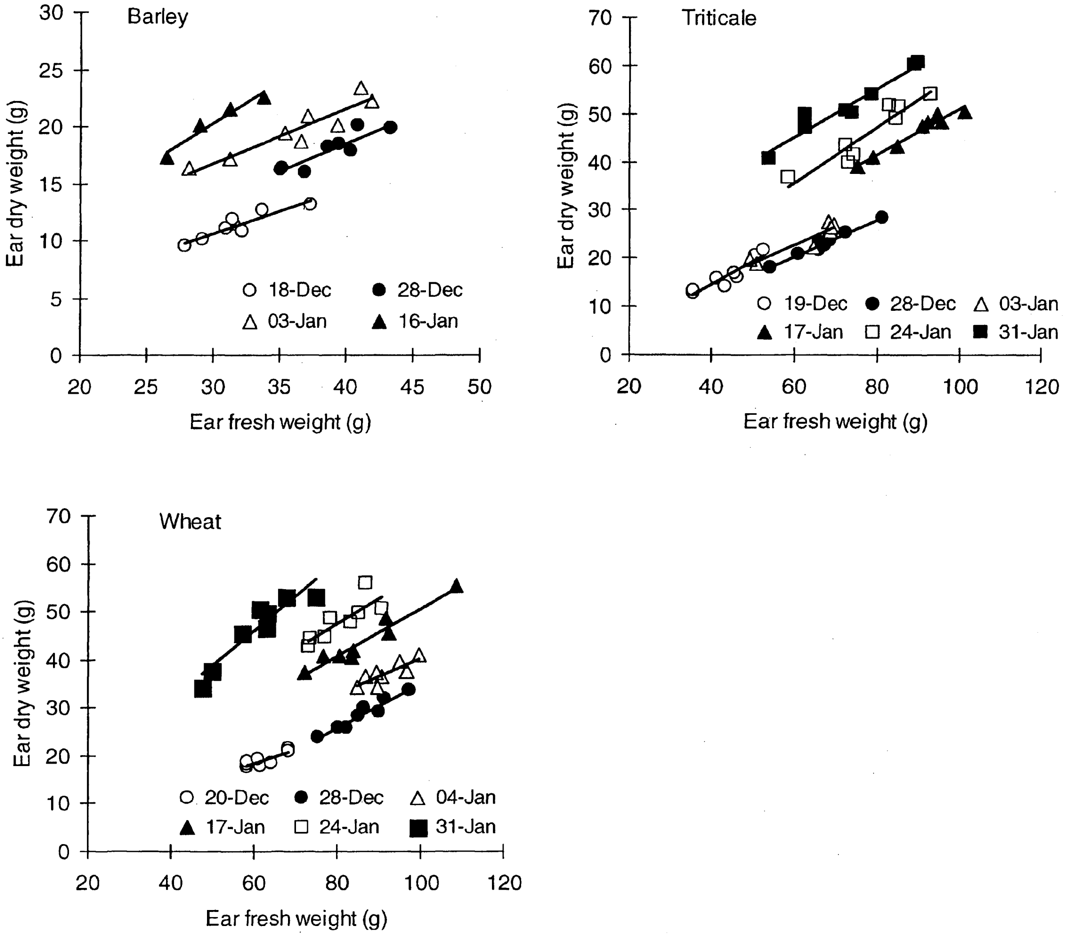
Ear %DM and whole-crop %DM

An alternative to whole-crop sampling was to monitor ear DM content and then predict whole-crop %DM from known relationships between the two variables. Observed deviations in these relationships were due more to irrigation (Figure 2) than nitrogen treatment effects (data not shown). For each cultivar, the drying patterns were described satisfactorily by a linear response in barley and triticale, with only minor separation between the irrigated and non-irrigated treatments. The relationship was more complex for wheat.

The 2001/02 season was uncharacteristically wet with 359 mm precipitation recorded between emergence (17 September) and grain maturity (15 February). Therefore, large differences were not expected between the irrigated and non-irrigated treatments. Relative differences in moisture content in triticale and barley ears and whole-crop, in the respective irrigation treatments, were represented by translational shifts within species (Figure 2).

Leaf proportion

There was potential to use leaf proportion to assist with harvest date decisions as consistent relationships were shown with whole-crop dry down (Figure 3). There was also considerable variation in the pattern of leaf loss that could be explained by respective nitrogen and water treatments. For the equivalent stage of leaf senescence, the irrigated treatments had lower whole-crop %DM content than the non-irrigated treatments. Similarly, high N treatments caused delayed leaf senescence for equivalent stages of whole-crop dry-down. As a general rule, all species had a mean of 5 % green leaf (by weight) when the whole-crop passed through the 40 %DM.



igure 1. Relationships between mean ear DW and ear FW for respective sampling dates. Data points re means over replicates for the factorial combinations of water and nitrogen treatments.

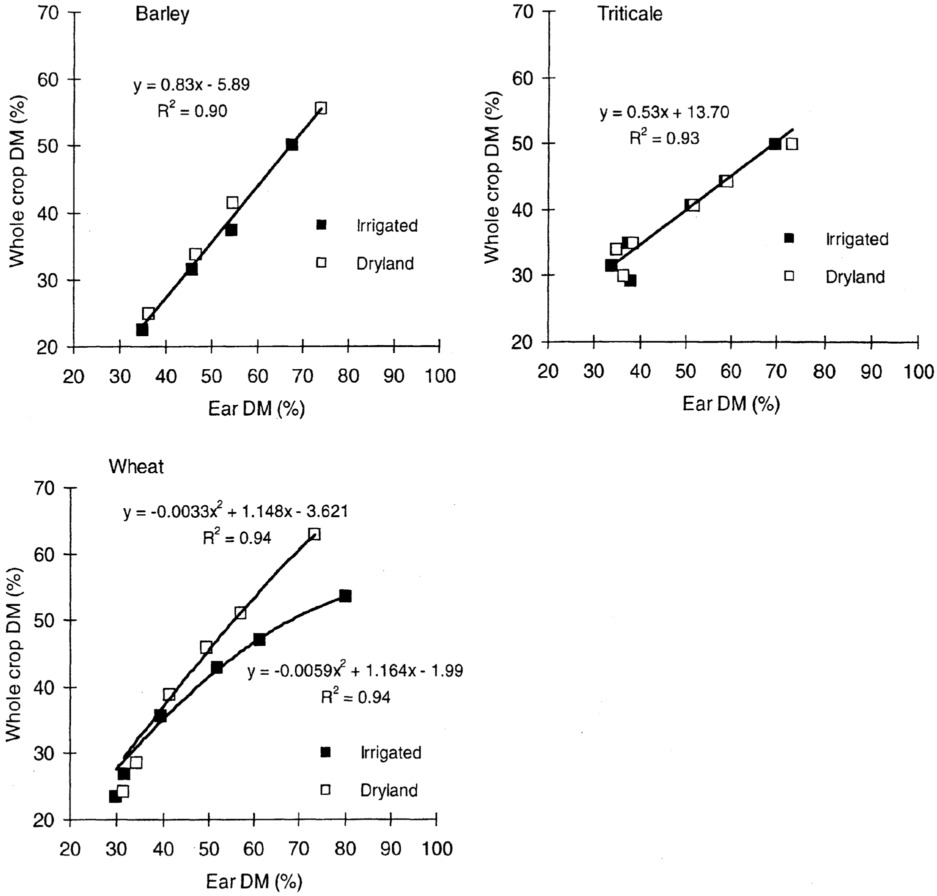


Figure 2: Relationship between whole-crop % DM and ear % DM ear for irrigated and non-irrigated treatments. Data points are means for nitrogen treatments.

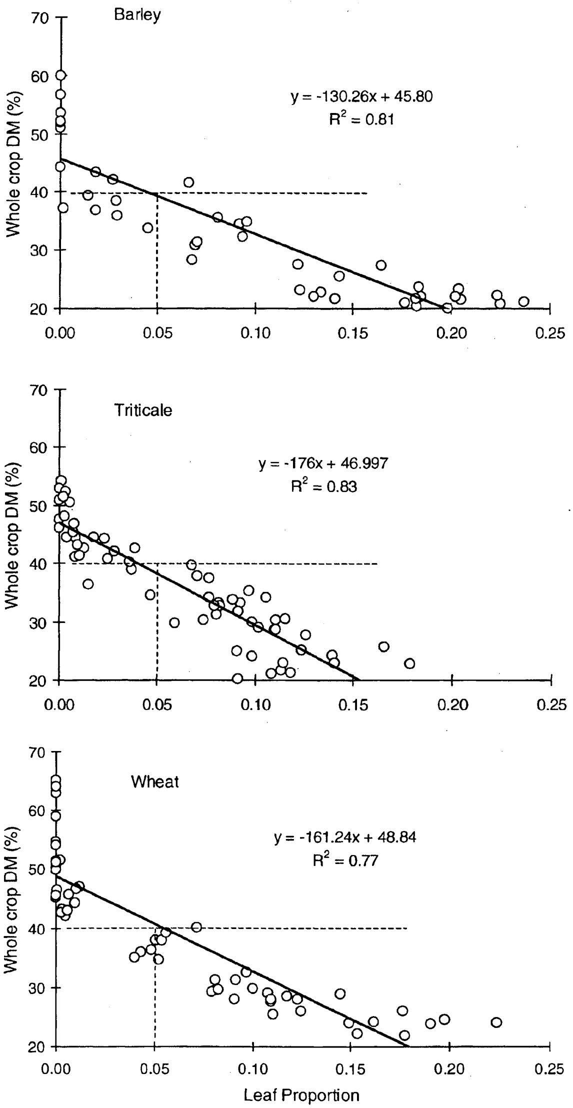


Figure 3: Relationship between whole-crop % DM and leaf proportion (green leaf DW/whole plant DW for Boss barley, Sapphire wheat and Rocket triticale. Data points are treatment means for the experiment in year 1.

A level of 10 % leaf relative to the total plant weight on a FW basis was considered optimal for crops with whole-crop %DM content not exceeding 40 %. In many treatments the green leaf fractions had declined to zero by the time the whole-crop %DM had reached 40 %.

Changes in crop quality during maturation

The year 2 trial showed that prediction of ideal harvest timing on a DM basis was important in terms of crop quality. For example, soluble sugar content increased from a low of 1 2% at GS49 to a high of 35 % at maturity (Figure 4A and 4B). All cultivars accumulated up to 30 % of the DW as soluble sugars plus starch (sampling for dry matter and quality in oats was incomplete because of bird damage). While the soluble sugar content increased during maturation there was a decline in protein content (Figure 4C). These variables were negatively correlated (r= -0.68, Table 2). This result was consistent with earlier work (de Ruiter *et al.*, 2002).

Negative correlations between fibre content (NDF and ADF) and soluble sugars were indicative of a strong effect of increasing grain starch composition with maturation (Table 2). The fibre content was relatively stable during the grain filling period, but the digestibility increased along with a gradual increase in the ME content toward maturation. ME was lowest during mid grain filling. Herbage quality continued to change until the whole crop reached 50 %DM. However the relative changes were proportionately less with progression toward maturity.

Response of %DM to thermal time

In the absence of weather extremes, whole-crop cereals dried down at predictable rates until grain maturity. Dry matter changes (in the period from GS49 to silage harvest) regressed against thermal time (air temperature with base 0°C) after awn tip appearance yielded linear responses with coefficients of determination exceeding 86.7 % (Table 1). However, there were differences in DM content at the time of awn tip appearance (GS49), for the three seasons. These differences were possibly a result of climatic and soil moisture effects in the period preceding grain development.

Patterns for dry down are shown for Boss barley, Rocket triticale and Sapphire wheat for the three seasons (Figure 5). Barley has a rapid dry down and narrow harvest window, whereas the rate of development in triticale, in general, was significantly slower with an extended harvest window (38-42 %DM). The period from awn tip appearance to ideal harvest DM content may vary from 25 to 45 days depending on the cultivar, crop management and weather conditions.

All trials were irrigated except for the dryland treatment in season 1 (2001/02). This year was wetter than average and therefore the differences in dry down pattern were not expected to be significant. The rate of dry-down for all cultivars was linear with coefficients of determination exceeding 93 %. The drying rate was not different in respective treatments for Rocket triticale. However, dry down was faster for both barley and wheat in the dryland compared to the irrigated treatment. The respective drying rates were 5.3 and 4.4 %DM/100°C (r^2 >0.97) for Boss barley and 4.7 and 3.9 %DM/100 °C (r^2>0.97) for Sapphire wheat. In the context of annual variation, these differences were not considered significant. Therefore, the dryland and irrigated treatments in year 1 were combined for subsequent data analyses.

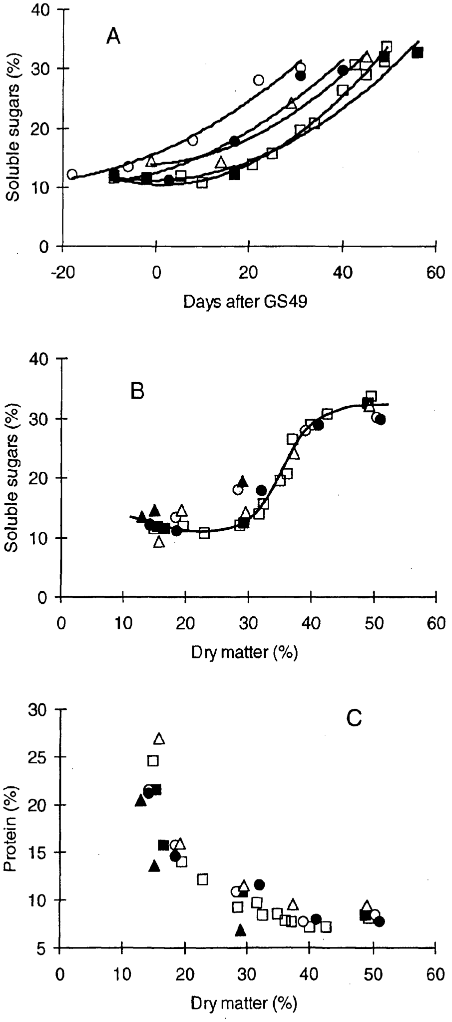


Figure 4. Changes in soluble sugar content of whole-crop cereals during maturation (year 2) in relation to calendar days (A) and progress of dry down (B), and change in protein content (C) with maturation. Data points are means for Boss barley (○), Omaka barley (●), Rocket triticale (□), CRTR22 triticale (■), Sapphire wheat (Δ) and Stampede oat (▲). Data were fitted with quadratic equations in A and by eye in B.

Table 2. Correlations between indicators of herbage quality for the 2002/03 experiment, (df=36).

	Ash	ADF	Digestibility	Protein	Lipid	NDF	Total soluble sugars
Ash							
ADF	0.30	--					
Digestibility	0.50	-0.57	--				
Protein	0.96	0.17	0.52	--			
Lipid	0.20	-0.01	0.29	0.11	--		
NDF	0.06	0.93	-0.69	-0.02	-0.05	--	
Soluble sugars	-0.65	-0.69	0.20	-0.68	0.03	-0.65	--
Metabolisable energy	0.39	-0.63	0.99	0.42	0.30	-0.72	0.29

Statistics for crop dry down in response to thermal time accumulation after awn tip appearance in all trials are given in Table 1. The linear relationships and high coefficients of determination indicated good fits to the data for all cultivars tested. If the assumption is made that thermal time is the key driver for whole-crop water loss, these relationships can be used with some degree of certainty in following seasons, provided checks are made on the progress of %DM in new season measurements. If the initial DM at awn tip appearance is known, harvest maturity (38 %DM) can be predicted with a high degree of certainty given that the dry down rate differs little among seasons.

The model's prediction of thermal duration to 38 %DM were compared with the observed duration (Figure 6) comprising single observations for each cultivar. Parameters for DM change were averaged when data from more then one year were available. The root mean square error (RMSE) calculated for the complete sample set was 60 degree days or equivalent to 11 % of the mean duration to 38 %DM. Differences between the predicted and observed duration were comparatively greater within the triticales. These differences may be partly explained by the increased duration to maturation within the triticales. The RMSE for triticale was 86 degree days compared to barley, wheat, and oats with 35, 35 and 45, respectively. Prediction accuracy was therefore within 2-3 days for the latter species.

Discussion

Dry matter content of 38 % was considered the optimal stage for harvesting for silage (de Ruiter *et al.*, 2002). The patterns of quality change during maturation in this study showed that overall crop quality was near optimum at 40 %DM but continued to slowly increase beyond this time. We do not report on the progress of yield development. However, previous research has shown that biomass optima occur when the whole-crop has dried to 60 %DM (de Ruiter 2001).

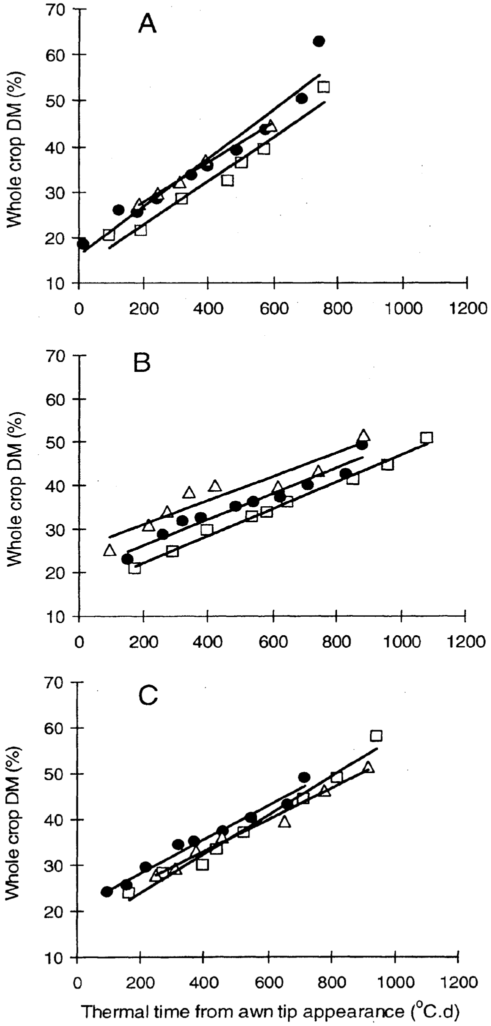


Figure 5. Pattern of whole-crop dry down in Boss barley (A), Rocket triticale (B) and Sapphire wheat (C) in 2001/02 (□) 2002/03 (●) and 2003/04 (Δ) seasons. Data for irrigated and dryland treatments in 2001/02 were combined.

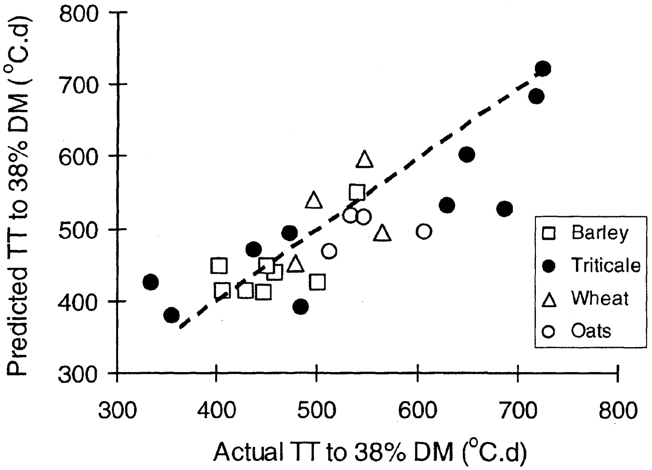


Figure 6: Comparison of observed and predicted thermal time (TT) durations using a single derived parameter for each cultivar describing rate of crop dry down in barley (□), triticale (•), wheat (Δ) and oats (o). Predicted DM% included adjustments made for crop DM% at awn tip appearance. The dashed line is the 1:1 response.

None of the alternative methods identified were ideal for estimating whole-crop dry down. However, several of the methods tested could be used effectively to predict when the crops would reach an ideal stage for silage harvest and could replace destructive measurements of whole-crop %DM content. Alternative measures were sought to provide quick estimates of the state of crop development preferably based on field observations rather than time-consuming full laboratory %DM determinations. Relationships between FW of ears and whole-crop %DM content were potentially useful because of consistent responses within the cultivars tested (Boss barley, Rocket triticale and Sapphire wheat). However, the relationships were not always linear and significant variation resulted from crop management treatments. Leaf fraction was also a useful indicator of the progress of crops toward silage maturity. A level of 5 % green leaf content was reported to be beneficial for ensuring adequate soluble sugar content and, therefore, the ensilability of herbage (Jaurena and Pichard, 2001).

Stable relationships were shown between ear %DM and whole-crop %DM. During crop dry down, ear %DM varied from 0-10 % higher than whole-crop %DM depending on the cultivar and crop treatment. The leaf fraction, which provides a good source of fermentable carbohydrate for ensiling, declined as the whole-crop %DM content increased.

Crop monitoring methods can be used to calculate a projected harvest date, but there is insufficient lead time for these methods to be of practical use. Up to 30 days advance notice of the harvest date is required to ensure contractor availability and to assist with crop scheduling. In most seasons, there is only a 5 to 7 day period when the crop is at an ideal moisture content for direct chop. If cut too early (under 35 %DM) there are potentially large %DM losses during ensiling, although the crop will compact well. When crops are harvested late (over 45 %DM), it is difficult to displace the air in silage stacks. This causes increased DM losses and undesirable fermentation. The mature grains may also be more difficult for stock to digest.

A simple calculator for harvest date prediction (Harvest-pred) was derived from crop dry down in the trials over three seasons. Time to silage maturity (38 %DM) differed for cultivar and seasonal weather conditions. Standard dry down rates, driven by thermal time (degree days) during the pre-flowering and grain filling stages, were defined using weather records at the trial sites. Cultivars were shown to have unique dry down characteristics with progress toward maturity being driven by thermal time after awn tip appearance (GS49). To ensure accuracy in harvest date prediction it was important for crop development, including %DM at GS49, and air temperatures to be monitored at the crop location.

Progressive adjustments can be made to harvest date predictions by monitoring the %DM changes and matching the results with the pattern developed in cultivar calibrations. Harvest date predictions using long term temperature means and established calibrations are the best option in the absence of on-site air temperature measurements.

The harvest calculator allows growers to predict silage harvest time more accurately with the added benefit of optimising crop quality and ensilability. The system is simple to use, allowing farmers to reserve contractor services with more certainty and with up to 30 days advance notice. It is recommended that harvest date predictions be checked by destructive sampling for whole-crop %DM. These observations should be matched with model predictions and adjustments made to the expected harvest date.

Most of the annual variation in drying patterns within cultivar could be attributed to the starting values for %DM and the consequent variation in thermal time duration from GS49 to maturity. Reliable predictions of duration to harvest using the calculator does, however, depend on an adjustment being made at least once during the season to confirm that the rate of dry down is occurring according to the established rates, and more importantly, that the initial %DM (β_0) is used to correct for seasonal differences. Translation of thermal time into daily duration also presents a difficulty when predicting dates for harvest. Procedures for adjusting thermal duration to calendar days are incorporated within the calculator by utilising long-term weather data and an assumption of minimised annual differences in mean thermal time accumulation.

An alternative prediction method was also developed. This method establishes a predicted dry down rate for the 15-day period after awn tip appearance, using on-site temperature monitoring. In this case, the model assumed that the mean temperature for the duration from GS49 to silage maturity was consistent with the average temperature in the 15-day period after GS49. Whilst mean temperatures for equivalent dates across seasons are relatively stable, there are within-season variations that may cause significant deviations in the predictive accuracy of the model if this option is used.

Conclusions

Timing of harvest has a significant influence on the yield and quality of whole-crop cereal silage. Changes in dry matter content (%DM) and its relationship to maturation were presented for a series of experiments over three seasons to determine whether %DM was a valid method for assisting with decision making close to harvest. Relationships were found between whole-crop %DM and other indicators of crop maturation e.g. ear FW, ear DW and ear %DM, but they were not considered practical for predicting time of harvest.

The relationship between crop development and thermal time duration forms the basis for a model used by growers to predict the rate of progress to crop maturity. A thermal time driver for whole-crop %DM proved to be the best method for predicting crop dry down and harvest date. The harvest date predictor uses information from field experiments for commonly grown cultivars. It comprises a simple menu interface displaying development of whole-crop %DM and predicted date of harvest.

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