

Seed Maturation and Harvest Timing in Turf Type Tall Fescue

R.P. Andrade¹, D.F. Grabe^{1,2} and D. Ehrensing¹

ABSTRACT

The lack of uniformity in tiller and inflorescence development in tall fescue (*Festuca arundinacea* Schreb.) seed crops leads to asynchronous seed maturation and difficulty in determining optimum harvest timing. This study was conducted to determine the seed moisture content at windrowing for achieving maximum seed yield in turf-type cultivars of tall fescue with differing maturity dates. The experiments were conducted in 1990, 1991, and 1992 with cv. Chesapeake, Bonanza, and Emperor tall fescue, which are early, medium and late flowering cultivars, respectively. Seed moisture content was determined daily. A plot-size windrower and a combine with a special pick-up attachment were used for windrowing and threshing the plots. Plots were windrowed six times at successively lower moisture contents. Natural seed shedding and total seed losses were evaluated for each harvest. Seed moisture loss during maturation occurred in two phases. Average daily moisture losses were 11.5 g kg⁻¹ in phase 1 and 34 to 52 g kg⁻¹ in phase 2. Maximum yields were obtained by windrowing at moisture contents from 350 to 410 g kg⁻¹. In this range, maximum dry seed weight and germination percentage were achieved and natural seed shedding was minimal. When windrowed at approximately 400 g kg⁻¹ moisture content, average harvest losses were 27 and 12% of the yield in 1991 and 1992, respectively. The number of growing degree days (GDD) accumulated after peak anthesis was not consistent enough to be used as a harvest timing index in place of moisture content or days after anthesis.

Additional index words: seed moisture, seed yield, harvest losses, growing degree days, windrowing.

INTRODUCTION

The lack of uniformity in tiller and inflorescence development in tall fescue seed crops leads to asynchronous seed maturation and difficulty in determining optimum windrowing time. Before optimum windrowing time, seed quality is low and maximum yield is not achieved because of the high proportion of immature and low-weight seeds. After the optimum windrowing time, seed losses from natural shedding and harvest shattering lower yields (Klein, Harmond, and Hurst, 1961; Nellist and Rees, 1963; Williams, 1972; Andersen and Andersen, 1980). These losses add to the soil seed bank and increase the population of volunteer plants in the following seed crop. Therefore, correct windrow timing not only provides maximum yield but also is an effective, cheap, and environmentally safe method of reducing volunteer plants in succeeding crops.

Seed moisture content has been recommended as an index of optimum windrowing time in cool season grasses (Klein and Harmond, 1971; Hill and Watkin, 1975). Unlike other seed harvest timing indices, instrumentation is available for seed moisture measurement and seed moisture integrates in one value the average condition of a population of seeds in different stages of maturation. The precision of this windrow timing index, however, can be improved by concomitant use of other seed maturity indicators such as endosperm consistency, colour of inflorescences and glumes, and degree of seed shattering (Roberts, 1969 and 1971; Williams, 1972; Pegler, 1976; Hebblethwaite and Ahmed, 1978; Andersen and Andersen, 1980). Maximum seed yields of cv. Alta, an early-flowering forage-type tall fescue, were obtained with windrowing at a moisture content of 430 g kg⁻¹ (Klein and Harmond, 1971). A

seed moisture content of 480 g kg⁻¹ has been found suitable to mow tall fescue cv. Grasslands Roa (Hare, Rolston, Archie, and McKenzie, 1990). It is not known whether these moisture indices also apply to turf-type cultivars of tall fescue, especially those with later maturity dates. Other researchers have indicated that optimum windrowing time occurs over a range of moisture contents instead of at a sharply defined single value (Andersen and Andersen, 1980). For instance, windrowing in the range of 400 to 500 g kg⁻¹ was recommended for achievement of maximum yields in perennial ryegrass (*Lolium perenne* L.), whereas the range of moisture contents for maximum yields of red fescue (*Festuca rubra* L.) was 300 to 400 g kg⁻¹. Windrow timing based on number of days after anthesis, although an easy method and commonly used, is not reliable (Hill and Watkin, 1975). An alternative time-related index, based on growing degree days (GDD) accumulated after anthesis, was suggested by Andersen and Andersen (1980). GDD would account for the influence daily temperature has on post-anthesis events in grasses.

Moisture decrease during seed maturation follows a characteristic pattern, allowing the use of "drying curves" to forecast optimum windrowing time based on seed moisture content (Klein and Harmond, 1971; Hill and Watkin, 1975; Andersen and Andersen, 1980). Development of cultivar-specific moisture-loss curves could allow seed growers to more accurately predict optimum windrowing time.

Many windrow-timing studies in grasses did not consider the effects of cultivar and yearly weather variations. Conclusions were often based on hand-harvested experiments that neglected machine-shatter losses. The objectives of this study were to examine patterns of moisture loss in maturing seed crops, and to determine the seed moisture content at

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windrowing for achieving maximum seed yield in cultivars of tall fescue with differing maturity dates. The use of GDD accumulated after mid-anthesis as a harvest index was also studied.

MATERIALS AND METHODS

The experiment was conducted at the Oregon State University Hyslop Crop Science Field Laboratory near Corvallis, OR, USA on a Woodburn silt loam soil (fine-silty, mixed, mesic Aquultic Argixerolls). Chesapeake, Bonanza, and Emperor, which are respectively early, medium, and late-flowering cultivars of turf-type tall fescue, were planted in September 1989 in rows 0.45 m apart. An application of 44.8 kg N and 24.6 P ha⁻¹ was made during seeding and the area was top dressed with 45 kg ha⁻¹ of N as urea on 3 March 1990. Straw and stubble were eliminated from the harvested plots on 5 September 1990 with two passes of a propane burner. Another application of 44.8 kg N and 24.6 kg P ha⁻¹ was applied on 1 October 1990. Nitrogen (45 kg ha⁻¹) was applied as urea on 8 March 1991. After the second year's harvest, a commercial vacuum-sweep machine (Rear's Mfg. Co., Eugene, OR) was used to chop and remove the straw from the plots on 9 September 1991. The plots were top dressed with 44.8 kg N and 24.6 kg P ha⁻¹ on 31 September 1991 and with two applications of N (25 kg ha⁻¹ each) as urea on 20 February and 18 March 1992.

Propiconazole (1-[2-(2,4-dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl-methyl]-1H-1,2,4-triazole) applications during spring controlled stem rust (*Puccinia graminis* Peers subsp. *graminicola* Urban). Volunteer plants were controlled with fall-applied herbicides. Application of all chemicals followed recommendations for tall fescue seed crops in the Willamette Valley.

Meteorological data were collected at the Hyslop Farm Weather Station about 100 m from the experimental site. GDD was calculated by the formula $GDD = \frac{1}{2}[(T_{max} + T_{min}) - T_b]$ where T_{max} and T_{min} are, respectively, daily maximum and minimum air temperature and T_b is a base temperature of 3°C.

The experimental design was a randomised complete block with four replications for each cultivar. Plots were 15 m long by 2.25 m wide (5 rows 15 m long) and the central three rows were harvested. Treatments were six windrowing times at successively lower seed moisture contents.

Seed moisture content was determined on a daily basis beginning several days before maturation. Moisture content was calculated on a wet-weight basis after drying 1 h at 130°C (ISTA, 1993). A plot-size windrower and a combine with special pick-up attachment were used for cutting and threshing the plots. The windrower had a 1.5m cutter bar with a draper that placed the windrowed material in a 0.5 to 0.7m windrow placed in the middle of the plot (Ehrensing, Crane and Bolton, 1991a). The combine was a Wintersteiger Nursery Master Elite (Wintersteiger America, Lincoln, NE) with a pick-up attachment for threshing small plot windrows. This pick-up was adapted from a commercially available unit (Sund Manufacturing, Newberg, ND) used with farm-scale combines. A rubber draper with flexible rubber fingers lifts and deposits the windrows on the combine platform (Ehrensing, Crane and Bolton, 1991b). Threshing occurred approximately 10 to 15 d after windrowing. Seeds were cleaned in air-screen machines to a final purity of over 95% before weighing for yield. Before seeds were cleaned,

a sample of air-dry seed was taken for seed weight determination. Germination tests (ISTA, 1993) were conducted approximately 6 m after harvesting.

Total seed losses were evaluated after the 1991 and 1992 harvests by vacuuming shattered seed from the ground in three 0.25 by 1.5m areas in each plot. Vacuuming was done with a small vacuum cleaner attached to a field generator.

Natural seed shedding was also evaluated in 1991 and 1992. Seeds were collected in 16 trays (0.16 by 0.24 m) placed in the inter-row space beneath the canopy of adjacent plots of cv. Chesapeake and Emperor. These plots were of the same age, seeding pattern, and management as the harvested plots. The trays were positioned at the beginning of the seed maturation period. A wide-mesh wire net, bent to form a tunnel over the trays, precluded seed shattering caused by emptying and repositioning of the trays. Seeds from the trays and from the vacuumed samples were cleaned with table-top air-screen machines and seed blowers.

Cv. Chesapeake plots lodged before anthesis during each of the three years. During the 1991 and 1992 seasons, soon after lodging and before anthesis, lodged plants of this cultivar were aligned parallel to the rows with a fork. Lodging also occurred to a lesser degree with cv. Bonanza and Emperor in 1990 and 1991. In these cultivars lodging occurred after anthesis, and the risk of causing seed shattering prevented organizing the lodged plants over the rows. Lodging was minimal in cv. Bonanza and did not occur in cv. Emperor during 1992, the drier of the three years. During 1991, and to a lesser degree during 1992, cv. Chesapeake also lodged in the area where natural seed shedding was measured. In this area, cv. Emperor did not lodge in either year.

Germination data were transformed with an arcsin transformation for analysis of variance. Spiline models (Freund and Littell, 1991) were used to represent the association between seed moisture content and GDD accumulated after peak anthesis. Peak anthesis was considered to occur at the mid-point of the flowering period. Prospective knots for changing of the slope of the regression lines were selected from charts. The knot producing the regression equation with the smallest mean square error was selected. For cv. Bonanza and Emperor, rain prevented moisture sampling for approximately 5 d in 1991 and the knot was estimated using the SAS procedure spline models with unknown knots (Freund and Littell, 1991). Daily rates of moisture loss were calculated by multiplying the average daily GDD accumulation by the rate of moisture loss per GDD obtained from each of the regression equations in the spline model. For each cultivar, after homogeneity of variances was tested with an F test ($P < 0.05$), the regression equations fitting each of the two phases of the drying process were compared between years following the method proposed by Neter, Wasserman and Kutner (1989). Yield data were regressed on seed moisture content and on GDD after mid-anthesis using quadratic polynomials. For those years in which the quadratic association between yield and standing seed moisture content was significant ($P < 0.10$), the seed moisture content for maximum yields was calculated by the formula $M.C._{(max.yield)} = -2a/b$ where a and b are parameters from the quadratic equation (Neter *et al.*, 1989).

RESULTS AND DISCUSSION

Weather Data

Climate conditions during 1990 and 1991 were favorable for seed production in tall fescue (Table 1). During 1992, however, rainfall was below normal for most of the reproductive

period and seed maturation occurred under water stress, especially for the late cultivar Emperor. Higher air temperatures during the inductive period of 1992 advanced maturity of the cultivars by approximately 4 w, and flowering occurred under cooler temperatures than in the previous years.

Table 1. Rainfall and temperature during the reproductive development of tall fescue cv. Chesapeake, Bonanza, and Emperor.

Month	Rainfall						Average Air temperature					
	1990		1991		1992		1990		1991		1992	
			mm						°C			
January	241	(+50)†	68	(-124)	116	(+59)	5.7	(+1.3)	7.8	(+0.1)	6.3	(+1.4)
February	147	(+24)	82	(-42)	116	(+13)	4.6	(-1.2)	9.1	(+3.0)	8.6	(+2.6)
March	56	(-61)	149	(+31)	27	(-90)	8.8	(+1.5)	7.1	(-0.2)	10.5	(+2.7)
April	60	(-2)	88	(+26)	104	(+39)	10.3	(+2.2)	9.5	(-0.7)	12.2	(+3.0)
May	36	(-12)	99	(+51)	0	(-50)	12.5	(-1.0)	11.4	(-1.3)	15.9	(+3.2)
June	39	(+8)	39	(+8)	30	(-1)	16.7	(+0.4)	14.2	(-1.7)	18.7	(+2.5)
July	11	(+4)	10	(+2)	30	(+17)	19.5	(+1.8)	19.6	(+0.9)	20.3	(+1.5)

† Numbers in parentheses refer to the departure from normal for the previous 10 years

Pattern of Seed Moisture Decrease During Seed Maturation

A two-phase pattern of moisture loss during seed maturation and ripening occurred in each cultivar in each year (Fig. 1). The first phase (P1) began shortly after anthesis at

levels above 600 g kg⁻¹. Seeds lost moisture at a fairly constant 0.8 g kg⁻¹ GDD⁻¹ or 11.5 g kg⁻¹ d⁻¹ until reaching a level of approximately 500 g kg⁻¹. The second phase (P2) started after this point with rates of moisture decrease three to four times higher than those during P1 (Table 2).

Table 2. Daily growing degree day (GDD) accumulation after mid-anthesis and rates of seed moisture decrease during the two phases of moisture loss in tall fescue cultivars

Year	First drying phase (P1)			cv.	Second drying phase (P2)		
	Daily GDD [†]	Rate of moisture loss			Daily GDD	Rate of moisture loss	
		per GDD	per day ^{††}		Per GDD	per day	
		g kg ⁻¹			g kg ⁻¹		
				cv. Chesapeake			
1990	14.24	0.73a [§]	10.4		13.68	2.5b	34.2
1991	15.37	0.77a	11.8		15.70	3.1a	48.9
1992	14.56	0.96a	13.0		14.53	2.4b	35.0
				cv. Bonanza			
1990	14.95	0.83a [#]	12.0		14.69	2.9a	42.2
1991	15.88	0.73a	12.0		15.54	3.4a	52.2
1992	12.86	0.58a	7.4		18.65	2.3a	42.5
				cv. Emperor			
1990	14.00	0.80a	11.2		18.33	2.7a	49.0
1991	15.47	0.72a	11.0		16.16	2.1a	34.0
1992	12.67	0.47a	5.9		18.63	2.0a	38.0

[†] Calculated from (GDD accumulated in the period)*(number of days in the period)⁻¹

^{††} Calculated from (g kg⁻¹ GDD⁻¹)*(Daily average GDD accumulated).

[§] Rates followed by different letters differ at F test (p≤0.05).

[#] Non-uniform variance prevented the comparison 1990x1991 for the first drying phase in cv. Bonanza. Letters refer to the remaining comparisons.

Fig. 1

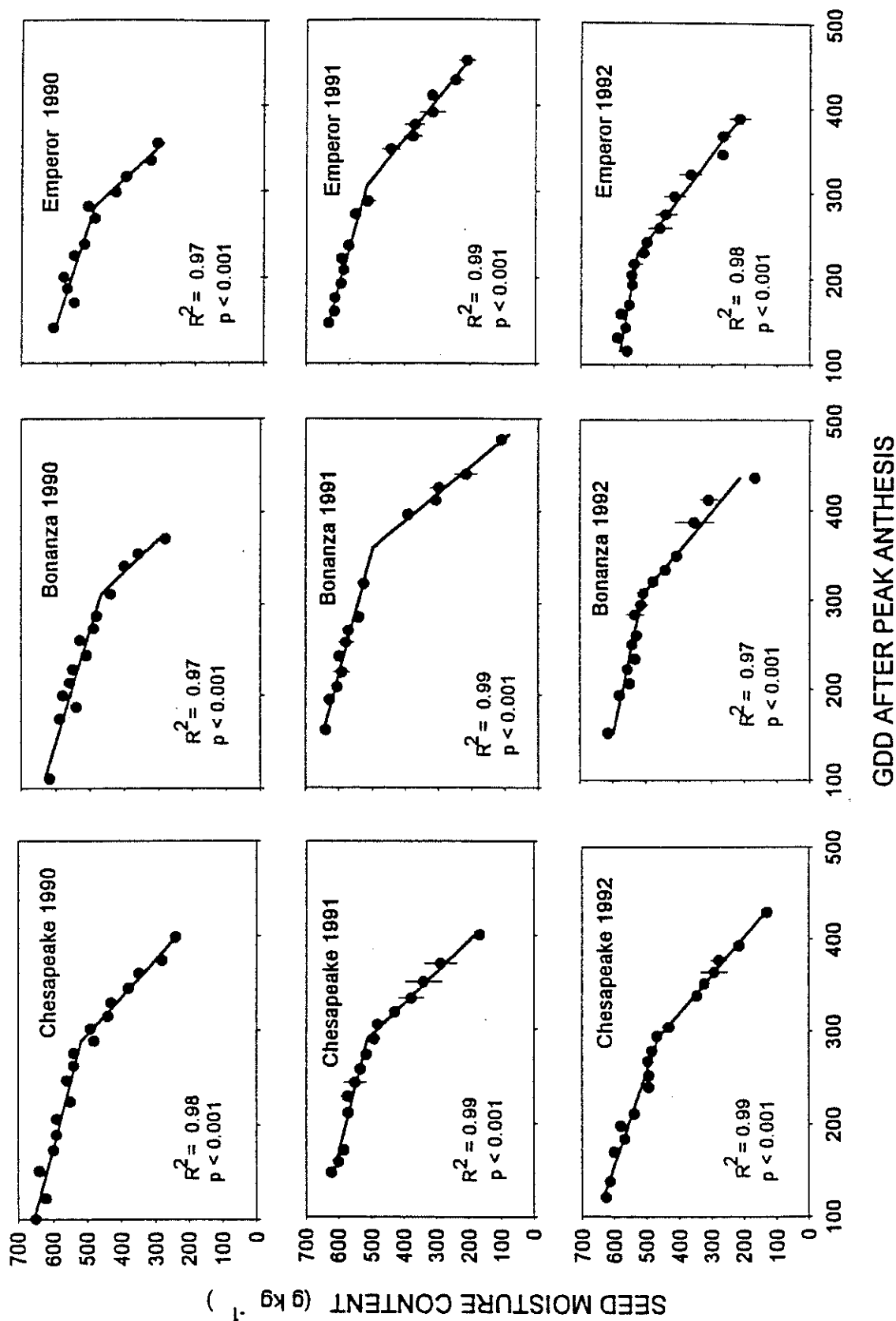


Fig 1. Relationship between growing degree days (GDD) after mid-anthesis and moisture loss during seed development in tall fescue. Vertical lines represent the mean standard error (n=4). For some data points the standard errors were smaller than the symbol. Mean standard error was not calculated in 1990.

For P1, the rates of moisture decrease did not differ between years (Table 2). In spite of the drier conditions, the rates of moisture loss observed in 1992 during P1 in cv. Bonanza and Emperor tended to be smaller than in the previous years. Average daily GDD during P1 in 1992 were the smallest for cv. Bonanza and Emperor and it is likely that these cooler conditions accounted for the lower rates of moisture decrease observed in that year. In glasshouse studies of tall fescue seed maturation,

the rates of moisture decrease were slower at 25°C (Bean, 1971).

Daily rates of moisture decrease during P2 varied between 2.5 to 3.1 g kg⁻¹ GDD⁻¹ or from 34 to 49 g kg⁻¹d⁻¹ (Table 3). The rate of moisture decrease per GDD during P2 was highest during 1991 (P≤0.05) for cv. Chesapeake. For the other two cultivars there was no difference between years in the rate of moisture decrease during this phase.

Table 3. Seed moisture content, GDD and days after mid-anthesis at the beginning of phase 2 of moisture loss.

Year	Seed moisture [†] g kg ⁻¹	GDD*	Days [§] d
cv. Chesapeake			
1990	510	288	20
1991	500	297	19
1992	460	299	21
cv. Bonanza			
1990	460	313	21
1991	510	361	23
1992	510	308	24
cv. Emperor			
1990	490	282	20
1991	510	306	20
1992	510	221	17

[†] Estimated from the spiline models fitting the moisture loss for each cultivar each year.

* GDD value for the joint point of the spiline model fitting the moisture loss with the smallest mean square error.

[§] Days after peak anthesis.

For each of the cultivars, the beginning of P2 occurred at moisture contents around 500 g kg⁻¹ in two out of three years (Table 3). In 1992, for cv. Chesapeake, and in 1990, for cv. Bonanza, this starting point occurred at 460 g kg⁻¹. P2 started at 490 g kg⁻¹ in cv. Emperor during 1990.

During the three years, P2 for cv. Chesapeake started after 288 to 299 GDD were accumulated after peak anthesis. With cv. Bonanza, despite a higher value in 1991, the GDD accumulation before P2 showed little variation between 1990 and 1992 and was fairly constant at values around 309 GDD. The number of GDD accumulated before P2 was variable between years for cv. Emperor. The number of GDD accumulated until P2 in cv. Emperor was smaller in 1992 probably because water stress reduced the period of seed maturation. During the three years, the number of days from peak anthesis until P2 varied from 19 to 21 d in cv. Chesapeake, and from 21 to 24 d in cv. Bonanza. For cv. Emperor, there were 20 d from anthesis to P2 during 1990 and 1991 and 17 d during 1992. During 1991, rain during the seed development period prevented moisture samplings and reduced the number of samplings around P2 for cv. Bonanza and Emperor (Fig. 1). Nevertheless, across cultivars and years, seed moisture content appeared to show less variability than GDD and days after anthesis for identifying the beginning of P2. Only for cv. Chesapeake were GDD and days after anthesis a reliable indicator of P2.

A two-phase pattern of moisture decrease during seed development has been observed in other cool season grasses (Grabe, 1956; Hill and Watkin, 1975; Andersen and Andersen, 1980) and in wheat (Sofield, Wardlaw, Evans, and Zee, 1977). The higher rates of moisture decrease during P2 indicate that the seed is no longer receiving water from the plant and has entered a process of drying. Deposition of lipids in the chalazal zone, as observed in wheat (Sofield *et al.*, 1977) and/or the formation of an abscission layer, which occurs concurrently with physiological seed maturity (McWilliam, 1980; Elgersma, Leeuwangh, and Wilms, 1988), restricts seed water uptake and causes acceleration of moisture loss.

Several authors have suggested the use of 'drying curves' for forecasting the best harvest time in cool season grasses (Klein and Harmond, 1971; Hill and Watkin, 1975; Andersen and Andersen, 1980). These authors, however, assumed a uniform rate of seed moisture decrease during seed development. These rates were 25 g kg⁻¹ for tall fescue cv. Alta (Klein and Harmond, 1971) and 18 to 20 g kg⁻¹ d⁻¹ for perennial ryegrass (Hill and Watkin, 1975). The present study indicates, however, that more precise forecasting would be achieved by considering a two-phase drying curve with different drying rates in each phase.

Natural Shedding

Natural seed shedding in cv. Chesapeake was first

observed at moisture contents lower than 170 g kg⁻¹ during 1991 (Fig. 2). Also in 1991, seed shedding in cv. Emperor started earlier during seed development at a moisture content of about 360 g kg⁻¹. Seed moisture was about 220 g kg⁻¹ in both cultivars when seed shedding started during 1992.

The relatively earlier shedding in cv. Emperor during 1991 can be attributed to the occurrence of strong winds on 19 and 20 June when wind speed was 70% higher than the average for the remainder of the seed maturation period. Lodging protected the cv. Chesapeake plants from the wind and probably reduced and delayed losses by shedding until late in the seed development period. During 1992, when lodging was not important and seed maturation proceeded without weather disturbances, seed shedding started at about the same moisture content in both cultivars. The smaller amounts of seed shedding observed in cv. Emperor in 1992 were proportional to the lower yields obtained.

Factors such as species, cultivars, lodging, wind, rain or hail can affect seed shedding (Jensen, 1976; Andersen and Andersen, 1980). Jensen (1976) found that seed shedding in meadow fescue (*Festuca pratensis* Huds.) started at moisture contents higher than those we observed for cv. Chesapeake and Emperor tall fescue. Physiological seed maturity occurs at moisture contents from 400 to 480 g kg⁻¹ for these two cultivars and seed shedding occurred later than this. Elgersma *et al.* (1988) found that breaking of the abscission layer in perennial ryegrass occurred 5 w after anthesis. The seeds, however, remained connected to the rachilla by a central cambium and the vascular bundles and a mechanical force was necessary to cause seed shedding. Although signs of seed shedding from inflorescences are indicative of the optimum windrowing time of some cool season grasses (Griffiths, Roberts, Bean, Lewis, Pegler, Carr, and Stoddart, 1976), this was not the case for cv. Chesapeake and Emperor tall fescue. Without mechanical disturbance, natural seed shedding started too late during the seed maturation period to be a useful indicator of optimum harvesting time in windrow-harvested tall fescue.

Total Seed Losses

The total amount of seed lost on the ground after harvesting operations was inversely related to seed moisture at harvest during both years (Fig. 3). Total seed losses were smaller in 1992 for all cultivars. When windrowed around 400 g kg⁻¹, losses were 18, 34, and 25% of the yield during 1991 for cv. Chesapeake, Bonanza and Emperor, respectively, and 10, 13 and 14% during 1992. Total seed losses increased at a rate of 35, 89 and 80 kg ha⁻¹ for each 100 g kg⁻¹ drop in the seed moisture content for cv. Chesapeake, Bonanza, and Emperor, respectively, during 1991 with harvests between 550 and 200 g kg⁻¹. During 1992 those rates were 20, 15 and 5 kg ha⁻¹, respectively.

Air movement through the combine screens was minimized to avoid seed losses and very few seeds remained attached to the inflorescences after threshing. Therefore, seed shedding from the windrows and seed shattering during windrowing and combining were the main causes of seed loss in the plots. Lodging might explain the relatively smaller amount and rate of seed loss measured in cv. Chesapeake during 1991. Lodged inflorescences of cv. Chesapeake were not touched by the windrower reel and, since the plants were lying on the ground, shaking caused by the cutter bar was reduced. Lodging of cv. Bonanza and Emperor was not severe enough to place the seed heads out of the reach of the reel or to reduce shaking caused by

the cutter bar during windrowing.

The percentage of losses we observed are smaller than the 38% losses reported for tall fescue cv. Alta by Klein *et al.*, (1961), but losses measured in our study probably underestimated the losses occurring with farm-size machinery. The operating speed used by growers is around 6–8 km h⁻¹ for windrowing and 5 km h⁻¹ for combining. In contrast, operating speeds for harvesting the plots were 0.8 km h⁻¹ for windrowing and 2 km h⁻¹ for combining. Farm windrowers normally have an auger to place the cut material in windrows and most farm combines use drapers with wire fingers to lift the windrow from the ground and deposit it on the combine platform. The plot windrower used a draper system which tends to cause smaller seed losses during windrowing. Also, compared with the traditional pick-up with wire fingers, the pick-up attachment with rubber fingers on the plot combine caused smaller agitation of the windrows during combining.

Although Williams (1972) showed that pre-harvest losses reduced yield in tetraploid ryegrass, natural seed shedding in cv. Chesapeake and Emperor occurred too late in the seed maturation period to be of concern. Occurrence of strong winds during seed development might, however, cause earlier seed shedding and reduced yield. Losses during harvesting operations reduce yields and supply the soil seed bank with seeds from which a generation of volunteer plants will infest the area. The amount of total losses observed in this study indicates that development of more efficient harvest machinery can be an alternative way to reduce losses and increase yield in turf-type tall fescue.

Yield

The seed moisture content at windrowing indicative of maximum seed yield varied between cultivars and between years for the same cultivar (Fig. 4). For cv. Chesapeake, the optimum seed moisture contents were 380, 340 and 310 g kg⁻¹ respectively, during 1990, 1991 and 1992. For cv. Bonanza, the optimum moisture varied from 410 in 1990 to 350 g kg⁻¹ in 1992. For cv. Emperor, optimum seed moisture was 360 g kg⁻¹ in 1992. Lodging of plants increased the variability of the yield data, preventing a quadratic association between seed moisture content and yield to be expressed in one year for cv. Bonanza and in two years for cv. Emperor, and prevented a comparison among the cultivars within those years (Fig. 4). The number of GDD at which maximum yields were achieved was also variable between years and cultivars (Fig. 5). A quadratic association between yield and GDD was detected in 1991 and 1992 for cv. Chesapeake, 1990 and 1992 for cv. Bonanza, and 1992 for cv. Emperor. Maximum yields in cv. Chesapeake were obtained at 360 and 354 GDD during 1990 and 1991. For cv. Bonanza, 308 GDD in 1990 and 345 in 1992 were needed for maximum yield. For cv. Emperor, maximum yield occurred when 306 GDD were accumulated in 1992 (Fig. 5).

Maximum yields in cv. Chesapeake probably occurred at lower moisture contents because lodging reduced seed losses (Fig. 3 and 4). These results also corroborate Andersen and Andersen's (1980) statement that windrowing can be delayed to lower moisture contents when the seed crop lodges. The year-to-year variation and the relative flatness of the curves associating yield and seed moisture content support the approach used by Andersen and Andersen (1980) of recommending ranges of moisture contents for windrowing a number of species. Hill and Watkin (1975) and Arnold and Lake (1965) also indicated

Fig. 2

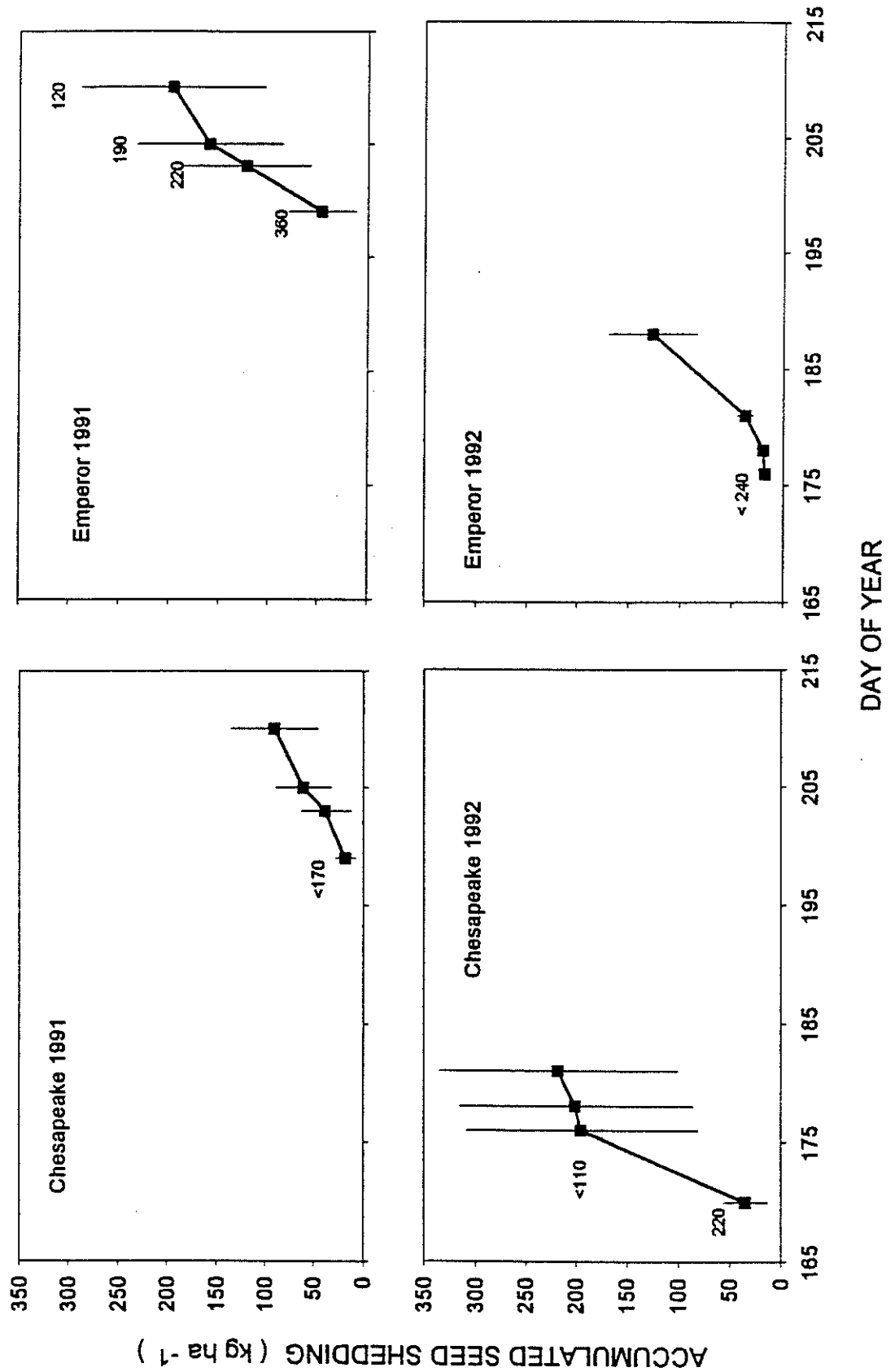


Fig 2. Natural seed shedding in tall fescue. Numbers inside the graphs are seed moisture content in g kg⁻¹ at that sampling date. Vertical lines represent the mean standard error (n=16). For some sampling dates the mean standard error was smaller than the symbol.

Fig. 3

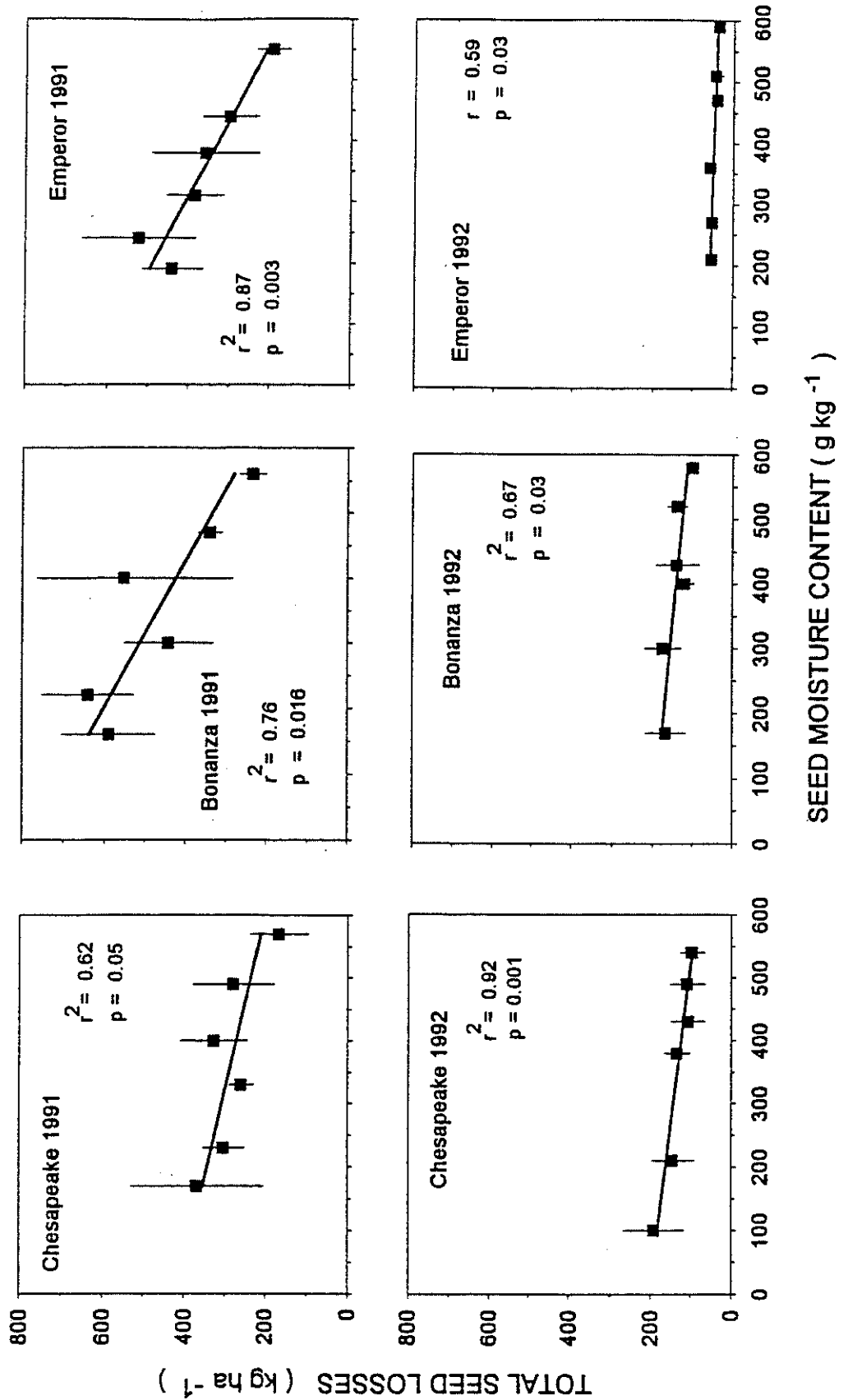


Fig. 3. Effect of seed moisture content at windrowing on total harvest losses in tall fescue cultivars. Vertical lines represent the mean standard error (n=12). For some moisture contents the mean standard error was smaller than the symbol.

Fig. 4

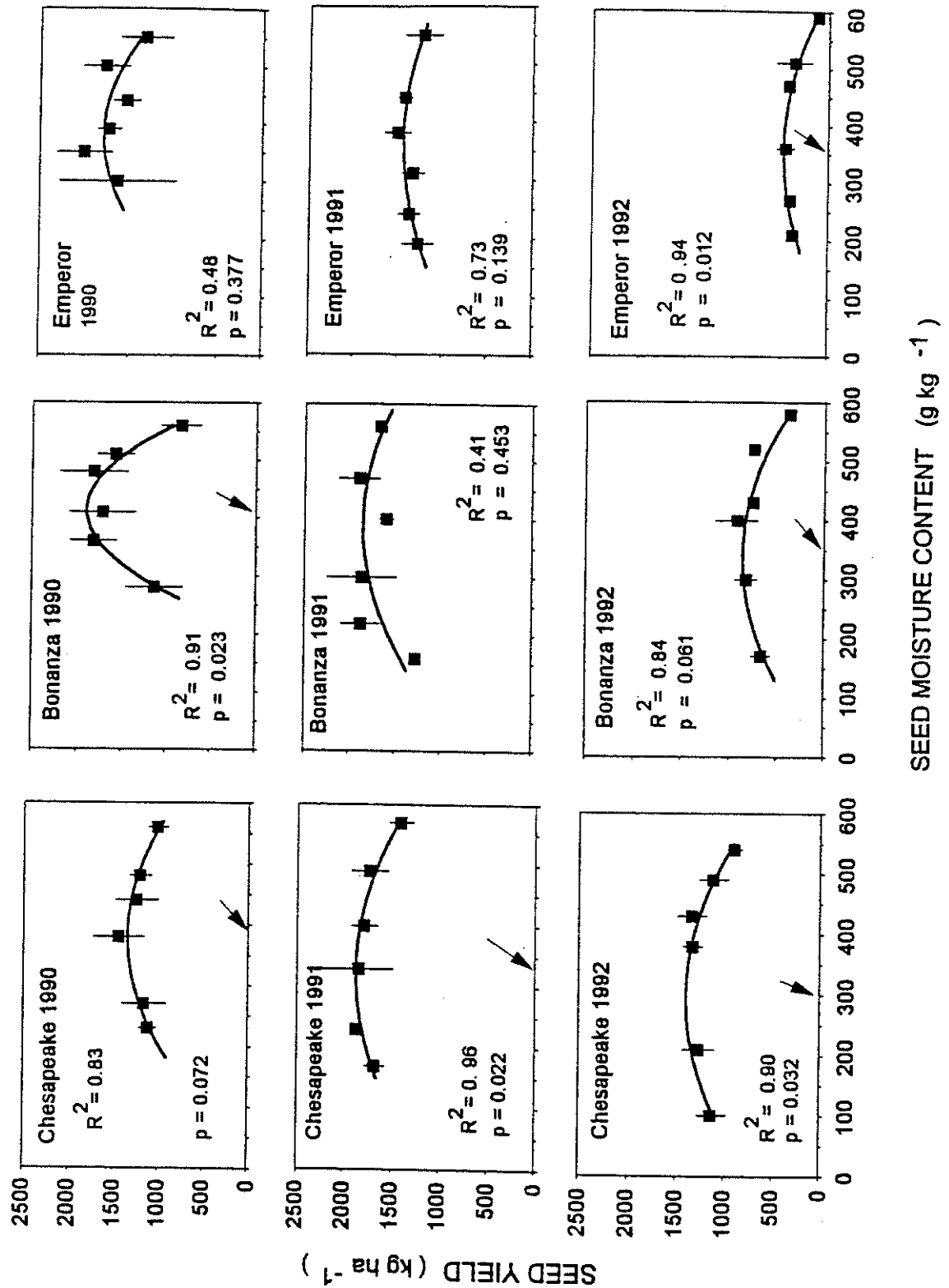


Fig 4.

Effect of seed moisture content at windrowing on seed yield in tall fescue cultivars. Arrows indicate moisture content for maximum seed yield. Variability of yield data prevented a quadratic association between seed moisture content and yield to be expressed in 1991 in cv. Bonanza and in 1990 and 1991 in cv. Emperor. Vertical lines represent the mean standard error for each harvest (n=4). For some harvests the mean standard error was smaller than the symbol.

Fig. 5

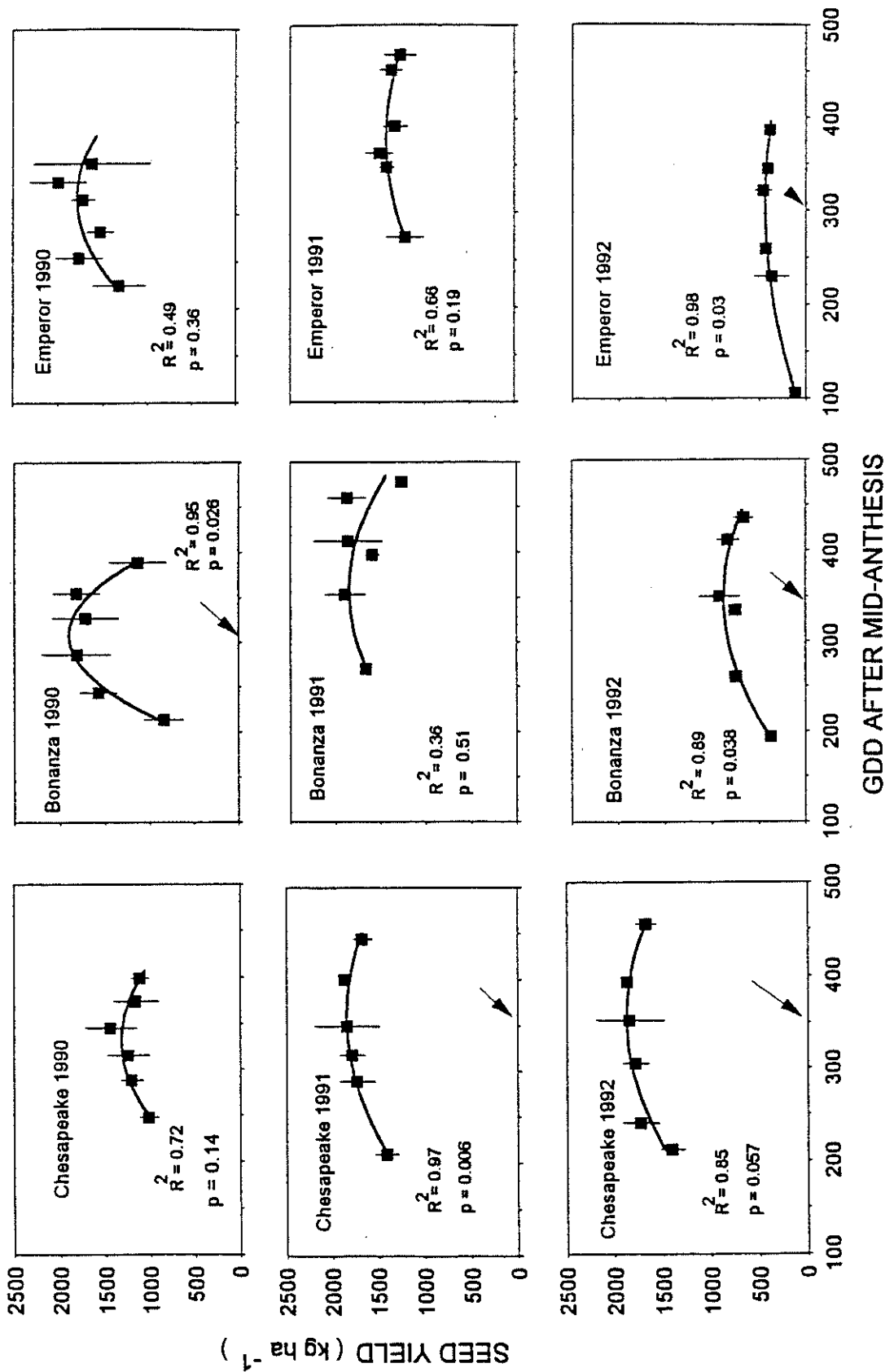


Fig 5. Effect of GDD after anthesis when windrowed on seed yield in tall fescue cultivars. Arrows indicate GDD for maximum seed yield. Vertical lines represent the mean standard error for each harvest (n=4). For some harvests the mean standard error was smaller than the symbol.

that maximum yield can be achieved with harvesting over a range of moisture contents because of completion of drying in the windrow. Further supporting the indication of a range of moisture contents for maximum yields, Evans (1959) suggested that in years without a well defined peak anthesis, a corresponding seed maturation plateau might occur on which maximum yield can be achieved.

The recommended windrow timing indexes for other cultivars of tall fescue (Klein and Harmond, 1971; Hare *et al.*, 1990) are above the range of moisture contents found in this study for the three cultivars of turf-type tall fescue. Unfortunately, the year-to-year variation in yield and losses encountered in those studies was not presented, and speculation about possible causes for the differences between the studies is not possible.

The use of GDD as an alternative to days after anthesis as an indicator of harvest timing was suggested by Andersen and Andersen (1980). Although the estimated GDD for maximum yields was constant for 1990 and 1991 in cv. Chesapeake, it was quite variable for cv. Bonanza between 1990 and 1992 (Fig. 5). This indicates that GDD also has year-to-year variation and might not be an improvement as an indicator of optimum harvest timing.

Because of the small plot width (three rows harvested), plants lodged in or out of the plots may have had a relatively

high influence on the yield and increased variability of results. It is likely that the use of wider and/or longer plots would reduce the relative influence of plants lodging on the sides of the harvested area and yield variability would be reduced.

Seed Weight and Germination

For all cultivars, dry seed weight tended to increase with harvests at successively lower moisture contents until a maximum weight was achieved at moisture contents below 450 g kg⁻¹ (Table 4). In some seasons and with some cultivars seed moisture content was well below 400 g kg⁻¹ at windrowing (cv. Chesapeake in 1990, cv. Bonanza in 1992, cv. Emperor in 1992) before maximum dry weight was reached. A similar tendency was observed for a number of cool season grasses (Grabe, 1956; Hill and Watkin, 1975; Williams, 1972). Seed moisture at physiological maturity varies with species. For example, maximum seed weight was achieved at 330 g kg⁻¹ moisture content for three cultivars of red fescue (Hebblethwaite and Ahmed, 1978). Pegler (1976), studying harvest timing in tall fescue cv. S 170, related seed maturation to number of days after anthesis and to endosperm consistency. With hand harvesting, seed weight tended to level off approximately 30 d after peak anthesis or when endosperm consistency was at the cheesy or hard stage. For cv. Chesapeake, Bonanza and Emperor, as an average, seed weight tended to level off from 20 to 28 d after peak anthesis.

Table 4. Seed weight and germination of tall fescue cultivars windrowed at different seed moisture contents.

Windrowing moisture g kg ⁻¹	1990			1991			1992		
	Seed weight mg	Germination %	Windrowing moisture g kg ⁻¹	Seed weight mg	Germination %	Windrowing moisture g kg ⁻¹	Seed weight mg	Germination %	
cv. Chesapeake									
560	2.00d†	94.7d	570	1.90c	91.9b	540	1.79b	87.8d	
480	2.32c	96.5cd	490	2.24b	94.7ab	490	1.87b	95.1c	
440	2.45b	96.9bc	400	2.31ab	96.0a	430	2.21a	97.1bc	
380	2.46b	97.7bc	330	2.36a	96.2a	380	2.22a	97.9ab	
270	2.53ab	97.8ab	230	2.37a	96.9a	210	2.25a	98.1ab	
230	2.55a	98.5a	170	2.42a	97.2a	100	2.27a	99.1a	
cv. Bonanza									
560	1.96d	92.4b	560	1.79b	83.4b	580	1.65c	83.9d	
510	2.14c	91.8b	470	2.14a	94.6a	520	1.89c	90.1c	
480	2.44b	95.6a	400	2.17a	95.4a	430	2.16b	92.5bc	
410	2.45ab	96.1a	300	2.19a	96.1a	400	2.22b	93.9ab	
360	2.54a	96.2a	220	2.26a	96.5a	300	2.32a	94.0ab	
280	2.54a	97.3a	160	2.28a	96.6a	170	2.32a	95.6a	
cv. Emperor									
550	2.01d	91.5a	550	1.90c	84.7d	590	1.63d	72.1c	
500	2.11cd	93.0a	440	2.24b	95.1c	510	1.88c	73.0c	
440	2.15bc	94.5a	380	2.31ab	95.8bc	470	2.07b	78.1c	
390	2.18abc	94.6a	310	2.36a	96.0bc	360	2.17a	85.5b	
350	2.25ab	94.6a	240	2.37a	97.1ab	270	2.19a	86.1b	
300	2.28a	94.6a	190	2.42a	97.9a	210	2.20a	95.3a	

† Dry seed weight and germination percentage followed by a different letter are significantly different according to the LSD test at $p \leq 0.05$.

Germinability of harvested seed increased from the first harvest and tended to level after maximum values were achieved, usually during the third or fourth harvest (Table 4). During the three years for cv. Chesapeake and during 1990 and 1991 for cv. Bonanza, germination values above 95% were obtained with harvests at moisture contents below 470 g kg⁻¹. For cv. Emperor, 95% germination was achieved at a seed moisture content of 440 g kg⁻¹ during 1990 and 1991. Seed germination above 95% in cv. Bonanza and Emperor was not attained until later harvests at lower moisture contents during the drier 1992 season. For the medium-maturity cv. Bonanza, seed germination was above 95% with harvests at moistures below 400 g kg⁻¹. Apparently, those drier conditions were more detrimental to seed germination in the late-maturing cv. Emperor. With this cultivar, germination of 95% was achieved only with the last harvest at a moisture content of 210 g kg⁻¹.

Although seeds of several grass species are able to germinate 1 to 2 w after anthesis (Pegler, 1975; Roberts, 1969 and 1971), maximum seed vigour occurs only when seeds achieve maximum dry weight (Grabe, 1956), and this characteristic needs to be considered in defining the optimum windrowing time. For the three cultivars, maximum seed weight and germination above 95% are likely to occur with windrowing at moisture contents lower than 450 g kg⁻¹. During dry years this tendency might change and (mainly for late cultivars) high seed germination might only be achieved with harvests at lower moisture contents.

CONCLUSIONS

Maximum yields were achieved by windrowing at moisture contents in the range of 350 to 410 g kg⁻¹. In this range, maximum dry seed weight and germination percentage were achieved and natural seed shedding was minimal. It is unrealistic to recommend a narrower range or a specific moisture content to indicate optimum windrowing time in tall fescue because of uneven maturity caused by an extended flowering period, lodging of plants, and yearly weather conditions. These factors, and the considerable plant-to-plant variation within cultivars, made it impossible to discern cultivar-specific requirements for optimum windrow timing in relation to moisture content.

Loss of seed moisture during tall fescue seed maturation occurs in two phases. During the first phase, moisture decreased about 11 g kg⁻¹d⁻¹. At about 500 g kg⁻¹, moisture loss accelerated, decreasing about 35 g kg⁻¹d⁻¹. At about 500 g kg⁻¹, moisture loss accelerated, decreasing about 35 g kg⁻¹d⁻¹. It is necessary to understand this two-phase moisture loss pattern to realistically predict when the target seed moisture content for windrowing will occur. The 350 to 410 g kg⁻¹ moisture range represents about a 2-d period for optimum time of windrowing.

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