SEED PHYSIOLOGY, PRODUCTION & TECHNOLOGY

Residue Management Strategies for Kentucky Bluegrass Seed Production

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ABSTRACT

Open-field burning provides effective, economical post-harvest residue management in Kentucky bluegrass (*Poa pratensis* L.) seed crops, but public concern over air quality necessitates the identification of nonthermal management strategies. On-farm trials were conducted in Oregon's Grande Ronde Valley to investigate the effect of nonthermal management in two cultivars of Kentucky bluegrass on crop regrowth, seed yield, and seed quality. Residue treatments imposed after the first, second, and third seed harvests included (i) removal of straw by baling (Bale), (ii) baling, flailing with a rotary scythe, followed by residue removal with a needle-nose rake (Rake), (iii) baling, followed by removal of the residue by vacuum-sweeper (Vacuum), (iv) flail-chopping residue three times with no removal (Flail 3X), and (v) open-field burning (Burn). Tillers were etiolated at the cessation of fall regrowth in Flail 3X (stubble height reduced, no straw removal) and Bale (no stubble height reduction, 75% straw removal) treatments. Fertile tiller number was lower in the following spring with Flail 3X and Bale treatments compared with Burn. Seed yield averaged across the 3-yr period was reduced 38% when managed with Flail 3X and 10% when managed with Bale compared with Burn. Crop regrowth, fertile tiller production, and seed yield resulting from Rake and Vacuum treatments were equivalent to the Burn treatment. Rake and Vacuum treatments reduced stubble height and removed at least 90% of the straw. High seed yield and seed quality can be maintained in Kentucky bluegrass without open-field burning when straw removal is thorough and stubble height is reduced prior to crop regrowth.

Management of straw and stubble in the field after seed harvest is an important step in the production of Kentucky bluegrass seed crops. Open-field burning has been an effective, economical method of crop residue removal and pest control in Kentucky bluegrass seed crops for more than 50 yr. Nevertheless, increased public concern about reduction in air quality caused by burning of grass seed crop straw and stubble has mandated that nonthermal residue management systems be identified.

Several investigators have studied nonthermal residue management in Kentucky bluegrass seed crops. Pumphrey (1965) demonstrated that seed yield in Oregon's Grande Ronde Valley was not reduced when residue was mowed and removed by raking. Canode (1972) reported that field burning reduced seed yield in eastern Washington in the second and third seed crops compared with clipping and raking. Nevertheless, burning produced higher seed yield than mechanical removal in the fourth and fifth seed crops. Young et al. (1984) found that close-clipping straw and stubble produced yields greater than burning in the second seed crop, equal to burning in the third seed crop, and lower than burning in the fourth seed crop in Oregon's Willamette Valley.

The post-harvest regrowth period is a critical phase of seed crop development that can strongly influence flowering and seed yield in cool-season perennial grasses (Canode and Law, 1978). The number and condition of tillers prior to the onset of an environment conducive to floral induction are limited by a relatively short regrowth period in late summer and early fall. If regrowth is retarded by poor weather conditions or inadequate management, then fewer tillers will be in a receptive state when floral induction begins.

Relationships between post-harvest regrowth characteristics and flowering potential have been documented in perennial grass seed crops. Tiller population density at the cessation of fall regrowth was highly correlated with fertile tiller number and subsequent seed yield in orchardgrass (*Dactylis glomerata* L.) (Chastain and Grabe, 1989a) and tall fescue (*Festuca arundinacea* Schreb.) (Chastain and Grabe, 1989b). Canode and Law (1979) found that Kentucky bluegrass tillers with a large basal diameter (2.0 mm) in late winter were much more likely to produce panicles in the following spring than tillers with small (1.0 mm) or moderate (1.5 mm) basal diameters. Similar findings were reported for smooth bromegrass (*Bromus inermis* Leysser) and crested wheatgrass [*Agropyron desertorum* (Fischer ex Link.) Schult.] (Canode and Law, 1978). These authors offered no explanation for why large tillers have greater potential for flowering than small tillers, although they did note that tillers of all size classes that did not flower had apical primordia that remained in a vegetative state.

The objective of our study was to determine the influence of crop residue management practices on regrowth and plant development, seed yield, and seed quality of Kentucky bluegrass.

MATERIALS AND METHODS

On-farm trials were initiated in 1992 in the Grande Ronde Valley near Imbler, OR (annual precipitation = 501 mm, elevation = 823 m) on Imbler fine sandy loam soil (coarse-loamy, mixed, mesic Pachic Haploxeroll). Trials were conducted in adjacent irrigated seed production fields of "Abbey" and "Bristol" Kentucky bluegrass seeded in 36-cm rows in April 1991 at a seeding rate of 3.9 kg ha^{-1}. Fertilizer and

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Abbreviations: Bale, removal of straw by baling; Burn, open-field burning; Flail 3X, flail-chopping residue three times with no removal; Rake, baling followed by flailing with a rotary scythe and residue removal with a needle-nose rake; Vacuum, baling followed by removal of the residue by vacuum-sweeper.

herbicide applications were uniformly made across all plots and at application timings and rates standard for Kentucky bluegrass seed production in the Grande Ronde Valley.

Management treatments included (i) removal of straw by baling (Bale); (ii) baling straw, followed by flail chopping the remaining stubble with a rotary scythe, with removal by a needle-nose rake (Rake); (iii) baling, followed by chopping and removal of residue by a vacuum-sweeper (Vacuum), (iv) flailing three times with no removal of residue (Flail 3X), and (v) open-field burning.

The experimental design in each trial was a randomized block with three replications. Each residue management plot was 6.7 by 122 m. Residue management treatments were imposed during the first two weeks in August 1992, 1993, and 1994 after the first, second, and third seed harvests in each field, respectively. The amount of straw in each field after nonthermal treatment was determined on three 0.25-m^2 samples taken along a line transect in each plot. Straw was placed in cloth bags and then oven-dried, soil was removed, and the straw was weighed. Stubble height was measured after each treatment.

Tiller and leaf development characteristics were evaluated at the cessation of fall regrowth on samples taken in late October 1992, 1993, and 1994. Two samples (23 by 30 cm) were taken at random along a line transect from each plot. Tiller number and aboveground dry matter were determined on the entire sample. Tiller basal diameter was determined by selecting a subsample of 200 tillers from each sample and by fitting the broad dimension of each tiller base in a gauge delineated in 1-mm increments. Tiller height and leaf number $tiller^{-1}$ (Haun, 1973) were determined on ten tillers randomly drawn from each basal diameter size class. The mean leaf number for each cultivar, treatment, and year combination was based on 6000 tillers.

Fertile and vegetative tiller numbers in spring were determined on three samples (23 by 30 cm) taken in each plot prior to peak anthesis in June 1993, 1994, and 1995.

Plots in the Abbey trial were harvested 13 July 1993, 17 July 1994, and 10 July 1995 with a farm-scale swather, and plots in the Bristol trial were harvested 27 July 1993, 19 July 1994, and 18 July 1995. Windrows remained in the field until the seed dried to $\approx$120 g kg^{-1} seed moisture content. Dried windrows were combined with farm-scale combines equipped with pickup header attachments. Abbey plots were combined on 7 Aug. 1993, 29 July 1994, and 19 July 1995. Bristol plots were combined on 11 Aug. 1993, 4 Aug. 1994, and 1 Aug. 1995. The harvested area in each plot consisted of one swather cutting width (3.6 by 122 m). Weigh wagons were used to measure the bulk seed weight harvested from each plot. Clean seed yields were calculated from percent cleanout values obtained from subsamples taken from the bulk seed material harvested in each plot and laboratory seed purity. Seed germination and purity was determined according to rules of the Association of Official Seed Analysts (AOSA, 1988).

Residue management treatment effects were tested by analysis of variance. Treatment means were separated by Fisher's protected least significant difference values. Regression analyses were conducted to elucidate the nature of relationships between fall regrowth characteristics and seed yield.

RESULTS AND DISCUSSION

The Bale treatment removed 75% of the straw remaining after harvest (by weight), whereas the Rake and Vacuum treatments removed 90 and 91% of the straw, respectively (data not shown). Baling is the most widely used straw removal method in clean nonthermal management of grass seed crops. The Rake and Vacuum treatments removed more than half the straw remaining after baling. Stubble height was greater in Flail 3X and Bale treatments (mean = 5.8 cm) than in Rake and Vacuum treatments (mean = 4.1 cm).

Crop regrowth in fall was affected by residue management in each of the 3 yr of our study. Fall tiller height was shortest in treatments that produced the most thorough residue removal and stubble height reduction (Rake, Vacuum, Burn), whereas tillers were taller in Flail 3X (stubble height reduced, no straw removal) and Bale (no stubble height reduction, 75% straw removal) treatments (Table 1). Increased stubble height and straw cover present in Flail 3X and Bale treatments likely shaded plant crowns, reducing light quantity or altering light quality, which may have caused tiller etiolation (Casal et al., 1985; Chastain and Grabe, 1988). Hickey and Ensign (1983) reported that leaf sheath length was not different in unburned Kentucky bluegrass when the stubble was clipped to 2.5 cm, but leaf sheaths were longer than the burned treatment when stubble height was 7.6 cm.

Canode and Law (1979) proposed that Kentucky bluegrass tillers must attain a threshold size or stage of development before they are receptive to inductive stimuli. Their premise was that thatch accumulation in unburned stands suppresses fall regrowth and reduces the number of large basal diameter tillers. In the fall of 1992, we noted that the number of large diameter tillers was reduced in nonthermal management treatments compared with burning (Table 1). The number of large diameter tillers in the population was generally related to the thoroughness of straw and stubble removal among nonthermal treatments. This trend was reversed in fall 1993 and in fall 1994, however. We initially thought that burning apparently reduced large tiller number in both Abbey and Bristol Kentucky bluegrass in 1995. Yet, when we examined how the Kentucky bluegrass tiller populations had changed across years, burning clearly did not reduce but instead maintained tiller number (Fig. 1). We found that tiller number increased with stand age in nonthermal treatments, probably because of greater rhizome production in nonthermal treatments. Hickey and Ensign (1983) reported increased number of rhizomes when Kentucky bluegrass seed crops were managed without fire. The rhizomes establish daughter plants that, in turn, probably produced the additional tillers recorded in our samples.

Fall dry matter production through time largely paralleled changes in the total tiller population (Fig. 1). Dry matter production did not differ among treatments in 1992, but by 1994, the lowest dry matter occurred in the Burn treatment (data not shown). Increased dry matter production during the fall regrowth period was associated with greater numbers of fertile tillers and seed yield in the following season in orchardgrass (Chastain and Grabe, 1989a) and tall fescue (Chastain and Grabe, 1989b).

Leaf development in fall-formed tillers of Kentucky bluegrass was not consistently affected by the presence

Table 1. Effect of residue management treatments on tiller and leaf production in Abbey and Bristol Kentucky bluegrass.

	Abbey			Bristol		
Treatment	1992–1993	1993–1994	1994–1995	1992–1993	1993–1994	1994–1995
			Fall tiller height (cm)			
Flail 3X	13b†	15c	12b	14c	15d	10b
Bale	12b	10b	16c	10b	9c	10b
Rake	9a	7a	8a	7a	5a	8a
Vacuum	8a	7a	7a	8ab	5a	8a
Burn	9a	7a	8a	7a	7b	7a
			Large fall tillers (% of burn)			
Flail 3X	65ab	35a	183ab	43a	86a	264b
Bale	64a	89b	171ab	48a	97a	237b
Rake	115c	99b	255bc	78b	156bc	236b
Vacuum	108c	101b	299c	92b	168c	315b
Burn	100c‡	100b	100a	100b	100ab	100a
			Leaf nnmber tiller^{-1}			
Flail 3X	2.3ab	1.7a	2.9a	2.1a	2.5ab	3.2a
Bale	1.9a	2.3b	2.7a	2.2a	3.0b	3.1a
Rake	2.8c	2.4b	2.7a	2.3a	2.1a	3.3a
Vacuum	2.7bc	2.1b	2.7a	2.3a	2.5ab	3.0a
Burn	2.3ab	2.4b	2.6a	2.2a	2.5ab	3.0a
			Fertile tillers (%)			
Flail 3X	14a	6a	6a	18a	14a	22a
Bale	28a	20b	13a	30b	17a	28ab
Rake	31a	28b	28b	32b	30bc	41bc
Vacuum	29a	25b	29b	39b	37c	38bc
Burn	28a	25b	29b	42b	26b	49c

† Means in columns followed by the same letter are not significantly different by Fisher's protected LSD values (P = 0.05).
‡ The burn treatment in Abbey had 4543, 5870, and 2130 large tillers m^{-2} in 1992, 1993, and 1994, respectively. Bristol had 3410, 2698, and 1151 large tillers m^{-2} in 1992, 1993, and 1994, respectively.

or absence of burning, nor was leaf development influenced by the thoroughness of straw and stubble removal among nonthermal treatments (Table 1). A greater leaf area index of tall fescue stands at the cessation of fall regrowth resulted in higher fertile tiller production and seed yield in the following summer (Chastain and Grabe, 1989b).

Managing straw and stubble without removal (Flail 3X) consistently resulted in low proportions of fertile tillers in the following spring (Table 1). Management by baling without additional straw removal by a secondary method (Rake or Vacuum) or stubble height reduction often resulted in a lower proportion of fertile tillers than in the Burn treatment. Fertile tiller production was the same in the Rake and Vacuum treatments and was equivalent to burning. The number of spring vegetative tillers was reduced by burning in 1993 and 1995, but not in 1994 (data not shown).

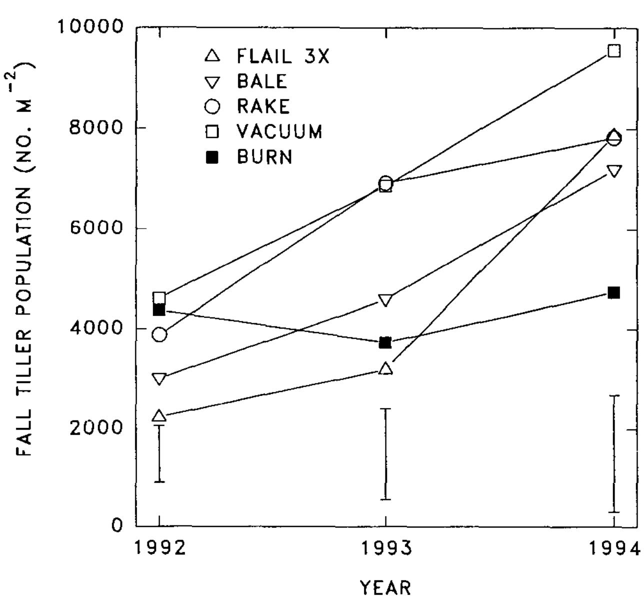

Fig. 1. Influence of residue management treatments and stand age on fall tiller population in Bristol Kentucky bluegrass managed for seed production. Vertical bars represent Fisher's protected LSD values (P = 0.05). Bale, removal of straw by baling; Burn, open-field burning; Flail 3X, flail-chopping residue three times with no removal; Rake, baling followed by flailing with a rotary scythe and residue removal with a needle-nose rake; Vacuum, baling followed by removal of the residue by vacuum-sweeper.

Harvest index was not affected by residue management in 1993, but was depressed by the Flail 3X treatment in both cultivars in 1994 and in 1995 (Table 2). Entz et al. (1993) found that harvest index was not affected by straw removal without burning in timothy (*Phleum pratense* L.). Kentucky bluegrass seed yields

Table 2. Effect of residue management treatments on harvest index and seed yield in two cultivars of Kentucky bluegrass.

		Harvest index		Seed yield	
Year	Treatment	Abbey	Bristol	Abbey	Bristol
				kg ha^{-1}	
1993	Flail 3X	11a†	7a	936a	483a
	Bale	14a	8a	1232b	672b
	Rake	15a	9a	1391b	719bc
	Vacuum	14a	9a	1310b	702bc
	Burn	15a	8a	1371b	755c
1994	Flail 3X	4a	3a	274a	253a
	Bale	8b	5b	549b	399b
	Rake	9b	7d	858c	506c
	Vacuum	8b	7d	740c	495c
	Burn	10b	6c	839c	486bc
1995	Flail 3X	8a	6a	713a	560a
	Bale	12b	9b	1084b	747c
	Rake	13b	6a	1344c	698bc
	Vacnum	11b	7ab	1303c	684b
	Burn	11b	8b	1074b	689b

† Means in columns within years and cultivars followed by the same letter are not different by Fisher's protected LSD values (P = 0.05).

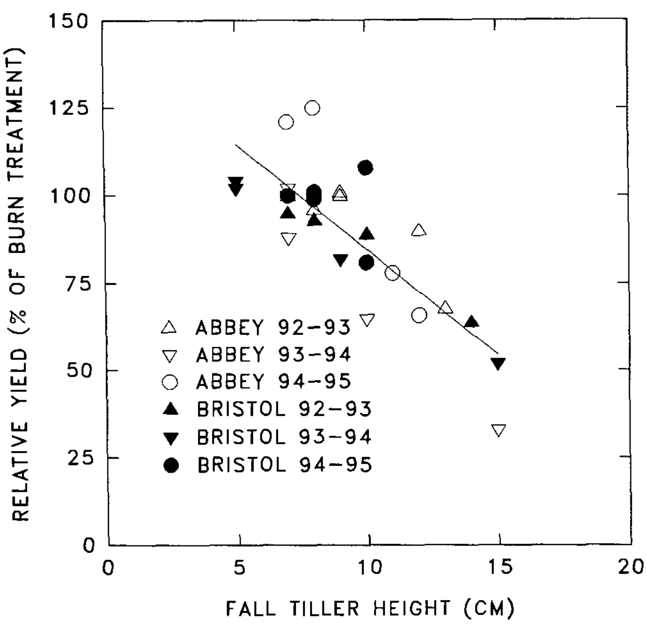

Fig. 2. Relationship of tiller height at the cessation of fall regrowth to relative seed yield of Abbey and Bristol Kentucky bluegrass in the following harvest season ($r^2 = -0.66, P < 0.01$). Relative seed yield values represent treatment means expressed as a percentage of the Burn treatment for each year and cultivar combination. Regression equation for the fitted line is $Y = 144.66 - 6.00X$.

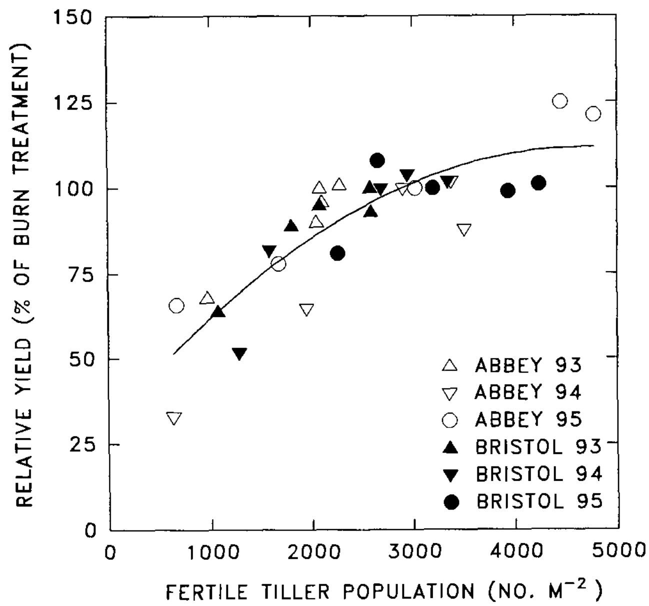

Fig. 3. Relationship of fertile tiller population at peak anthesis to seed yield in two cultivars of Kentucky bluegrass ($r^2 = 0.70, P < 0.01$). Relative seed yield values represent treatment means expressed as a percentage of the Burn treatment for each year and cultivar combination. Regression equation for the fitted line is $Y = 32.74 + 0.03X - 3.82 \times 10^{-6} X^2$.

were the same in the Rake and Vacuum treatments and were equivalent to field burning (Table 2). To attain seed yields that were not different from the Burn treatment, Rake and Vacuum treatments had to remove at least 90% of the straw and reduce stubble height to <5 cm. Removal of straw by baling without further reduction in stubble height (Bale) did not always produce seed yields that were equivalent to burning. When no straw was removed (Flail 3X), Kentucky bluegrass seed yield was consistently reduced. Thompson and Clark (1989) reported that fertile tiller production and seed yield in Kentucky bluegrass was greater when straw was removed and stubble height was reduced to 2.5 cm than with only straw removal.

We conclude that a sizeable portion of seed yield potential in Kentucky bluegrass is set in fall before the onset of conditions favoring vernalization of the crop (low temperatures and short days in winter). We believe that this component of the yield potential is largely a function of the quality of crop regrowth in fall and that there is no physiological effect of field burning as had been widely thought in the lay community. Field burning simply removes stubble and straw that inhibit regrowth, improving the chances for successful induction of flowering. Factors such as heat and drought, pests, and nutrient deficiency can, individually and collectively, influence the realization of the seed yield potential during spring and summer months.

Several regrowth characteristics may be associated with flowering and seed yield. For example, large diameter tillers in fall were important early indicators of seed yield, particularly in younger stands. Large tillers alone did not account for the variation in seed yield, however. The height of tillers in fall was inversely related ($r^2 = -0.66, P < 0.01$) to the seed yield harvested the following season (Fig. 2). To produce seed yields equivalent to field burning, Kentucky bluegrass seed growers need to manage straw and stubble so that height of fall regrowth does not exceed 8 cm. Other morphological, and possibly biochemical, characteristics of quality regrowth in Kentucky bluegrass still need to be identified. Seed yield was equivalent to burning when fertile tiller number accounted for 27% (≈2700 fertile tillers m^{-2}) of the spring tiller population at anthesis (Fig. 3). Increased numbers of fertile tillers above this level did not result in corresponding increases in seed yield.

Seed germination was not reduced by nonthermal management in our study (Table 3). Seed purity was reduced in the Flail 3X treatment in 1995, as indicated by an increased content of inert matter. No increases in weed seed, other crop seed, or contamination by ergot

Table 3. Influence of residue management on seed quality in Abbey Kentucky bluegrass.

Year	Treatment	Purity: Pure seed	Purity: Inert matter	Germination
		%	%	%
1993	Flail 3X	92.4a†	7.7a	87a
	Bale	90.8a	9.2a	89a
	Rake	91.4a	8.6a	89a
	Vacuum	92.6a	7.4a	86a
	Burn	91.3a	8.7a	88a
1994	Flail 3X	85.5a	14.5a	81bc
	Bale	89.8a	10.1a	75a
	Rake	89.0a	11.0a	78ab
	Vacuum	91.9a	8.1a	83c
	Burn	92.4a	7.6a	80bc
1995	Flail 3X	83.9a	16.0c	83a
	Bale	88.2c	11.7a	86a
	Rake	85.5ab	14.5bc	85a
	Vacuum	87.5bc	12.5ab	88a
	Burn	86.9bc	13.0ab	85a

† Means in columns within years and cultivars are not different by Fisher's protected LSD values ($P = 0.05$) when followed by the same letter.

sclerotia (*Claviceps purpurea* L.) were detected in seed purity analyses (data not shown).

Growers should not use flail chopping without straw removal to manage post-harvest residues in Kentucky bluegrass. Low seed yields, higher seed cleaning costs, and the potential for low seed quality would reduce profitability for growers managing straw without removal. Our work clearly shows that under conditions in the Grande Ronde Valley, seed yield and seed quality can be maintained in Kentucky bluegrass without burning if growers use management techniques (Rake or Vacuum) that remove most of the straw and reduce stubble height. The potential for nonthermal production of Kentucky bluegrass seed has been demonstrated elsewhere with different cultivars and production conditions (Murray and Swensen, 1994; Coats et al., 1994). Thorough removal of straw and reduction in stubble height is necessary to ensure optimum crop regrowth in fall and consistent production of the highest seed yields. Our results provide the basis for the future development of residue management strategies that will both effectively manage costs and conserve resources.

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