

## Kentucky Bluegrass (*Poa pratensis* L.) Establishment as Affected by Light Quantity and Quality Beneath Spring Wheat and Wild Oat Canopies<sup>1</sup>

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### ABSTRACT

Kentucky bluegrass (*Poa pratensis* L.), which is typically spring planted, produces no seed during the establishment year. Burning after harvest sustains productivity for five or more years; however, burning is being banned in Washington and may be restricted in Idaho and Oregon. Without burning, reduced number of seed harvests, and increased wild oat problems are expected. Establishment with companion crops may improve profitability. Relationships between spring wheat (*Triticum aestivum* L.) and wild oat (*Avena fatua* L.) density, and light transmittance to bluegrass during establishment are unknown. Kentucky bluegrass establishment in monoculture or with either spring wheat or wild oat was related to light transmittance in two successive years. Light transmittance and bluegrass biomass declined exponentially as companion plant density increased. At 50 plants m<sup>-2</sup>, wheat at the heading stage reduced light available to bluegrass by 55 and 80% in 1994 and 1995 respectively, while wild oat at the same density and stage of growth reduced light available to bluegrass by 80 and 90%, respectively. The corresponding bluegrass biomass was reduced 68 and 91% by wheat and 65 and 89% by wild oat in 1994 and 1995, respectively, compared to biomass of the monoculture. Bluegrass seedlings growing with companion plants received lower red:far red (R/FR) light ratios and produced fewer tillers than seedlings with no companion plant. At the jointing stage, light passing through wheat canopies had higher R/FR ratios than light penetrating wild oat canopies. Bluegrass establishment with either spring wheat or wild oat caused a reduced first year seed yield compared to monoculture. Subsequent four-year seed yield measurements will be used to evaluate the profitability of companion cropping and cost effectiveness of wild oat control during establishment.

*Additional index words:* biomass, companion cropping, competition, plant density, seed production, tiller number.

### INTRODUCTION

Kentucky bluegrass is an environmentally desirable perennial crop, used to protect erodible slopes and maintain high water quality. Over 90% of the bluegrass seed supply in the US is produced in the Pacific northwest. In 1992, 50,000 ha of bluegrass seed was produced, with Idaho ranked first in US production (Census of Agriculture, 1992).

Bluegrass is typically spring planted, and does not produce seed in the year of establishment. Plants must complete juvenility requirements and then be vernalized to produce seed (Canode, Maun and Teare, 1972; Meijer, 1984). Following the first and subsequent seed harvests, residue is burned. Burning sustains seed yield for five or more years by increasing light penetration into plant crowns (Ensign, Hickey and Bernardo, 1983). This improves autumn regrowth and allows timely completion of autumn juvenility and vernalization requirements. In addition, fire thins the stands (Canode *et al.*, 1972), and reduces some annual weeds, insects, and diseases.

Burning will be phased out in Washington by 1998 and may be restricted in Idaho and Oregon. Without

burning, the consecutive number of economic seed crops may be reduced and annual grass weeds, including wild oat are expected to increase. More frequent establishment of bluegrass will therefore be required to maintain current levels of seed production.

Establishment of bluegrass with a companion crop may be a better option if competition for light, nutrients, and moisture (Bula, Smith and Miller, 1954) does not adversely affect plant and tiller populations, and subsequent seed yield. Annual weeds such as wild oats can reduce establishment and seed yield of Kentucky bluegrass by competing with the growing crop, and reduce profits by contaminating the harvested seed (Lemieux, Watson and Deschenes, 1987; Rolston and Hare, 1986; Aamlid, 1994). The magnitude of such competition will likely reduce Kentucky bluegrass seedling biomass, tiller production, and subsequent seed yield. Profit may also be reduced if frequent herbicide application is required. Grass weeds are a significant problem in Kentucky bluegrass stand establishment, because there are few herbicides available for grass weed control.

In monoculture, seed yield of Kentucky bluegrass is

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highest at low plant densities (Evans, 1980; Meijer, 1984; Aamlid, 1994). Increased light levels at low plant populations have been associated with observed increases in tillering and plant vigour (Ensign *et al.*, 1983). Also, more space is available for extension of axillary shoots and rhizomes (Canode *et al.*, 1972). Ensign *et al.* (1983) reported that a 67% reduction in incident light for 130 days (September-January) reduced tillering by 63%, increased leaf sheath length by 23%, and reduced seed yield of Kentucky bluegrass by 24% compared to unshaded plants grown on open-field burns. Kentucky bluegrass stopped tillering when more than 85% of the light was intercepted by a cover crop (Meijer, 1987).

Companion crop or weed density and plant distribution can affect the quantity and quality of light within a canopy (Kasperbauer, 1987). Low red (R) to far-red (FR) light ratios are characteristic in canopies due to selective absorption of red by leaf chlorophyll and transmission or reflection of FR (Kasperbauer, 1987). Shade decreased tillering in Italian ryegrass (*Lolium multiflorum* Lam.), smutgrass [*Sporobolus indicus* (L.) R.Br.], dallisgrass [*Paspalum dilatatum* (Poir.)] and red fescue (*Festuca rubra* L.) (Deregibus, Sanchez, and Casal, 1983; Casal, Deregibus and Sanchez, 1985; Skálová and Krahulec, 1992). Plants within a shaded canopy generally have reduced carbohydrate levels and shoot-to-root ratios (Buxton and Wedin, 1970).

The objectives of this research were to evaluate the influence of spring wheat and wild oat density on Kentucky bluegrass establishment, and to relate biomass and tiller number to light quantity and quality available in companion plant and monoculture stands.

## MATERIALS AND METHODS

Kentucky bluegrass cv. Glade was established with either spring wheat cv. Wakanz or wild oat on April 16, 1994 and April 24, 1995, near Moscow, Idaho. Glade is an aggressive, shade tolerant cultivar (Jacklin, Thorne, Engel, Dickson and Funk, 1977) with a recommended sowing rate of 4.5 kg ha<sup>-1</sup>. The experiment established in 1994 was on a Palouse-Latahco silt loam complex (50% Palouse fine-silty, mixed, mesic Pachic Ultic Haploxerolls, 35% Latahco fine-silty, mixed, frigid Argiaquic Xeric Argialbolls and 15% other soil types not mapped) with 0 to 3% slope. In 1995, the soil type was a Palouse silt loam, (fine-silty, mixed, mesic Pachic Ultic Haploxerolls) with 7 to 25% slopes. These soils had 2.7 to 3.2% organic matter, and a pH of 5.9 to 6.5.

### Plot design and establishment

Each year the experimental design was a randomised complete block split-plot, replicated four times with subplots 2.4 by 6.1 m. Main plots were 3.4, 6.7, and 10.1 kg ha<sup>-1</sup> sowing rates of Kentucky bluegrass at 17.5 cm row spacings. Subplots were population densities of either wheat or wild oat companion plants to achieve 20, 40, 80, 120, and 160 plants m<sup>-2</sup> and a Kentucky bluegrass

monoculture control. The average density of wild oat plants infesting cultivated fields in Idaho is 170 plants m<sup>-2</sup> (Morishita and Thill, 1988). No plots contained all three plant species. The same seed sources were used for both experiments. The wild oat seed used was harvested in 1991 from a field near Moscow, Idaho.

The recommended sowing rate for dryland spring wheat in Idaho is 100 to 115 kg ha<sup>-1</sup>, which is equivalent to 334 to 370 plants m<sup>-2</sup> with 100% emergence (mean 1000 seed weight for cv. Wakanz was 30.2 g).

A cone-type double disk plot drill with press wheels was used to plant the three species. The companion plants were sown first in an east-west direction, 3 cm deep in 17.5 cm spaced rows, and the soil was rolled using a brillion drill. Kentucky bluegrass was sown perpendicular to the companion plants, 1 to 1.5 cm deep. Each subplot consisted of two drill passes of five rows of companion plants (ten rows total per subplot) and 25 rows of bluegrass.

Wheat and wild oat plants were counted in one 0.5 m<sup>2</sup> quadrat in each plot, four to six weeks after sowing, to determine the actual densities achieved. Kentucky bluegrass stand density was estimated at the same time by laying a 75 cm long metal ladder with 2.5 cm spacing along one of the sown rows in each plot. The percentage of cells with bluegrass present was used to estimate mean percent cover across all treatments for each year.

Broadleaf weeds were controlled with 0.21 kg a.i. ha<sup>-1</sup> bromoxynil and 22 g a.i. ha<sup>-1</sup> thifensulfuron-tribenuron plus a 0.25% v/v non-ionic surfactant<sup>1</sup> (Chemical and Pharmaceutical Press, Inc. 1996). Herbicides were applied on May 11, 1994 and May 22, 1995 using a self-propelled sprayer.

Ammonium nitrate (34-0-0) and ammonium phosphate (16-20-0) fertilisers were applied to achieve a total of 38 kg N ha<sup>-1</sup>. These were incorporated into the seedbed before sowing.

### Sampling

Growing degree days (GDD) were calculated from the date of sowing using a base temperature of 0°C as follows:

$$\text{GDD } ^\circ\text{C} = \frac{(\text{Max. Temp.} + \text{Min. Temp.})}{2}$$

Biomass samples were collected from 0.5 m<sup>2</sup> quadrats on two dates corresponding to the wheat and wild oat jointing (Haun stage 6+, GDD = 674 to 691) and heading stage (Haun stage 10.2 wheat, 10.5 wild oat, GDD = 1003 to 1145) (Haun, 1973). Above ground biomass of Kentucky bluegrass was determined by weighing samples after oven drying for 48 to 72 hours at 60°C. Only biomass data corresponding to the plots with light measurements are presented (6.7 kg ha<sup>-1</sup> Kentucky bluegrass sowing rate).

In 1995, Kentucky bluegrass tiller number and rhizome biomass were measured throughout the growing season by removing a 11.5 cm diameter soil core of Kentucky bluegrass from each plot in the 6.7 kg ha<sup>-1</sup> sowing

<sup>1</sup> R-11 (Octyl phenoxy ethanol, isopropanol, and compounded silicone, 90%). Wilbur-Ellis Co., 320 California St, San Francisco CA 94104, USA.

rate. After soaking the cores in water for 12 hours, the tillers were counted and rhizomes removed and oven dried for 12 hours at 60°C. Data from cores collected closest to the biomass samples at jointing (GDD = 850) and heading (GDD = 1152) are presented.

Spectral distributions of light were measured using a LICOR LI 1800 spectro-radiometer equipped with a remote cosine corrected point sensor<sup>2</sup>. Light measurements were recorded at 2 nm intervals from 600 to 750 nm in the plant canopies, on clear days within one hour of solar noon. The probe was placed at soil level in the canopy throughout the growing season. Spectral irradiances at 645 nm and 735 nm  $\pm$  4 nm, were used to calculate the R/FR light ratios, which correspond to phytochrome action peaks in green plants (Kasperbauer, 1987). Light measurements were only made in the plots containing the 6.7 kg ha<sup>-1</sup> sowing rate of Kentucky bluegrass. Light quantity was also measured in these plots by using a LICOR line quantum sensor that was placed at ground level between two rows of companion plants in an east-west direction. Light data collected closest to the biomass samples at jointing (GDD = 796 to 849) and heading (GDD = 1152 to 1159) are presented.

Spring wheat was harvested from a 1.4 by 2.4 m area using a Hege plot combine on August 8, 1994 and August 22, 1995.

### Statistical procedures

Regression analysis was used to describe the relationship between light, biomass, and companion plant density. Regression diagnostic techniques were employed to determine the best model fit. The choice of the most suitable model was based on the magnitude of residual mean squares, predicted sum of squares, and the overall residual structure. The response of light quantity to increasing companion plant density was modelled at the companion plant jointing and heading stages. In 1995, light quantity data represent the average of three days, which encompass the GDD observed in 1994 at jointing. At heading in 1995, light quantity data represent the average of two days, which encompass the GDD observed for heading in 1994. A power function of the form:

$$y_i = \beta_0 x_i^{\beta_1} \quad (1)$$

was selected to relate light quantity to companion plant density in both years, where  $y_i$  is the recorded light quantity ( $\text{m mol m}^{-2} \text{ s}^{-1}$ ) and  $x_i$  is the wheat or wild oat density in plants  $\text{m}^{-2}$ . Equation 1 was linearised by taking the natural logarithm (base e) of both sides for the purpose of estimating parameters. The fitted model is given by:

$$\ln(y_i) = \beta_0 + \beta_1 \ln(x_i) + e_i \quad (2)$$

where  $\beta_0$  and  $\beta_1$  are the regression coefficients and  $e_i$  is the model residual.

To relate light quantity available to Kentucky bluegrass over the growing season, an inverse exponential model was chosen:

$$y_i = \beta_0 e^{\beta_1 (1/x_i)} \quad (3)$$

where  $y_i$  is the recorded light quantity ( $\text{m mol m}^{-2} \text{ s}^{-1}$ ) and  $x_i$  is the GDD from planting. The fitted form of this model is:

$$\ln(y_i) = \beta_0 + \beta_1 (1/x_i) + e_i \quad (4)$$

where  $\beta_0$  and  $\beta_1$  are the regression coefficients and  $e_i$  is the model residual.

An inverse model best described the effect of increasing companion plant densities on Kentucky bluegrass biomass. The fitted form of the model is:

$$y_i = \beta_0 + \beta_1 1/x_i + e_i \quad (5)$$

where  $y_i$  is the weight of Kentucky bluegrass biomass ( $\text{g m}^{-2}$ ),  $x_i$  is the companion plant density in plants  $\text{m}^{-2}$ ,  $\beta_0$  and  $\beta_1$  are the regression coefficients and  $e_i$  is the model residual. Comparison of the wild oat and wheat models in each year was performed using a dummy variable contrast procedure. All statistical computations were carried out using SAS/STAT ® (SAS Institute, 1989).

## RESULTS AND DISCUSSION

There were significant differences between 1994 and 1995 (Table 1) for rainfall and temperature. Therefore, measured variables were analysed separately for respective years.

### Companion Plant Density. Light Quantity

In both years as wheat and wild oat density increased, light penetration decreased, with the largest decrease between 0 and 50 plants  $\text{m}^{-2}$  (Fig. 1). At each companion plant density, photosynthetic photon flux density (PPFD) was related to growth stage (GDD) of the crop using an inverse exponential model (4). Comparisons within each species showed a much faster rate of decline of PPFD in 1995 compared to 1994 (Hamilton, 1995).

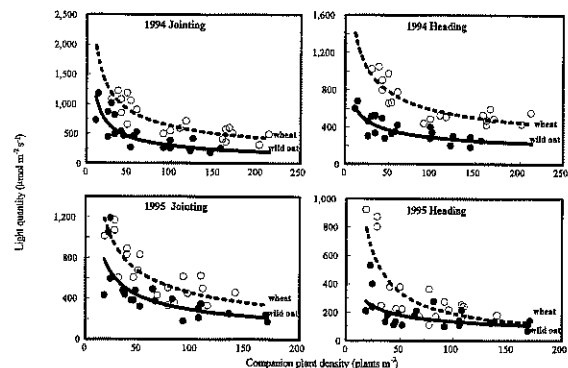


Fig 1. Predicted and observed light quantity beneath canopies of wheat and wild oat at jointing and heading in 1994 and 1995. Standard errors in parentheses beneath parameter estimates. Regression coefficients for  $\ln y(\text{Quantity}) = \beta_0 + \beta_1 \ln(x_i) + e_i$  are listed in Table 2.

**Table 1** Total monthly rainfall and mean maximum and minimum temperature for the 1994 and 1995 growing seasons at the University of Idaho Plant Science Farm, Moscow, ID, USA.

Month	Rainfall			Temperature						
	1994	1995	30 year mean	1994		1995		30 year mean		
	mm			Max	Min	Max	Min	Max	Min	
				°C						
March	31	99	61	12	1	10	0	9	-1	
April	66	57	55	17	4	13	1	14	2	
May	56	35	57	21	6	20	5	19	5	
June	43	90	45	24	6	22	8	23	7	
July	3	29	24	32	9	28	9	28	9	
August	3	44	29	31	8	27	7	29	9	
Total	202	354	271	Mean	23	6	20	5	20	5

**Table 2.** Estimated regression<sup>1</sup> coefficients and tests for coincidence of regression lines for the influence of plant density on light quantity and biomass of Kentucky bluegrass established with wild oat and spring wheat.

	Intercept	Density	r <sup>2</sup>	Pr>F <sub>slopes</sub>	Pr>F <sub>lines</sub>
<b>1994 Jointing</b>					
<b>Light Quantity</b>					
Wild oat	8.453(0.363) <sup>2</sup>	-0.596(0.089)	0.71		
Wheat	8.860(0.338)	-0.523(0.074)	0.73		
				0.550	0.0001
<b>1995 Jointing</b>					
<b>Light Quantity</b>					
Wild oat	8.346(0.461)	-0.581(0.112)	0.60		
Wheat	8.720(0.399)	-0.564(0.098)	0.65		
				0.911	0.0002
<b>1994 Heading</b>					
<b>Light Quantity</b>					
Wild oat	7.254(0.263)	-0.344(0.065)	0.61		
Wheat	8.216(0.252)	-0.398(0.055)	0.74		
				0.540	0.0001
<b>1995 Heading</b>					
<b>Light Quantity</b>					
Wild oat	6.858(0.546)	-0.426(0.132)	0.62		
Wheat	9.132(0.640)	-0.843(0.157)	0.36		
				0.049	0.0001
<b>1994 Jointing</b>					
<b>Biomass</b>					
Wild oat	1.695(0.577)	96.502(17.884)	0.62		
Wheat	2.229(0.838)	100.935(52.776)	0.17		
				0.933	0.6267
<b>1995 Jointing</b>					
<b>Biomass</b>					
Wild oat	0.151(0.193)	23.617(7.582)	0.35		
Wheat	0.409(0.447)	13.402(15.097)	0.04		
				0.589	0.8574
<b>1994 Heading</b>					
<b>Biomass</b>					
Wild oat	2.577(1.593)	259.187(49.364)	0.61		
Wheat	1.734(1.470)	275.760(92.567)	0.33		
				0.888	0.9022
<b>1995 Heading</b>					
<b>Biomass</b>					
Wild oat	-0.290(0.970)	123.232(38.032)	0.77		
Wheat	1.005(0.287)	42.040(9.696)	0.51		
				0.029	0.0653

<sup>1</sup>  $\ln y(\text{Quantity}) = \beta_0 + \beta_1 \ln(X_i) + e_i$  and  $y(\text{Biomass}) = \beta_0 + \beta_1 1/x_i + e_i$

<sup>2</sup> Standard errors in parentheses.

In 1994, at 50 plants  $m^{-2}$ , wheat in the jointing stage reduced PPFD available to Kentucky bluegrass seedlings by 50%, while wild oats at the same density and growth stage reduced PPFD by 75%. At the same density at heading, wheat and wild oats reduced PPFD by 55 and 80%, respectively.

In 1995, at 50 plants  $m^{-2}$  incident PPFD at jointing was reduced 60% by wheat and 75% by wild oat (Fig. 1). At the same density at heading, incident PPFD was reduced by 80% by wheat and 90% by wild oat plants.

Wheat permitted more light to penetrate the canopy at each growth stage than wild oat (Table 2 and Fig. 1). A comparison of model means averaged across density, showed 43 and 49% more light penetrated the wheat canopies at jointing in 1994 and 1995, respectively, compared to wild oat canopies. At heading, Kentucky bluegrass beneath wheat canopies had 70% more light in 1994 and 95% more light in 1995 than when beneath wild oat canopies. This is consistent with the more erect form and shorter stature of wheat plants compared to the more variable stance and taller growth form of wild oat seen at heading. Cudney, Jordan and Hall (1991) reported that taller wild oat plants reduced light penetration and growth of wheat when grown in mixture, by producing a greater proportion of leaf area near the top of the canopy.

Differences in light penetration between years may be due to the amount and distribution of rainfall, and cooler temperatures in 1995 compared to 1994 (Table 1). Rainfall in 1995 was 1.75 times greater than in 1994, and was above normal in April and near normal in May and June. However, July and August in 1994 were very dry, resulting in a low average seed yield (2746  $kg\ ha^{-1}$ ) and visually reduced upper canopy development compared to 1995. In 1995, rainfall was three times above normal in March resulting in excellent soil moisture. In June 1995, rainfall was twice normal, and July rainfall near normal, resulting in a seed yield of 4568  $kg\ ha^{-1}$ , twice that measured in 1994. The combination of higher harvest index in 1995 (58% vs 38% in 1994), and increased upper canopy development in 1995 likely decreased light penetration to bluegrass seedlings more in 1995 than in 1994.

### Companion Plant Density. Kentucky bluegrass biomass.

Modelling Kentucky bluegrass biomass as a function of companion plant density was less accurate than modelling light penetration as a function of companion plant density due to the variability of biomass data (Fig. 2). Uneven and slow establishment of bluegrass due to low initial soil moisture, very dry conditions in July and August (Table 1), and small variations in seedbed condition was common in commercial fields and occurred in these studies. Biomass data were highly variable at jointing stage in both years, and in 1995 low biomass, due to less light penetration and slower establishment of Kentucky bluegrass compared to 1994, skewed the data and there was therefore a poor fit for the regression model.

The inverse model (5) was the best fit for the Kentucky bluegrass biomass data with increasing companion plant density (Fig. 2). As wheat and wild oat

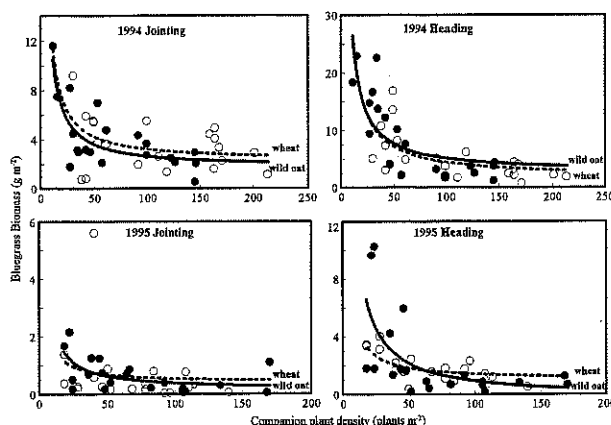


Fig. 2 Predicted and observed Kentucky bluegrass biomass with increasing wheat and wild oat density at jointing and heading in 1994 and 1995. Standard errors in parentheses beneath parameter estimates. Regression coefficients for  $y(\text{Biomass}) = \beta_0 + \beta_1 1/x_1 + e$ , are listed in Table 2.

density increased, Kentucky bluegrass biomass decreased. In 1994, at jointing, a comparison of density parameter estimates showed wild oat significantly decreased bluegrass biomass ( $P=0.006$ ), compared to wheat (Hamilton, 1995). At heading, bluegrass biomass was the same at all wheat and wild oat densities.

In 1995, variability and small biomass weights resulted in non-randomly distributed residuals. Modelling was not successful. In both years, all parameter estimates for wheat and wild oat density at heading were significantly different from zero ( $P=0.01$ ). Wheat and wild oat densities of 50 plants  $m^{-2}$  reduced Kentucky bluegrass biomass by 68 and 65%, respectively, in 1994, and by 91 and 89%, respectively, in 1995, compared to the Kentucky bluegrass monoculture (Fig. 2).

Ground cover of Kentucky bluegrass estimated before jointing was 55% in 1995 and 88% in 1994. The poorer establishment of Kentucky bluegrass in 1995 resulted in a dramatic shift of the biomass response curve with respect to companion plant density. Less biomass in 1995 was consistent with the lower levels of light measured in the wheat and wild oat canopies in 1995. Comparisons of the regression lines and rate of Kentucky bluegrass biomass reduction between wheat and wild oat were made using a contrast procedure (Table 2). The lines did not differ between species in 1994 and were only marginally different ( $P = 0.06$ ) at heading in 1995.

There was a significant positive linear association between available light quantity and Kentucky bluegrass biomass at heading for wheat ( $r = 0.60$ ,  $P = 0.005$ ) ( $r = 0.78$ ,  $P = 0.0001$ ) and wild oat ( $r = 0.84$ ,  $P = 0.0001$ ) ( $r = 0.43$ ,  $P = 0.056$ ) in 1994 and 1995, respectively. At jointing, only in the wild oat canopy in 1994 was there a significant correlation ( $r = 0.54$ ,  $P = 0.01$ ) between light quantity and Kentucky bluegrass biomass. The existence of significant correlations may allow inferences to be made about the influence of light quality on Kentucky bluegrass biomass. However, hypotheses relating to these effects remain untested because of high variability in the data.

**Table 3. Mean R/FR light ratio available to Kentucky bluegrass seedlings in 1994 under wheat and wild oat canopies**

Companion plant	Density (plants m <sup>-2</sup> )	R/FR ratio	
		Jointing % of control	Heading
None (control)	0	100	100
Wild oat	23	17	36
	32	23	54
	52	16	30
	103	15	67
	139	12	56
Wheat	36	87	75
	53	64	50
	101	15	42
	139	20	45
	174	21	36
Standard errors		3.7	3.9

**Table 4. Mean R/FR light ratio and Kentucky bluegrass mean tiller number in 1995**

Companion plant	Density (plants m <sup>-2</sup> )	R/FR ratio		Tiller no.	
		Jointing	Heading	Jointing % of control	Heading
None (control)	0	100	100	100	100
Wild oat	32	28	17	35	25
	35	21	17	8	11
	60	26	16	29	8
	114	17	15	22	4
	139	14	17	18	10
Wheat	33	38	19	43	15
	39	26	23	35	25
	69	23	19	27	9
	94	22	22	26	10
	120	23	19	24	5
Standard errors		1.2	0.6	2.1	1.3

**Companion Plant Density. Light Quality.**

The ratio of R/FR light available to Kentucky bluegrass seedlings was reduced by companion plant canopies. Ratios decreased with increasing companion plant density in both years (Tables 3 and 4). Pre-planned pairwise and group comparisons of means indicated differences in R/FR light ratios between wheat and wild oat canopies at jointing in 1994 and 1995 ( $P < 0.001$ ) (Hamilton, 1995). Light penetrating wheat had higher R/FR light ratios than light penetrating wild oat when averaged

across densities. Analysis of variance contrasts made within species between the low and middle density of the companion plant showed differences only in wheat canopies ( $P = 0.0001$ ). At heading in 1995, light penetrating wheat had significantly higher R/FR light ratios compared to light penetrating wild oat across the densities ( $P = 0.001$ ). In 1994, there was no significant density treatment effect at heading, and thus no contrasts were performed. Some of the variability observed at heading was due to increased difficulty in avoiding sun flecks. This problem was more

evident in taller plants (heading stage) than shorter plants (jointing stage).

Kentucky bluegrass tiller number decreased when grown with a companion plant (Table 4). At jointing, wheat at 33 plants  $m^{-2}$  reduced tiller number by 57% compared to the Kentucky bluegrass monoculture which had 4745 tillers  $m^{-2}$ . Wild oat at 32 plants  $m^{-2}$  reduced tiller number by 65% compared to the monoculture. At the same densities at heading, bluegrass tillers were reduced 85 and 75% for wheat and wild oat, respectively. Analysis of variance confirmed that bluegrass tiller number was influenced by a species by density interaction at both jointing and heading ( $P=0.0001$ ) (Hamilton, 1995). Therefore the environment under the companion crop cover had variable effects on bluegrass growth.

More Kentucky bluegrass tillers were produced in wheat canopies compared to wild oat, although differences in biomass production between species were marginal or non existent. This may imply that Kentucky bluegrass leaf weight increased when grown with a companion plant. Cordukes and Fisher (1974) reported that shading of Kentucky bluegrass leaf sheaths influenced stem length, and that shaded stems were much longer than unshaded ones. Leaves and stems of annual ryegrass, smutgrass and dallisgrass grew longer at lower R/FR ratios (Casal, Sanchez and Deregibus, 1987). Similar results were found in this study, as changes in light quality because of the presence of companion wheat or wild oat plants, appeared to regulate the development of Kentucky bluegrass tillers.

No correlation existed between the responses of tiller number and R/FR light ratio. This is in contrast to reported results with other grasses (Deregibus *et al.*, 1983; Skálová and Krahulec, 1992; Frank and Hoffman, 1994). The absence of a correlation between Kentucky bluegrass tiller number and R/FR light ratios within the canopy may have been a consequence of the destructive sampling method needed to count tiller numbers. Small sample numbers and high variability exacerbated the problem. Non-destructive tiller counts of Kentucky bluegrass were not possible, due to the small plant size and location of the tillers. A repeated measures sampling scheme may have reduced variability with the Kentucky bluegrass seedling tiller counts, but damage to the companion crop canopy would have ensued.

Kentucky bluegrass rhizome biomass was reduced by wheat and wild oats compared to the Kentucky bluegrass monoculture (Hamilton, 1995). As companion plant density increased from 32 to 139 plants  $m^{-2}$ , no further rhizome biomass reduction occurred. Many samples had no rhizomes. Establishment of a healthy root and rhizome system is essential for survival of Kentucky bluegrass through the winter. Buxton and Wedin (1970) noted that shading, resulting from interspecies competition during perennial forage grass establishment, had a greater effect on root than shoot development, and that the effect persisted through subsequent years. The reduction in rhizome biomass under wheat and wild oat canopies compared to monoculture suggests that light quality and quantity may regulate partitioning of photosynthate between shoots and rhizomes in Kentucky bluegrass. Under low R/FR light ratios, shoot growth appears to be favoured over rhizome

and root development in seedling Kentucky bluegrass.

Companion plants reduced rhizome development. However, the most active growth of Kentucky bluegrass occurs in the autumn and spring when temperatures are cooler and days shorter. After the companion plant has been removed, the Kentucky bluegrass would have potential to rejuvenate its biomass providing that moisture is not limiting. Thus, under dryland farming practices, timing of autumn rains would influence survival and vigour of the stand. In years where the companion plant has been particularly vigorous and rainfall low, detrimental effects to the Kentucky bluegrass may persist much longer than in stands established without a companion crop.

## SUMMARY

Spring wheat and wild oat had a dramatic effect on the quantity and quality of light available to establishing Kentucky bluegrass. At 50 plants  $m^{-2}$ , wheat at the heading stage reduced light available to bluegrass by 55% in 1994 and 80% in 1995, while 50 wild oat plants  $m^{-2}$  at heading reduced available light by 80% in 1994 and 90% in 1995. At jointing, R/FR light ratios were reduced on average 59 and 74% by wheat and 83 and 74% by wild oat in 1994 and 1995, respectively. At jointing, Kentucky bluegrass biomass was reduced 91% by wheat and 89% by wild oat at 50 plants  $m^{-2}$  in 1995, and tiller number and rhizome biomass were reduced on average 69 and 86% by wheat and 78 and 85% by wild oat. If wild oat is not controlled by heading, another 50% reduction in tiller number may occur. Failure of bluegrass to develop sufficient tiller numbers of a certain size required before vernalisation can proceed will delay or prevent autumn floral induction, and will result in poor seed yields (Canode *et al.*, 1972; Meijer, 1984). Since the average density of wild oat in cereal stands in this area is 170 plants  $m^{-2}$  (Morishita and Thill, 1988), uncontrolled wild oat would be expected to have a major impact on seed yield. Wild oat must be controlled to prevent the replenishment of seed to the soil seed bank. Once grass weeds become established within a grass crop, selective removal becomes increasingly more time consuming and inefficient, and is aggravated by lack of suitable selective herbicides. Thinner bluegrass stands produced under wheat canopies may extend the consecutive number of seed harvests when using mechanical methods for residue removal. Subsequent studies that will measure bluegrass seed yield over a four-year period with mechanical post-harvest residue removed are continuing.

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