

## Competitive Effects of Spring Wheat and Wild Oat on Kentucky Bluegrass (*Poa pratensis* L.) Seed Yield<sup>1</sup>

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### ABSTRACT

Restrictions to traditional post-harvest residue burning of Kentucky bluegrass (*Poa pratensis* L.), may reduce profitability and productive stand life, and increase weeds such as wild oat (*Avena fatua* L.). Wild oat is an aggressive competitor of Kentucky bluegrass for which few effective control methods exist. Using a spring wheat (*Triticum aestivum* L.) companion crop with Kentucky bluegrass may generate income during the establishment year and improve weed control, but may reduce long term profitability. The influence of spring wheat and wild oat densities on seed yield of Kentucky bluegrass and the economics of growing a spring wheat companion crop with Kentucky bluegrass were investigated in studies established in 1993 and 1995. Kentucky bluegrass first year seed yield decreased with increasing wheat and wild oat densities. Bluegrass seed yield was reduced between 83-91% when fifty plants m<sup>-2</sup> of either wheat or wild oat were established in 17.5 cm-wide rows, compared to weed free bluegrass seed yield. Mean bluegrass first year seed yield was 79 and 249 kg ha<sup>-1</sup> when infested with wheat or wild oat in 1993 and 1995, respectively. Kentucky bluegrass seed yield was similar for sowing rates from 3.4 to 10.1 kg ha<sup>-1</sup>. When Kentucky bluegrass was sown with spring wheat cv. Wakanz, net return was less than Kentucky bluegrass established alone over a three-year-period (-\$217 to-\$798 ha<sup>-1</sup>). Profit margins of bluegrass from wild oat control with imazamethabenz were \$99 to \$148 ha<sup>-1</sup> and \$170 to \$277 ha<sup>-1</sup> more than bluegrass with untreated wild oat in 1993 and 1995 respectively.

*Additional index words:* companion cropping, economics, plant density, row spacing.

### INTRODUCTION

The establishment of Kentucky bluegrass seed crops with a cereal companion crop is not commonly practiced under dryland farming conditions in Idaho, USA. Poor soil moisture, the efficiency and selectivity of herbicides, and the hazardous nature of seedling establishment itself, make some growers wary of using companion crops. Future limitations to traditional open-field burning, however, will reduce the productive stand life of Kentucky bluegrass (Hickey and Ensign, 1983; Young, Youngberg and Chilcote, 1984) and require more frequent stand re-establishment, making Kentucky bluegrass seed production less profitable. Successful establishment of Kentucky bluegrass with a companion crop may generate an income for the grower during the establishment year and help offset establishment costs, because no Kentucky bluegrass seed is produced during that year. However, the long-term impact of a spring wheat companion crop on Kentucky bluegrass seed yield in northern Idaho is unknown.

Cereal companion crops have been used extensively in establishing perennial forage crops such as cocksfoot (*Dactylis glomerata* L.), timothy (*Phleum pratense* L.), and lucerne (*Medicago sativa* L.) to increase forage yield and decrease weeds (Kilcher and Heinrichs, 1960; Lemieux, Watson and Deschenes, 1987; Lanini, Orloff, Vargas, Orr, Marble and Grattan, 1991). However, unpredictable yields of perennial grass seed crops established with a companion crop have hindered grower acceptance. In Canada, wheat as a companion crop sown at a 30.5 cm row spacing, reduced first and second year seed yield of Russian wild ryegrass (*Elymus junceus* Fisch.) (Lawrence, 1967) by 99 and 76% respectively, but had no influence on

seed yield of crested wheatgrass (*Agropyron desertorum* (Fisch.) Schult) grown at the same row spacing (Lawrence, 1970). Chastain and Grabe (1988a) reported that during the establishment year in Oregon, red fescue (*Festuca rubra* L.) growth was affected adversely when planted with either winter wheat or barley (*Hordeum vulgare* L.) companion crops. However, first-year red fescue seed yield was not affected by companion crops (Chastain and Grabe, 1988b) and establishment with wheat cv. Yamhill increased net income by \$508 ha<sup>-1</sup> over a three-year period. Tall fescue (*Festuca arundinacea* Schreb.) seed yield was 15% greater in the second seed year when established with cereals (spring wheat, barley, and oats) compared to the monoculture (Chastain and Grabe, 1989). The success of companion cropping with grass seed crops also may be determined by choice of companion crop and by shade tolerance and competitive ability of the grass crop.

The major risk to using companion crops is failure of Kentucky bluegrass establishment. However, several strategies may be employed to reduce the risk and lessen interspecies plant competition. Wider row spacing and reduced sowing rates of the companion crop have improved yield and increased the success rate of companion cropping (Nordestgaard, 1984; Meijer, 1987; Chastain and Grabe, 1988a, 1988b; de Ruiter and Hare, 1993).

Weeds reduce yield and profit of grass seed crops by competing with the growing crop and contaminating the resultant seed lot (Rolston and Hare, 1986; Lemieux *et al.*, 1987; Aamlid, 1994). Economic losses result from low seed yield, poor seed quality, and increased herbicide use. Weed competition reduces the reproductive tiller density, and as weed cover increases, seed

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yield declines. In studies with cocksfoot, brown top (*Agrostis capillaris* L. (Syn = *A. tenuis* Sibth.)) and Harding grass (*Phalaris aquatica* L. (Syn = *P. tuberosa* L.)), Rolston and Hare (1986) calculated a grass seed loss of 7 kg for every 1% increase in weed cover. Weed contamination, among other factors, contributes to many first-year grass seed crops failing to meet certification requirements (Lee, 1965; Rolston, Brown, Hare and Young, 1985).

Wild oat is a pernicious annual weed infesting more than one million hectares of arable land in Idaho. Seed longevity in soil makes wild oat difficult to eliminate. A heavy wild oat population during establishment reduces Kentucky bluegrass seed yield, lowers seed quality, and replenishes the wild oat seed supply in the soil, making weed control more difficult in subsequent years (Canode and Robocker, 1966). No effective chemical control of wild oat in bluegrass has been available until recently. In 1997, a 1:1 ratio of Imazamethabenz and difenzoquat was registered for wild oat control in bluegrass during the establishment year.

Weed competitiveness is influenced by the environment, sowing rate, species, and row spacing of the neighbouring crop. Growing more aggressive bluegrass cultivars with vigorous rhizome systems and using higher sowing rates may diminish the competitive effects of weeds. Aamlid (1994) reported reduced weed contamination with increased sowing rates of Kentucky bluegrass; however, increasing the sowing rate from 5 to 10 kg ha<sup>-1</sup> reduced seed yields. This substantiates earlier findings that have shown Kentucky bluegrass seed yield to be favoured by low plant density in monoculture (Evans, 1980; Meijer, 1984).

The objectives of this research were to assess the impact of spring wheat and wild oat on Kentucky bluegrass seed yield and determine the potential for establishing Kentucky bluegrass with a spring wheat companion crop under dryland farming in northern Idaho and adjacent eastern Washington.

## MATERIALS AND METHODS

Kentucky bluegrass cv. Glade was established with spring wheat cv. Wakanz or wild oat on May 15, 1993, and April 24, 1995, near Moscow, Idaho. Field sites were level or gently sloping with 2.7 to 3.2% organic matter, and pH 5.9 to 6.5. In 1993, the soil type was 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.

Fertiliser was incorporated into the seedbed before sowing according to soil fertility tests. Ammonium nitrate (34-0-0) and ammonium phosphate (16-20-0) were applied in the establishment year to achieve a total of 38 kg N ha<sup>-1</sup>. In the autumn, 168 kg N ha<sup>-1</sup> was surface applied during the establishment year, and for the subsequent year.

Each year the experimental design was a split-plot replicated in four randomised complete blocks with subplot size 2.4 x 6.1 m. Main plots consisted of 3.4, 6.7 and 10.1 kg ha<sup>-1</sup> sowing rates of Kentucky bluegrass in 17.5 cm-spaced rows. The same seed

sources were used for both experiments. The wild oat seed used was harvested in 1991 from a field near Moscow, Idaho. 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. Sowing rate for dryland spring wheat in Idaho is 100 or 115 kg ha<sup>-1</sup>, which is equivalent to 331 to 381 plants m<sup>-2</sup> with 100% emergence (average seed weight for cv. Wakanz was 3.02 g per 100 seeds). No plots contained all three plant species. A cone-type double disk plot drill with press wheels was used to plant the three plant species. The companion plants were sown first in an east-west direction, 3 cm deep in 17.5 cm spaced rows. 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). In 1993, the surface was rolled using a brillion drill after all planting was completed.

In 1995, the ground was rolled between sowings of the companion plant and Kentucky bluegrass.

Wheat and wild oat plants were counted in 0.5 m<sup>2</sup> randomly placed quadrats in each plot, four to six weeks after sowing to determine actual densities achieved, which are reported. Kentucky bluegrass stand was estimated 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 percent cover averaged across all treatments.

Broadleaf weeds were controlled in the establishment year (1993 and 1995) with an application of bromoxynil at 0.21 kg a.i. ha<sup>-1</sup> + thifensulfuron-tribenuron at 22 g a.i. ha<sup>-1</sup> plus a 0.25% v/v non-ionic surfactant<sup>7</sup>. Herbicides were applied on June 8, 1993, and May 22, 1995 with a self propelled sprayer. Weeds were controlled in established second and third year Kentucky bluegrass plots (1993 establishment year) with 0.21 kg a.i. ha<sup>-1</sup> of bromoxynil, 45 g a.i. ha<sup>-1</sup> thifensulfuron-tribenuron, and 0.46 kg a.i. ha<sup>-1</sup> of imazamethabenz methyl ester plus a 0.25% v/v non-ionic surfactant. Herbicides were all applied on April 22, 1994, April 21 and May 22, 1995 to established Kentucky bluegrass and weeds. In 1996, weeds in both experiments were controlled with primisulfuron and dicamba. Primisulfuron was applied at 53 g a.i. ha<sup>-1</sup> plus a crop oil concentrate at 1.0% v/v on April 3 and on May 9. Dicamba was applied at 0.56 kg a.i. ha<sup>-1</sup> on April 25.

Kentucky bluegrass plants were harvested by hand from a 36 by 71 cm area in 1994 and from an 18 by 43 cm area in 1995 and 1996, and threshed using an Almaco<sup>8</sup> plot thresher. Samples were sieved by hand using 4 mm and 8 mm sieves to remove loose straw and fed through a laboratory pulverising mill<sup>9</sup> to remove the lint. After sieving through a 1.7 mm round sieve, seed was cleaned using an Oregon seed blower<sup>10</sup>. Seed quality was estimated using germination test results and weight of 100 seeds. Germination was tested using a modification of the Association of Official Seed Analysts' method (AOSA, 1993). One hundred seeds were placed on two 8.5 cm round blotter papers soaked in 2% KNO<sub>3</sub> solution, in labelled petri dishes. After pre-chilling in the dark for five days at 10°C, seeds were transferred to a germinator set at 12 hour light at 25°C and 12 hour dark at 15°C. Germination was counted at 7, 14 and 28 days.

Spring wheat was harvested from a 1.4 by 2.4 m area using a plot combine on September 16, 1993, and August 22, 1995.

<sup>7</sup> R-11 (Alkyl aryl polyethoxylate, and compounded silicone, 90%). Wilbur-Ellis Co., 320 California St., San Francisco, CA 94104, USA.

<sup>8</sup> Allan Machine Company, Ames, IA, USA.

<sup>9</sup> Weber Bros., and White Metal Works Inc., Hamilton, USA.

<sup>10</sup> Hoffman Manufacturing, OR, USA

<sup>11</sup> Rears Manufacturing Company, Eugene OR, USA.

Wheat and wild oat stubble and the Kentucky bluegrass was chopped to a uniform 2.5 cm height and removed each year, using a crew cutter vacuum machine<sup>11</sup> on September 22, 1993, and August 10, 1994 and September 5, 1995.

#### Statistical procedures and economics.

Regression analysis was used to describe the relationship between Kentucky bluegrass seed yield and companion plant density in the first seed year. An exponential model of the form:

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

was chosen, where  $y_i$  is the Kentucky bluegrass seed yield (kg ha<sup>-1</sup>) and  $x_i$  is the wheat or wild oat density in plants m<sup>-2</sup>. 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:

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

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

Linear and nonlinear models (Shafii, Harper and McGeehan, 1990) were examined to describe the relationship between wheat yield and wheat density for 1993 and 1995, across the three rates of Kentucky bluegrass. Examination of residual mean square, predicted sums of squares, and lack of fit analysis determined the model choice. A quadratic plateau model of the form;

$$y = \beta_0 + \beta_1 x + \beta_2 x^2 \text{ if } x \leq x_0 \quad (3)$$

$$y = M \text{ if } x > x_0$$

was chosen for 1993 data, where  $y$  = wheat yield in kg ha<sup>-1</sup>,  $x$  = wheat density (plants m<sup>-2</sup>),  $x_0$  = wheat density at theoretical maximum, and  $M$  = asymptote (theoretical plateau for  $y$ ). Parameters of Equation 3 were estimated using non-linear estimation techniques. A linear model was chosen to describe the relationship between wheat yield and wheat density for 1995. Statistical computations were carried out using SAS/STAT<sup>®</sup> (SAS Institute, 1989).

A partial budget technique was employed to estimate the effect of spring wheat companion cropping on the costs and returns of Kentucky bluegrass seed production in northern Idaho based on the results of the 1993 planted experiment (Castle, Becker and Smith, 1972). By using wheat yields and Kentucky bluegrass seed yields obtained in this experiment, profits were calculated on the basis of the crop prices at time of harvest. The effect of wild oat competition on Kentucky bluegrass seed

production profitability was estimated by determining the loss in yield revenue compared to the cost of wild oat control using imazamethabenz at each density (Hamilton, 1995).

## RESULTS AND DISCUSSION

Environmental conditions varied greatly during the course of this study (Table 1). Dry, warm conditions prevailed over the growing season in 1994 compared to the wetter than average years of 1993, 1995 and 1996. In 1993, Kentucky bluegrass was slow to establish at all sowing rates (> 21 days to emerge) and did not produce a uniform population. Average percent ground cover of Kentucky bluegrass estimated eight to nine weeks after sowing was slightly lower in 1993 (42%) than in 1995 (55%). Rolling after sowing Kentucky bluegrass in 1993, for the purpose of improving seed to soil contact, buried the seed deeper than anticipated, and emergence was delayed. In 1995, bluegrass emerged quickly (14 days).

#### Kentucky bluegrass first year seed yield.

First year seed yield of Kentucky bluegrass from the 1993 and 1995 plantings declined with increased companion plant density (Table 2), but the association of increased companion plant density and seed yield of Kentucky bluegrass was weak and highly variable (Fig. 1). Analysis of variance indicated no bluegrass sowing rate by companion plant density interaction for 1993 and 1995 established Kentucky bluegrass. The three rates of Kentucky bluegrass were combined in each year and fitted to the exponential model (1) as there was no rate effect for 1995 established Kentucky bluegrass and only a weak rate effect in 1993 established Kentucky bluegrass. Studentised residuals plotted against companion plant density showed a random and uniform distribution around the expected value of zero in both years. All model coefficients for the first year of seed harvest (1994 and 1996) were significantly different from zero ( $P < 0.002$ ) (Table 3).

The presence of a companion plant significantly reduced first year seed yield of Kentucky bluegrass established in 1993 and 1995, compared to the monoculture (Table 2). Using estimated parameters of equation 2, 50 wild oat plants m<sup>-2</sup> reduced first year seed yields by 84 and 86% in 1994 and 1996, respectively, whereas 50 wheat plants m<sup>-2</sup> reduced first year seed yields by 91 and 83% in 1994 and 1996, respectively. Severe seed yield reductions were anticipated after observing light transmittance and Kentucky bluegrass biomass decline exponentially with increasing companion plant density (Hamilton, Murray, Thill and Shafi, 1997).

Table 1. Total monthly rainfall and mean maximum temperature for 1993, 1994, 1995 and 1996 growing seasons at the University of Idaho Plant Science Farm, Moscow, ID.

Month	Rainfall mm					Temperature °C				
	1993	1994	1995	1996	30 year mean	1993	1994	1995	1996	30 year mean max
March	76	31	99	46	61	10	12	10	10	9
April	131	66	57	145	55	13	17	13	14	14
May	62	56	35	101	57	22	21	20	16	19
June	47	43	90	18	45	22	24	22	24	23
July	68	3	29	10	24	23	32	28	30	28
August	1	3	44	2	29	26	31	27	30	29
Total	385	202	354	322	271 Mean	19	23	20	21	20

Table 2. Kentucky bluegrass seed yield averaged over sowing rate, grown with companion plants at 17.5 cm-row spacing. Kentucky bluegrass was sown in spring 1993 and 1995.

Companion plant	Mean density in 1993 (plants m <sup>-2</sup> )	kg ha <sup>-1</sup>			Mean density in 1995 (plants m <sup>-2</sup> )	1st year (1996) kg ha <sup>-1</sup>
		1st year (1994)	2nd year (1995)	3rd year (1996)		
None (control)	0	638 a <sup>1</sup>	327 ab	466 b	0	1554 a
Wild oat	33	245 b	425 a	639 ab	32	468 b
Wild oat	58	115 c	249 bcd	622 ab	36	400 bc
Wild oat	95	68 e	274 bcd	778 a61	276 cd	
Wild oat	142	38 f	176 d	635 ab	115	92 e
Wild oat	147	15 c	207 bcd	589 ab	139	84 e
Wheat	40	164 c	435 a	663 ab	33	361 bc
Wheat	59	92 cde	335 ab	479 b39	344 bc	
Wheat	104	35 ef	272 bcd	563 ab	69	174 de
Wheat	161	13 f	266 bcd	665 ab	95	136 e
Wheat	184	5 f	196 cd	680 ab	120	157 de
LSD (P<0.05)		72	133	296		135

<sup>1</sup> Means within a column followed by the same letter are not statistically different (P<0.05).

Table 3. Estimated coefficients for regression models used to predict Kentucky bluegrass first year seed yield with companion plant density at Moscow, ID.

Variable	Parameter estimate	Standard error	t Value	Prob> t
<b>Sown 1993</b>				
Intercept ( $\beta_0$ )	5.7630	0.4001	14.41	0.0001
Wild oat density ( $\beta_1$ )	-0.0231	0.0037	-6.19	0.0001
Intercept ( $\beta_0$ )	5.0117	0.3565	14.06	0.0001
Wheat density ( $\beta_1$ )	-0.0193	0.0028	-6.92	0.0001
<b>Sown 1995</b>				
Intercept ( $\beta_0$ )	6.3387	0.1483	41.76	0.0001
Wild oat density ( $\beta_1$ )	-0.0150	0.0017	-9.07	0.0001
Intercept ( $\beta_0$ )	6.0186	0.2023	29.42	0.0001
Wheat density ( $\beta_1$ )	-0.0129	0.0025	-5.13	0.0001

#### Kentucky bluegrass second year seed yield.

The Kentucky bluegrass monoculture second year seed yield declined 49% from the first year seed yield (Table 2). Averaged across all densities of spring wheat and wild oat, second year seed yield was 3.6 times greater than the first year yield. There was no significant sowing rate effect on bluegrass second year seed yield.

Kentucky bluegrass second year seed yield was only reduced by wheat at 184 plants m<sup>-2</sup> and by wild oat at 142 plants m<sup>-2</sup>, compared to the monoculture seed yield. Because the second year Kentucky bluegrass seed yield was not significantly influenced by companion crop density this relationship was not modelled.

#### Kentucky bluegrass third year seed yield.

Seed yield of Kentucky bluegrass was not significantly different from that of the monoculture, except at the 95 plants m<sup>-2</sup> density of wild oat (Table 2). At this density bluegrass seed yield was about 1.7 times higher than monoculture seed yield.

Germination percentages and 100 seed weights for Kentucky bluegrass established with wheat or wild oat were not different from the monoculture plots in any year. Mean 28 day germination for 1993 Kentucky bluegrass establishment was 69% in 1994 (first seed year), 72% in 1995 (second seed year) and 88% in 1996 (third seed year). Average 100 seed weight at 14% seed moisture content was 37.3 mg in 1994, 38.5 mg in 1995, and 43.4 mg in 1996. Kentucky bluegrass establishment in 1995 had an average 100 seed weight of 44.3 mg and mean 28 day germination of 88% in 1996 (first seed year).

#### Wheat yield 1993.

The quadratic plateau equation (3) was used to develop a production curve for wheat undersown with Kentucky bluegrass averaged across all rates of Kentucky bluegrass. From this equation, the optimum wheat density necessary to reach an optimum wheat yield was calculated. The convergence criterion was met for all non-linear regression models using the Marquardt algorithm (Marquardt, 1963)

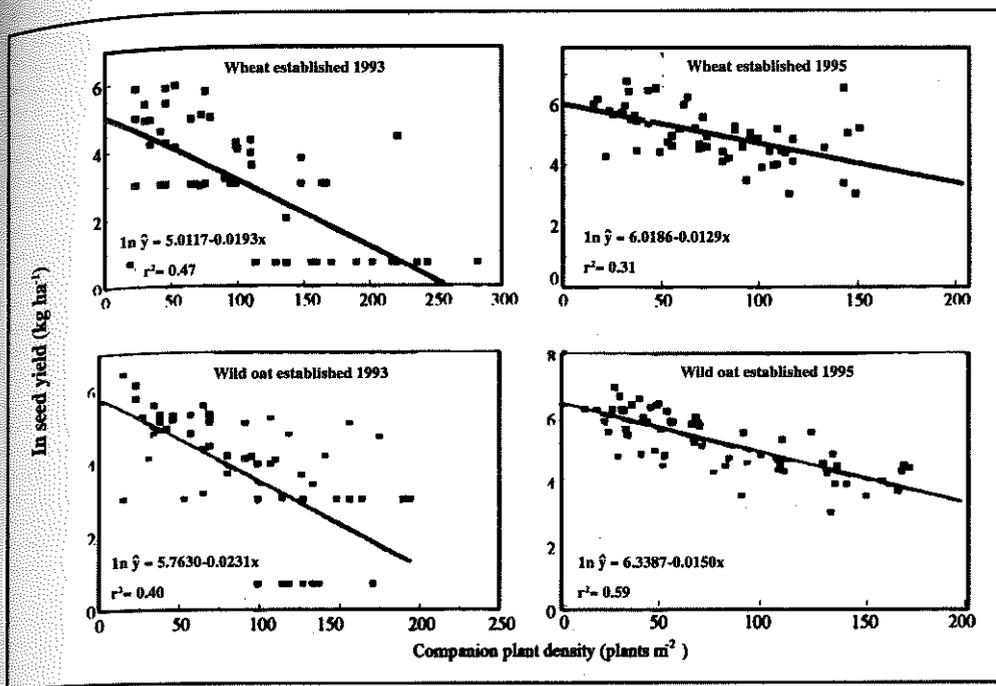


Figure 1. Predicted and observed first year Kentucky bluegrass seed yield established in 1993 and 1995 with increasing wheat and wild oat density.

indicating that a minimum sum of squares was determined for each model. As wheat density increased, wheat yield increased up to a maximum (Fig. 2). The wheat yields were between 1211 and 4898 kg ha<sup>-1</sup> with a plateau maximum of 4094 kg ha<sup>-1</sup>. Further increases in density after this point did not increase yield within the range of the data (19 to 282 plants m<sup>2</sup>). In 1993, a wheat density of 191 plants m<sup>2</sup> was required to obtain the maximum wheat yield when established with Kentucky bluegrass.

#### Wheat yield 1995.

In 1995, a linear model was chosen to relate wheat yield to wheat plant density across all rates of Kentucky bluegrass (Fig. 2). All model coefficients were significantly different from zero ( $P < 0.0001$ ) (Table 4). Wheat densities attained in 1995 were lower than 1993, and within the range of data, no maximum wheat yield was achieved. Wheat yield ranged from 790 to 7189 kg ha<sup>-1</sup>.

#### Spring wheat economics.

Averaged over a three-year period all net returns were negative (-\$217 to -\$798 ha<sup>-1</sup>) (Hamilton, 1995). Sale of wheat grain did not compensate for the low first year Kentucky bluegrass seed yield and the additional production costs.

Spring wheat proved to be highly competitive with Kentucky bluegrass in this study. Over a four year period these experiments show that dryland grown Kentucky bluegrass was not established economically with spring wheat in northern Idaho. Kentucky bluegrass seed yield will be monitored in subsequent years to determine if there is any long-term potential for establishing Kentucky bluegrass with a spring wheat companion crop.

#### Wild Oat economics.

Economic losses were 12% greater for the second year seed yield with wild oat as a companion plant compared to spring wheat. The greater impact of wild oat

on second year bluegrass seed yield is likely a result of volunteer wild oat, emphasizing the importance of controlling wild oat before the seed bank is replenished. If wild oat is not controlled during establishment, future control is expensive and difficult. Imazamethabenz at 0.46 kg a.i. ha<sup>-1</sup> was assumed to control 60% of the wild oat population in a seedling bluegrass stand (Neider and Thill, 1996). First year Kentucky bluegrass seed yields were estimated by using equation (1) with mean wild oat densities reduced by 60% in both 1993 and 1995 establishments. Profit margins from wild oat control with imazamethabenz were \$99 to \$148 ha<sup>-1</sup> more than untreated wild oat plots, for the mean densities established in 1993, and \$170 to \$277 ha<sup>-1</sup> more than untreated plots for the mean densities established in 1995. It was profitable to control wild oat with imazamethabenz at all densities observed for the 1993 and 1995 Kentucky bluegrass establishments. Highest net return was with wild oat at 58 and 115 plants ha<sup>-2</sup> for 1993 and 1995 respectively. Improved seed yield of Kentucky bluegrass at wider companion plant spacing is expected as a result of lower companion plant competition and greater light availability in the canopy (Meijer, 1987; Chastain and Grabe, 1988a; 1988b; 1989).

Table 4. Estimated coefficients for regression models used to predict wheat grain yield in 1993 and 1995.

Variable 1993	Parameter estimate	Asymptotic std. Error	Asymptotic 95% conf. int. Lower	Asymptotic 95% conf. int. Upper
Intercept ( $\beta_0$ )	1216.5261	243.6881	728.5492	1704.5030
Wheat density ( $\beta_1$ )	30.0708	5.2023	19.6532	40.4883
Wheat density <sup>2</sup> ( $\beta_2$ )	-0.07855	0.0232	-0.1251	-0.0319
Variable 1995	Parameter estimate	Standard error	t Value	Prob> t
Intercept ( $\beta_0$ )	2686.5767	325.8627	8.245	0.0001
Wheat density ( $\beta_1$ )	26.8220	4.07	6.588	0.0001

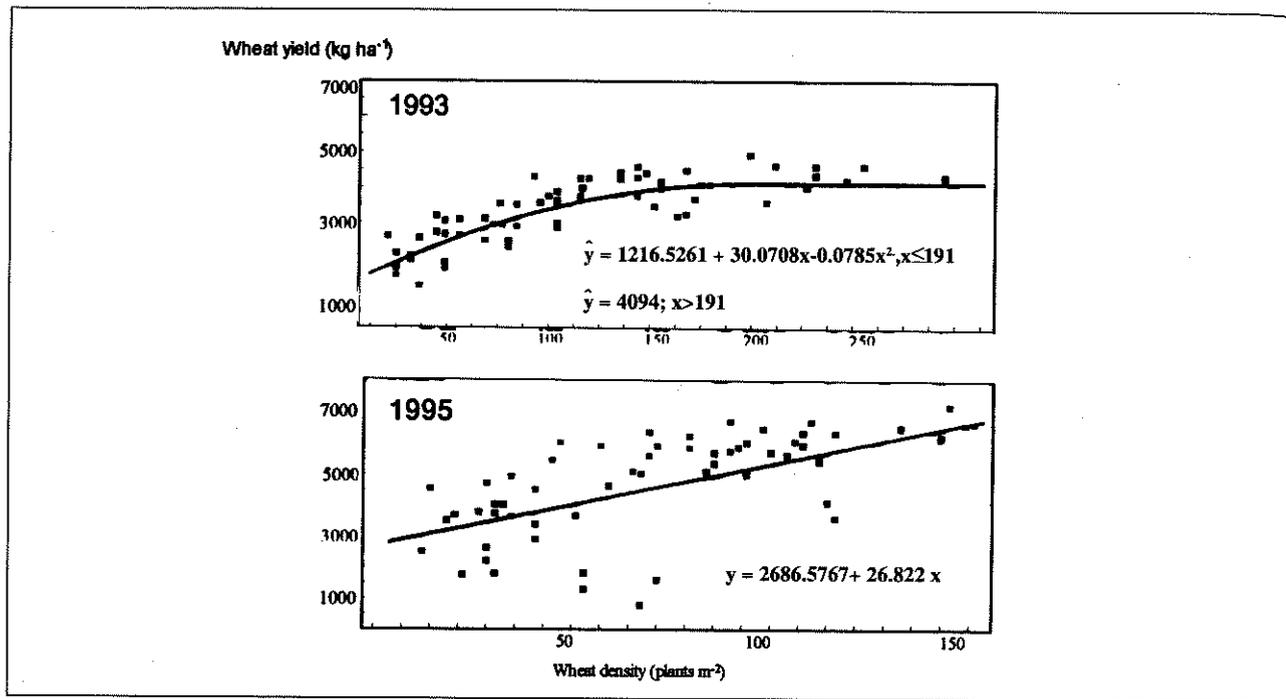


Figure 2. Predicted and observed wheat yields in 1993 and 1995 with increasing wheat density.

Wild oat is more effectively controlled with imazamethabenz in wheat and barley crops compared to Kentucky bluegrass stands where crop competition enhances control. Kentucky bluegrass is a poor competitor with wild oat, which emphasises the importance of timely and effective wild oat control in Kentucky bluegrass establishment for seed production, especially if mechanical residue removal replaces burning. If Kentucky bluegrass could be established successfully with a companion crop, wild oat populations may be suppressed by the more competitive cereal crops. Due to the shallow root system of Kentucky bluegrass and the unpredictability of dryland farming, establishment of Kentucky bluegrass with a spring wheat companion crop would probably be more successful under irrigated production systems.

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