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Grass weed competition with bread wheat in Ethiopia: II. Prediction of grain yield loss and implications for economic weed control

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ABSTRACT

Two multi-year studies were conducted in Ethiopia to examine the effects of competition by the predominant grass weed species on bread wheat *(Triticum aestivum* L.). In the first experiment, the effects of four grass weed species *(Avena abyssinica* Hoechst, *Lolium temulentum L., Snowdenia polystachya* Fresen (Pilg), and *Phalaris paradoxa* L.) at eight seedling densities (from 0 to 320 m^2) on wheat grain yield were studied. A. *abyssinica* and *S. polystachya* were highly competitive, resulting in a greater reduction of wheat grain yield (i.e., 85 and 86%, respectively, at 320 seedlings m^-2) than *L temulentum* and *P. paradoxa. L temulentum* exerted a greater competitive effect than *P. paradoxa.* Competitiveness of the grass weeds varied with weed seedling density. The second experiment studied the competitive interactions of *Avena fatua* L. sown at four seedling densities (from 0 to 90 m^-2) in competition with four bread wheat cultivars commonly grown by peasant farmers in Ethiopia. The semi dwarf cultivar Dashen was the most sensitive to *A. fatua* competition, exhibiting a yield loss of 63% at the maximum density of 90 wild oat seedlings m^-2. Competitive indices were derived from each experiment to facilitate the prediction of wheat grain yield loss, and to derive economic thresholds for herbicidal intervention in relation to weed seedling density.

Key Words: Competition, grass weeds, herbicide, wheat, yield loss

RESUME

Des etudes durant deux annees etaient conduites en Ethiopie pour examiner les effets de competition par especes predominantes des adventices sur le ble *(Triticum aestivum* L.). Dans le premier essai, les effets de quatre especes d'adventices *(Avena abyssinica* Hoechst, *Lolium temulentum* L., *Snowdenia polystachya* Fresca (Pilg), et *Phalaris paradoxa* L.) a huit densites de semis (de 0 a 320 m^-2) sur le rendement en grain de ble etaient etuies. *A. abyssinica* et *S. polystachya* etaient hautement competitifs, resultant en une pins grande reduction du rendement en grain de ble (de 85 et 86% respectivement a 320 plants m^-2) que *L. temulentum* et *P. paradoxa. L temulentum* exercait un plus grand effet competitif que *P. paradoxa.* Le niveau de competition des adventices variait avec le taux de germination des adventices. Le second essai etudiait lea interactions competitives de *Avena fatua* L. seme a quatre densites (de 0 a 90 m^- 2) en competition avec quatre varietes de ble communement cultivees par les exploitants fermiers en Ethiopie. La variete seminaine Dashen emit la plus sensible a la competition de *A. fatua,* exhibant une perte de rendement de 63% a la densite maximale de 90 plantes d'avoine sauvage m^-2. Les indices de competition etaient derives de chaque essai pour faciliter la prediction en perte de rendement en grain de ble et pour deriver les seuils economiques pour l'intervention d'herbicide en relation avec le taux de germination des adventices.

Mots Cles: Adventices, ble, competition, herbicide, perte du rendement

INTRODUCTION

Grass weeds represent a major constraint to wheat *(Triticum* spp.) production in Ethiopia because of: 1) the high proportion of wheat and barley *(Hordeum vulgare* L.) in the farming systems of the highlands, and 2) the repeated application within all wheat production systems of herbicides effective against broadleaf weeds, particularly low-cost 2,4-D (Birhanu, 1985; Rezene, 1985). Wheat grain yield losses due to competition from the major grass weeds have not been extensively studied in Ethiopia. However, wheat yield losses due to mixed weed infestations have been estimated at up to 58.1% (Slovtsov *et al.,* 1980), while *Avena fatua* resulted in losses ranging from 26 to 63% across four Ethiopian bread wheat cultivars tested (Tanner *et al.,* 1995).

Among the annual weeds of Ethiopia, surveys have shown that *Snowdenia polystachya, Phalaris paradoxa, Lolium temulentum, Avena abyssinica, A. fatua, Bromus pectinatus* and *Setaria pumila* comprise the major problematic grass weeds in wheat growing regions (SPL, 1980; Birhanu, 1985; Rezene, 1985; Tanner and Giref, 1991). The first five species are included in this study.

Grass weeds compete with wheat plants for light, water and nutrients, reducing wheat grain yields, lowering the market value of the grain due to weed seed contamination, and interfering with harvesting operations (Auld *et al.* 1987). Hand weeding is difficult during early growth stages of the broadcast crop due to similar morphology between some grass weeds and wheat: Ethiopian farmers tend to delay hand weeding until the weeds are distinct from crop plants, thus exposing the crop to weed competition for an extended period (Tanner and Giref, 1991). Chemical control of grass weeds, on the other hand, necessitates the use of relatively expensive herbicides which farmers may not be able to afford; often, grass herbicides are not readily available in Ethiopia (Tanner and Giref, 1991).

Control measures are necessary to prevent weed infestations from reaching levels at which economic loss is incurred. Thus, the decision to apply a specific weed control measure should be based on an accurate estimation of the potential crop loss as a result of weed competition; this must be weighed against the cost of weed control (Auld *et al,* 1987).

Most crops are infested with mixed populations of weed species. It is necessary, however, to consider the relative competitiveness of a range of individual weed species before addressing the more complex problem of multi-species competition (Wilson and Wright, 1990). The expected competitive effects of weeds in a mixed infestation may be estimated using competitive indices to predict crop yield losses; such indices have been determined in North America (Carlson and Hill, 1985), the United Kingdom (Wilson *et al.,* 1990): and in Canada (Dew, 1972). However, such information has been lacking in the Ethiopian context (Parker, 1990).

This study, therefore, was initiated to determine the competitive effects of varying densities of five major annual grass weed species in Ethiopia on bread wheat grain yield, to derive competitive indices, and to examine the threshold weed densities associated with an economical weed control intervention.

MATERIALS AND METHODS

Experiment I.

The first experiment was conducted at the Ambo Plant Protection Research Centre (PPRC) from 1992-1994. The PPRC is located at an altitude of 2225 m a.s.I. about 125 km west of Addis Ababa (8 degrees 57' N, 37 degrees 52' E). The PPRC soil is an unclassified Vertisol. Mean annual maximum and minimum temperatures are 26 and 11.5 C, respectively. The mean annual rainfall is 1160 mm, having an unequal bimodal distribution.

The experimental design was a split-plot arrangement of a RCBD with three replications. Main plots consisted of the four grass weed species, *A. abyssinica [Aa], L temulentum [Lt], S. polystachya [Sp], and P. paradoxa [Pp].* Eight subplots consisted of weed seedling densities (0, 5, 10, 20, 40, 80, 160, 320 seedlings/m^2). The weed densities included a range of levels to facilitate both the determination of economic thresholds and of maximum yield losses, and were also representative of the range of weed densities commonly encountered in farmers' fields (Amanuel *et al.,* 1992).

Additional details of the experiment are given in Taye *et al.* (1996).

Experiment II.

The design of the second experiment has been discussed in detail by Tanner *et al.* (1995). The trial was conducted at the Kulumsa Research Centre (altitude 2200 m asl, lat. 8 degrees 02' N, long. 39 degrees 10' E), during the three cropping seasons of 1991-1993.

In brief, the experimental design was a split-plot layout of a RCBD with three replications. Main plots consisted of 4 bread wheat cultivars (Israel, Enkoy, ET13 and Dashen) commonly grown by peasant farmers in Ethiopia and representing a range of cultivar releases over time (i.e., from an unimproved, tall line to a modern, CIMMYT-derived semi-dwarf). *Avena fatua [Af]* seedling densities, consisting of an additive series of 0, 30, 60 and 90 seedlings m^-2, were established as subplots within the varietal main plots.

Subplots consisted of 10 rows of wheat spaced at 20 cm and extending 5 m in length. Rows were marked by hand, and fertilizer (39 kg N and 30 kg P ha^- 1) was placed in the rows and partially mixed with the soil using sticks. Wheat was then sown in the rows at the commercially recommended seed rate of 150 kg ha^-1 during early July of each year.

Subsequent to covering the wheat seed, but on the same day, rows for *Af* were marked equidistant between the wheat rows, and seed of *Af* was sown at 90, 180 and 270 seeds m^-2. At the 2-3 leaf stage, *Af* seedlings were manually thinned to the desired seedling densities, and two subsequent thinnings at successive two week intervals were carried out to maintain the desired densities by removing late germinating *Af* seedlings and all other non-target weeds.

Other plot management and harvest procedures were similar to those used in Experiment I.

Data Analysis.

Wheat grain yield data were simultaneously regressed on square root transformed weed densities across the four weed species in Experiment I and the four wheat cultivars in Experiment II, using indicator variables to represent species or cultivars (Neter *et al.,* 1990). Thus, the regression analysis conformed to a model with four classes (i.e., 3 indicator variables) for the qualitative variable (representing weed- species or cultivars) with interactions added. The fitted regression model was:

$$Y = b0 + b1X1 + b2X2 + b3X3 + b4X4 + b5X1X2 + b6X1X3 + b7X1X4$$

where $X1 = (\text{weed density})^{1/2}$,

X2 = 1 for *Aa* in Exp. I or Enkoy in Exp. II,
0 otherwise,

X3 = 1 for *Lt* in Exp. I or Dashen in Exp. II,
0 otherwise,

X4 = 1 for *Sp* in Exp. I or Israel in Exp. II,
0 otherwise.

Each multiple regression analysis initially included all components; an iterative process was adopted, sequentially eliminating components exhibiting the least contribution to the regression sum of squares and being non-significant individually (P>0.05). Ultimately, only those components with significant (P<0.05) contributions to the multiple regression were retained for each regression model.

Economic Analysis.

Subsequent to generating grain yield response functions for both experiments, the economics of herbicidal grass weed control were studied in order to determine threshold levels of the specific grass weeds under varying cost and price assumptions. A high efficacy herbicide, fenoxaprop-P-ethyl (product trade name Puma S^R marketed by the Hoechst company) applied at 70 g a,i. ha^-1 (= 11 product ha^-1), was selected for the determination of threshold weed levels on the basis of its superior efficacy in prior on-farm screening carried out in Ethiopia (Amanuel *et al.,* 1992). Pre-emergence application of fenoxaprop-P-ethyl has provided an average of 94, 81 and 99% control of the target grass weeds *Af, Pp* and *Sp,* respectively (Rezene *et al.*, 1990; Amanuel *et al.,* 1992). From the same sources, mean grass weed control by this product was 85%; in the absence of a specific rating for *Lt* control, this mean value was applied in the threshold analysis for *Lt*. The 94% efficacy rating for *Af* was applied in the threshold analysis for *Aa*. Current prices associated with herbicide

purchase and application and grain marketing were obtained from government extension agents and from market surveys (Mohammed Hassena, unpublished data). The cash cost of herbicidal weed control was estimated at 348 Ethiopian Birr (EB)ha^-1 (= 330 EB l^-1 of PumaS^R and 18 EB ha^-1 for custom spray application by backpack sprayer). Two cost levels were assumed in this analysis: the breakeven cost (473.28 EB ha^-l) which includes a six month capital cost of 36% and a more conservative cost level (696 EB ha^-1) which includes a 100% minimum acceptable rate of return (MARR) on the farmer's investment in herbicidal weed control (CIMMYT, 1988). The mean wheat grain price of 1.15 EB kg^-1 was varied by +/-0.2 EB kg^-1 to evaluate the sensitivity of threshold levels. Mean grain prices were reduced by harvesting costs of 0.12 EB kg^-1 to derive net field prices.

Economic threshold weed densities (associated with herbicidal control by fenoxaprop-P-ethyl) for the individual weed-crop combinations were determined based on the methodology of Auld *et al.* (1987). For each weed-crop competitive interaction, the value of crop grain yield recovered (VR) per ha by herbicidal weed control was calculated as follows:

$$V[R] = pbe(x)^{1/2}$$

where p = the net field price per kg of grain [market price - the cost of harvesting the additional yield],
b = the relevant coefficient from the yield loss regression function (kg grain/ha/seedlings^1/2m),
e = the efficacy of the herbicidal intervention expressed as a proportion (0.0 to 1.0), and
x = weed seedling density (seedlings/m^2).

The threshold weed seedling density at which herbicidal weed control becomes profitable at any given cost level, c, is encountered when V[R] = c. Thus, at the threshold level:

$$c = pbe(x)^{1/2}$$

$$x = [c/(pbe)]^2.$$

RESULTS AND DISCUSSION

In both experiments, the effects of grass weed seedling densities on wheat grain yield were consistent and highly significant during each of the three years of conducting the trials (Tanner *et al.,* 1995; Taye Tesseme, 1995; Taye *et al.* 1996). In Experiment I, mean grain yield (across weed species) decreased from 3223 kg ha^{-1} for the weed-free check to 951 kg ha^{-1} at the maximum weed density of 320 seedlings m^{-2}. In Experiment II, mean grain yield (across wheat cultivars) declined from 3966 kg ha^{-1} to 2317 kg ha^{-1} at the maximum weed seedling density of 90 m^{-2}. Several studies reported elsewhere have reviewed the relationship between wheat grain yield and weed density (Dew, 1972; Chancellor and Peters, 1976; Wilson and Peters, 1982; Wilson and Wright, 1990).

Highly significant weed species by seedling density interaction in Experiment I and wheat cultivar by *Af* seedling density interaction in Experiment II indicated: 1) differences in competitive ability with wheat among the four grass weeds studied in Experiment I (Taye Tessema, 1995), and 2) differential abilities of wheat cultivars representing a range of phenotypes to compete with a grass weed (i.e. *Af* in experiment II) (Tanner *et al.* 1995). Such interactions establish the importance of generating species- or cultivar-specific response functions to analyse the effects of weed competition on wheat grain yield.

Prediction of yield loss.

Cousens (1985) reviewed several mathematical models used to describe weed competition effects on grain yield, and discussed the relative merits and limitations of each. The data from the current trials were initially fitted to several models, including the linear, the square root, and the rectangular hyperbola; since the best fit was obtained with the square root model (Dew, 1972), this model was used for subsequent analyses.

Experiment I.

Regression equations for the four grass weed species competing with wheat cv. K6295-4A were derived from the multiple linear regression analysis using the combined data with indicator variables to represent species (Neter *et al.,* 1990). The resultant regression constants are listed in Table 1 and the response lines are displayed graphically in Figure 1. The multiple R^2 (0.898) indicated an excellent fit of the data to the regression model (Table 1) and the estimated weed-free grain yields (WFY) (a) were very near the observed values obtained from the control plots (i.e., the weed-free treatments). From both Table 1 and Figure 1 it is apparent that *Aa* and *Sp* result in the most rapid decline in wheat grain yield as weed seedling density increases, *Lt* exhibits an intermediate level of competition, and Pp is the least competitive grass weed in the current study.

TABLE 1. Regression coefficients[a] describing the effects of the density of four weed species on wheat grain yield (kg ha^{-1})

Weed species	a (kgha^-1)	b (kg ha^-1 seedling^-1 m^2)	WFyb (kg ha^-1)	b1^c
A. abyssinica	3032	169.4	3256	0.0559
L. temulentum	3187	123.8	3176	0.0388
S. polystachya	3043	171.7	3226	0.0564
P. paradoxa	3187	89.0	3233	0.0279

(n=288, R2=0,898, P<0.001).

^a Derived from a multiple linear regression analysis including interactions, using grain yield as the dependent and the square root of weed density and indicator variables for weed species as independent variables (after Neter *et al.,* 1990).
^b Weed-free yield (observed values).
^c Competitive index (Dew, 1972).

Figure 1. Effects of competition from four grass weed species on the grain yield of bread wheat cultivar K6295-4A (fitted via multiple linear regression analysis on the square root of weed density, R2=0.898, P<0.001, n=288)

A competitive index (b1) for each of the grass weed species was derived using Dew's equation (Dew, 1972) as follows:

b1 = b/a

where b = the regression coefficient and a = the weed-free grain yield (intercept). This index, indicating the competitive relation, is unique for each weed-crop combination. The competitive indices derived from the data of Experiment I are shown in Table 1; the four grass weeds exhibited the following ranking for competitiveness: *Aa* = *Sp* > *Lt* > *Pp.*

The b1 index can be used to estimate potential crop loss due to weeds when weed and crop populations emerge at approximately the same time. It is only necessary to estimate the weed-free yield, or "a" value, based on known management practices as well as climatic probabilities for a specific area. The yield loss equation derived using Dew's equation (Dew, 1972) follows:

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L=a-y where L = loss, a = weed-free yield, and y = predicted yield.
Since,   y = a - b(x)^x [where x = weed seedling density]
And,    b1 = b/a, b = ab1

Then,    y = a - ab1(x)^x
Thus,    L = a - [a - ab1(x)-] = ab1(x)^x
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This equation can be used to estimate the economic feasibility of a weed control intervention after the emergence of crop and weed seedlings. For example, a crop of wheat cv. K6295-4A that may be expected to yield 3000 kg ha^-1 under weed-free conditions is found to be infested with a mean density of 60 *Aa* seedlings/m^2 soon after emergence. The value of b1 for *Aa* in the bread wheat cv. K6295-4A in Experiment I has been shown to be 0.0559; thus, from the equation developed above, the anticipated yield loss due to this level of infestation would be:

L = 3000(0.0559)(60)^x = 1299 kg ha^-1

Thus, using such a yield loss equation, the cost/ benefit relationship of herbicide application can be estimated by extension agents to determine if the intervention would be economic, provided the. efficacy of the herbicide is known.

Experiment II.

In a similar manner to the methodology used in Experiment I, regression equations were determined for each of the four bread wheat cvs. grown in competition with a range of seedling densities of *Af.* The resultant regression constants are listed in Table 2 and the response lines are displayed in Figure 2. The figure clearly illustrates differences in the yield potential (i.e., weed-free yields) of the four cvs, and in their competitive ability with *Af*, the semi-dwarf cv. Dashen exhibited the greatest yield decline with increasing *Af* density. The multiple R^2 (0.591) was highly significant and the estimated weed-free grain yields (a) were near the observed values (WFY), indicating an excellent fit of the data to the regression model. The b value of 124.2 calculated for the three tall wheat genotypes compares with the value of 91.5 reported by Dew (1972) for *Af* infestation in Canada.

TABLE 2. Regression coefficients^a describing the effects of the density of ***A. fatua*** on the grain yield (kg ha^-1) of four cultivars of bread wheat

Wheat cultivar	a (kg ha^-1)	b (kg ha^-1 seedling^-1 m^2)	WFY^b (kg ha^-1)	b1^c
Enkoy	4221	124.2	4082	0.0294
Dashen	4706	300.2	4621	0.0638
Israel	3938	124.2	3763	0.0315
ET13	3182	124.2	3399	0.0390

(n=144, R2=0.591, P<0.001)
^a Derived from a multiple linear regression analysis including interactions, using grain yield as the dependent and the square root of weed density and indicator variables for wheat cultivars as independent variables (after Neter *et al.,* 1990).
^b Weed-free yield (observed values).

^c Competitive index (Dew, 1972).

Figure 2. Effects of competition from *A. fatua* on the-grain yield of four bread wheat cultivars (fitted via multiple linear regression analysis on the square root of weed density, R2=0.591, P<0.001, n=144)

Competitive indices (b1) were calculated for *Af* competition with each bread wheat cultivar, and are included in Table 2. In general, the indices for *Af* competition with the four cvs. in Experiment II were lower than the value (0.0559) calculated for the combination of *Aa* with K6295-4A in Experiment I; the exception to this generalisation was the b1 value of 0.0638 for the weak competitor Dashen. The cultivars Enkoy and ET13, used in Experiment II, are similar in phenology and phenotype to K6295-4A in Experiment I, yet their b1 values were only 0.0294 and 0.0390, respectively.

Experimental factors, apart from agro-ecological differences between the two sites and species differences between *Aa* and *Af*, that could explain the relatively lower indices of competition in Experiment II are enumerated as follows:

- Wheat seed rates differed: a seed rate of 120 kg ha^'1 was used in Experiment I vs. 150 kg ha^-1 in Experiment II. A denser stand of wheat is expected to be more competitive (Carlson and Hill, 1985).

- Relative sowing dates differed: in Experiment I, weeds were sown earlier than wheat to ensure coincidence of emergence; in Experiment II, weeds and wheat were sown on the same day. Relative time of emergence can significantly affect the wheat-weed competitive relationship (Chancellor and Peters, 1976).

- Weed seeds were sown in rows equidistant between wheat rows in Experiment II, while weed seeds were broadcast in Experiment I and wheat was subsequently sown in rows. Confining grass weeds to rows may have increased inter-plant competition, thereby reducing their impact on wheat.

- Fertilizer was broadcast at the nutrient rate of 60 kg N and 26 kg P ha^-1 and was soil incorporated in Experiment I, while in Experiment II fertilizer at 39 kg N and 20 kg P ha^-1 was mixed with soil in the wheat seed rows. The latter localisation would favour wheat *vis-a-vis* the competing weed plants.

- The choice of experimental weed seedling densities can also affect the predictive outcome of specific regression models (Cousens, 1985). Experiment I utilised a geometric series for weed seedling density, while Experiment II utilised an arithmetic series.

Calculation of Economic Thresholds for Weed Control.

The grain yield loss functions developed in the previous section were subjected to sensitivity analyses to determine robust economic threshold levels for grass weed control recommendations, using the high efficacy herbicide fenoxaprop-P-ethyl.

The value of the recovered grain yield as related to weed seedling density in Experiment I is displayed in Figure 3. Economic threshold levels for each weed species occur at the point of intersection with the weed control cost lines. As the cost of weed control is increased (i.e., the MARR scenario vs. the breakeven level), the threshold increases, particularly for the less competitive grass weed species. As shown in Table 3, threshold weed levels under the more conservative MARR scenario were approximately double the corresponding levels under the breakeven assumption.

Figure 3. Value of recovered grain yield (Ethiopian Birr ha^-1) of bread wheat cultivar K6295-4A in relation to the cost of herbicidal control of four grass species (1 US$ = 6.35 EB)

Comparing the calculated weed threshold levels at the current median grain price of 1.15 EB kg^-1 (Table 3) with reported grass weed densities in peasant farmers' bread wheat fields in Ethiopia (Amanuel *et al.* 1992) reveals that even under the conservative MARR scenario, the recommendation of the expensive herbicide Puma S^R may be warranted under high weed density conditions: the highly competitive weed species *Aa* and *Af* have been recorded at densities up to 90 seedlings m^-2 in farmers' fields.

The contrast between the semi-dwarf and tall cultivars in Experiment II was striking. Herbicidal weed control resulted in a much higher value of recovered grain yield in the semi-dwarf cultivar (Fig. 4) and threshold weed levels were correspondingly lower for the semidwarf (Table 3). Due to the higher yield loss experienced by the semidwarf under weed competition (i.e., a larger b value), the threshold weed level for the tall cultivars under any given price and cost scenario was 5.8 times the corresponding threshold level for the semidwarf. As Ethiopian farmers are increasingly adopting semidwarf bread wheat cultivars to benefit from their higher grain yield potential (Table 2), extension agents must be made aware of the differential competitive ability of the modern cultivars and the associated difference in economic threshold weed levels.

TABLE 3. Threshold levels for economic control of four grass species in bread wheat cultivar K6295-4A and ***Avena fatua*** in one semidwarf and three tall bread wheat cultivars under varying herbicide costs and grain prices

Herbicide cost:	473.28^a			696.00^b		
Grain price:	0.95	1.15	1.35	0.95	1.15	1.35
A. abyssinica	13	8	6	28	18	13
P. paradoxa	62	41	28	135	88	62
S. polystachya	11	7	5	24	16	11
L. temulentum	29	19	13	63	41	29
Semidwarf cv.	4	3	2	9	6	4
Tall cvs.^c	24	15	11	52	33	23

^a Breakeven herbicide cost including a capital cost of 36% for six months.
^b Total cash cost of herbicide plus a 100% minimum acceptable rate of return (MARR) on cash costs.
^c The three tall cultivars exhibited an equal rate of yield decline in response to *A. fatua* competition.

Figure 4. Value of recovered grain yield (Ethiopian Birr ha^-1) of tall and semi-dwarf bread wheat cultivars in relation to the cost of herbicidal control of *Avena fatua* at two grain price levels (1 US$ = 6.35 EB)

Under practical field conditions in Ethiopia, one rarely encounters a wheat crop infested by a single grass weed species; thus, there is a need to estimate grass control threshold levels in fields with multiple species. It is biologically sound to assume that at low to moderate total grass weed densities the competition of the weed plants for growth resources is similar to the situation in the sole infestations (Wilson and Wright, 1990); only at higher weed densities will there be significant competition among the weed species. Thus, the coefficient of competition for each weed species can be used to estimate its contribution to the combined competitive effect. Thus, to estimate the effect of Puma S^R application to a mixed infestation of grass weeds in a crop stand of the cultivar K6295-4A on the value recovered in grain yield, the following equation is applicable:

$$V[R] = p.(159.2 . Aa^x + 72.1 . Pp + 170 . Sp + 105.2 . Lt)$$

where p = the net field price as defined previously, and
Aa = the density of *Aa*, etc., as used previously.

Upon entering the density of individual grass weed species in the equation and the current price of grain, a decision on whether to apply a weed control intervention can be based on a comparison with the current cost of the intervention. At high weed densities the equation will not hold, but an assessment can be made on the specific density of the most competitive weed species.

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