Efficient weed control in wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.)

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Summary

Efficient weed control in wheat (*Triticum aestivum* L.) or maize (*Zea mays* L.) requires that inputs to control weeds should provide maximum economical returns in the year of treatment with consideration of their impact on future activities. With severe weed infestations, efficient control may require a combination of competitive crop rotations, tillage, pre-emergence and post-emergence herbicides. With light infestations, the inputs should not exceed that needed to give adequate weed control for maximum economic return together with a consideration of their impact on future infestations and costs. In wheat, many post-emergence herbicides are available to control most weeds. A model was developed to predict the economics of various herbicide treatments for wild oats (*Avena fatua* L.) control.

Farmers have not accepted the computer model, and prefer to use experience and available information to make judgement decisions. In maize, a computer model has been developed which uses weed seed populations in the soil and weeds in the maize to determine herbicide use. The model reduced herbicide usage and increased economic returns compared to a fixed herbicide system. The system using only post-emergence herbicides did not give the economic returns of the flexible system. The post-emergence herbicide used only gave 60% grass weed control. The recent development of highly effective herbicides for grass weed control if used in conjunction with broadleaf control herbicides in maize could greatly change the need and usefulness of models and provide an opportunity for more economical use of herbicides in maize. Post-emergence herbicides can be used on the weeds present. This may reduce herbicide use if a simple model is produced to predict the benefits from such treatments. Hand removal may provide an economical means for removal of sparse weed infestations where labour costs are low or removal of all weeds is important to future infestations. Most presented models do not consider cost of future weed infestations which is essential for long term farming operation.

Introduction

Wheat (6) occupies more land area than any other crop worldwide at about 231 million hectares. Wheat production is 596 million metric tonnes or more than the 521 for rice (6). The immense area dedicated to wheat production indicates its tremendous importance to the sustenance of humankind and also indicates the need for effective yet economical weed control. Weeds infesting wheat fields reduce yields therefore weed control by whatever means is a tremendously important task. For example, the world wide loss in wheat and barley (*Hordeum vulgare* L.) yields in 1977 from wild oats was estimated at 13 million tonnes per year which represents enough calories to sustain 50 million people (16). The loss was mainly in wheat as barley is planted to less area and is more competitive with wild oats so the loss is less.

Maize (6) occupies about 128 million hectares worldwide with about 27 million hectares in the United States. Maize is grown for grain, silage, and forage. The total world grain production was 469 million tonnes with 75 million in the United States, Thus, wheat and maize account for a high amount of the food production and any losses from weeds in these crops has a substantial impact on the well being of many people.

The greatest yield losses in wheat and maize are from many of the common weeds. Losses vary with the weed species, weed density, time of infestation and the edaphic and climatic conditions. Average wheat yield loss from 100 plants per square metre was 30% for wild oats and wild mustard (*Brassica kaber* (DC). Wheeler), and 10% for foxtail (*Setaria* spp.) and wild buckwheat (*Polygonum convolvulus* L.) (15). Losses from green foxtail (2) have varied greatly with environmental conditions. One hundred green foxtail (*Setaria viridus* (L). Beauv.) plants per square metre reduced yields 21 to 44% depending upon the wheat variety in 1975. In 1977, 1600 green foxtail plants m^{-2} did not reduce wheat yields. Wild oat competition with wheat was quite consistent over environments (1). The similarity of wild oats and wheat in response to environment probably accounted for the consistent competition. *Setaria* required warmer conditions for germination and growth than wheat and is more competitive under these conditions soon after seeding (18). These results indicate that the development of predictive models for losses from foxtail would need to include environmental parameters in addition to weed density. The r^2 of a predictive model for foxtail was only 0.62 when it included foxtail density, soil texture, temperature and precipitation for four weeks after wheat and foxtail emergence. However r^2 was only 0.10 when density alone was considered for 23 experimental sites.

Maize yield was reduced 35% by smooth pigweed (*Amaranthus hybridus* L.) and 17% by giant foxtail (*Setaria fabberi* Herrm) at 25 plants per metre of row (15). Competitiveness of weeds in maize varied with species, emergence relative to maize, and soil fertility as summarized in a review by Zimdhal (22). Research comparing the yield of maize with cultivation to the yield with cultivation plus herbicides was conducted at the University of Illinois from 1966 through 1975 and at the University of Minnesota in 1961 and 1962 with three experiments each year (5). An average of the two sets of experiments indicated about a 15% yield increase when herbicides were included in addition to cultivation.

The literature well documents the yield losses from weeds and the variability in the losses with species and environments. The information on weed competition in conjunction with surveys of weeds has been used to estimate economic losses due to weeds and the benefits from their control in various areas. In North Dakota, the wheat production loss was estimated at 1.28 million tonne from seven weed species in 1979 (5). The economic benefit from using herbicides beyond cultivation for weed control in maize was estimated at $1.6 billion for 12 North Central states of the U.S. when considering 1982 maize prices and herbicide costs (5).

The importance of weed control to maximizing crop production is clearly evident. However, developing models of weed control that maximize the economic return is difficult because of the unpredictability of weed densities and environments. Further, the cost associated with weed control in subsequent crops as result of seeding from uncontrolled weeds has received little attention.

With the advent of effective post-emergence herbicides for use in maize, predicting the benefits from weed control soon will become more feasible. Post-emergence treatments allow for application according to known weed species and densities.

Economic losses from weeds are difficult to estimate as weeds in addition to yield reduction cause indirect losses. Weeds require the use of herbicides, tillage, cultivation and hand labour for control and less productive systems of fallow, delayed seeding, and crop rotations; and can reduce crop quality and increase harvesting losses. This presentation will be directed at a discussion of various means of increasing the efficiency of weed control in wheat and maize.

Efficient weed control in wheat

Tremendous progress has been made in the control of weeds in wheat over the past 40 years. Most major annual broadleaf weeds are controlled adequately by herbicides today. However, specific resistant annual species of minor importance exist in localized areas and may become major problems in the future. Perennial weeds are still important problems in wheat production, but progress is being made with clopyralid and tribenuron for control of Canada thistle (*Cirsium arvense* (L.) Scop.). Field bindweed (*Convolvulus arvensis* L.) still is a severe problem in many of the drier production areas. Grass weed control has improved with recent development of herbicides and management systems for wild oats, green and yellow foxtail (*Setaria glauca* L. Beauv.), slender foxtail (*Alopecurus* *myosuroides*), silky bentgrass (*Apera spica-venti*) and Italian ryegrass (*Lolium multiflora* Lam.). Control is somewhat limited for cheat (*Bromus secalinus*), downy brome (*Bromus tectorum* L.), jointed goatgrass (*Aegilops cylindrica* Host.) and quackgrass (*Elytrigia repens* (L.) Nevski).

Herbicide costs have been questioned relative to the economic returns. Several experiments were conducted in North Dakota to determine the returns from herbicide usage for weed control in wheat. The results from the small plot experiment are summarized in the Table 1.

Table 1 *The returns from the control of wild oats and other weeds with various practices in wheat, Fargo, ND 1978 and 1982.*

Weed control treatment	Wheat yield Total	Gain	Total return	Weed control[a] Cost	Return
	kg a^{-1}			\$ ha^{-1}	
None	599	-	66	0	-
Hoeing	975	376	107	1839	-1732
Triallate +bromoxynil	1426	827	157	44	113
Triallate +bromoxynil +diclofop	1755	1156	193	74	119
Triallate +bromoxynil +diclofop +hoeing (74h)	2253	1654	248	692	-444

[a] Wheat at \$0.ll kg^{-1}, hoeing at \$3.35 h^{-1} and other weed control costs were herbicide plus application plus incorporation.

Weeds caused severe competition with the wheat in these experiments. The wheat without weed control only yielded 599 kg ha^{-1}. The yield was increased by 376 to 1645 kg ha^{-1} by various weed control practices. The triallate + bromoxynil + diclofop herbicides and application cost was \$74 ha^{-1} with a \$113 net return. Hand hoeing was included for reference, but the cost was \$1839 ha^{-1} with lower yields than the herbicide treatments, giving a net loss of \$1732 h^{-1}. Thus when competitive weeds are present in wheat relatively high expenditures on herbicides can provide a favourable return. The relative returns for herbicides compared to hand hoeing will vary depending on local costs of labour and herbicides. The data in Table 1 are averages over two years and in one year the increased return from adding diclofop to the bromoxynil and triallate was \$27 ha^{-1} and in the other year only a \$2.50 ha^{-1} net return. In the year with the \$27 ha^{-1} return the earlier triallate treatment had not adequately controlled the wild oats while in the year with the \$2.5O ha^{-1} net return the triallate gave good wild oats control and additional diclofop was not needed. In practice, the diclofop being a post-emergence treatment, would not normally have been applied. Weed control is maximized when various control strategies are combined. Mouldboard ploughing as part of a conventional tillage systems reduced the occurrence of kochia (*Kochia scoparia* (L.) Schrad.) and green foxtail by burying below the emergence depth of their small seeds with short survival in the soil (13). The influence of tillage systems in combination with various herbicides on weeds in continuous wheat over four years is shown in Table 2.

Table 2 *Weed plants per square meter in continuous wheat populations with various tillage and herbicide treatments average 1978 - 1983.*

Herbicide	Tillage system No till	Reduced	Conventional
	(Wild oats)		
None	97	155	121
Diclofop	5	10	10
2,4-D	130	210	148
Diclofop + 2,4-D	8	15	13
	(Green foxtail)		
None	95	83	60
Diclofop	17	20	15
2,4-D	85	80	68
Diclofop + 2,4-D	23	23	18
	(Kochia)		
None	22	28	11
Diclofop	25	38	10
2,4-D	5	8	3
Diclofop + 2,4-D	3	3	3
	(Wild mustard)		
None	15	24	21
Diclofop	22	53	45
2,4-D	0	O	0
Diclofop + 2,4-D	0	0	0

Weed populations were effectively reduced under most tillage systems with herbicides. However, if herbicide treatments did not provide broad spectrum weed control, it accentuated a particular weed problem. Control of broadleaf weeds without control of grass species increased the wild oat problem, or control of grass species without control of broadleaf species increased the wild mustard problem under all tillage systems. Further, the data indicates that weed control would be maximized when the most effective tillage system is used in combination with a herbicide. However, herbicides alone gave adequate weed control and could replace the need for tillage.

Competitive crops used in combination with herbicides help maximize weed control, in addition to selection of the most effective tillage system (Table 3). Wild oats seed in the soil was reduced by triallate from 18 million per hectare to 5 million in three years when barley was the continuous crop, but to only 11 million with wheat. Without triallate, the wild oats seed reserve generally increased with continuous spring wheat, remained constant with barley, increased with flax, and decreased with rye (14). These data indicate the importance of a combination of control treatments to maximize weed control.

Table 3 *Wild oats seed reserves in the soil as influenced by crop when grown with or without triallate, a wild oats herbicide, at Fargo, North Dakota.*

Crop	Year 1	2	3
	(Million seed ha^{-1} - No triallate)		
Rye	14.8	6.7	2.5
Soybeans	18.8	13.1	2.2
Wheat	26.7	28.9	39.8
Barley	21.2	2.5	27.2
Flax	29.4	34.3	47.7
Control (no crop)	32.4	55.8	138.3
Black fallow	13.6	6.2	0.5
	(Million seed ha^{-1} - No triallate)		
Rye	12.1	5.7	1.0
Soybeans	13.1	6.4	0.7
Wheat	18.5	15.6	11.4
Barley	15.6	12.1	4.7
Flax	21.5	19.8	14.1

• Initial wild oat seed density was 18.3 million seed ha^{-1}

Efficient weed control has many possible interpretations. Economic returns generally are of primary importance, but energy and soil conservation, and future costs are also important considerations. Recently, a lot of attention has been directed at developing models for aiding weed control decisions based upon expected weeds or on weeds present for post-emergence treatments. A computer program was developed for selection of post-emergence herbicides based upon expected yield, wild oat densities, and herbicide application costs (21). The model was never used by farmers. Possibly the program was developed at a time when few farmers had computers or the task of counting the wild oats exceeded their perceived need of treatment or the program gave farmers no confidence beyond their own visual interpretation.

A pilot project to evaluate various systems for wild oat control on farms indicated that intensive control systems in severely infested fields of wheat would increase yields sufficiently to provide a substantial economic return (20). Intensive herbicide use in conjunction with competitive crops in the rotation gave immediate net economic returns and resulted in substantial reductions in seed reserves so that the high inputs were not needed after two years. Treatment for wild oat control could be economically left to only post-emergence herbicides, based upon wild oat density in the wheat. The objective was to have farmers sample soil for wild oats seed to determine the need for pre-emergence treatments. However, soil sampling never was accepted. But infestation at harvest has been used as a guide to the use of pre-emergence herbicides as a first step in controlling potentially dense infestations. One farmer who had previously used pre-emergence herbicides on all his wheat land indicted that the new approach saved him $25,000 in one year. Computer models may become more acceptable as farmers use them and as prediction of economic returns become more precise. However farmers presently feel that their own, or their consultants judgment, is sufficiently precise and less demanding on their time than available models.

The pilot wild oat control program demonstrated the importance of combining control strategies under field conditions (20). The combination of pre-emergence and post-emergence herbicides together with competitive crops in the rotation, provided a system where fields severely infested with wild oats could in two years be reduced to infestation levels where control could be limited to post-emergence treatments. The combination of treatments provided yields similar to those expected in the area. The initial inputs were high but are considered efficient as economic returns were generally greater than with less inputs.

Weed control methods are available for control of most weeds in wheat and many involve the use of herbicides. Most of the herbicides are applied post-emergence which allows application according to the weed present. However, information is limited on the potential return from controlling various densities of specific weeds or combination of weeds in various environments or the impact of uncontrolled weeds on future activities. In wheat the cost of herbicides prevents usage in areas where yield is low and when capital is limited. Thus, there is a need for alternative to herbicide use or to reduce their cost. Hand labour may provide economical control if weed populations are sparse and when considering future infestations (5). Five hours were required to just walk a field looking for weeds and not much more time was required for an infestation of 2500 plants ha^{-1}. The labour cost would be economical if the alternative to hand labor was a herbicide with a higher cost or if the herbicide would not give complete control and prevention of seed production was important because of the already low density. Hand labour for controlling weeds at high densities requires a high input and would not maximize yields because of damage to the wheat from hoeing, pulling, or trampling in a crop like wheat. However, the efficiency in time for removal of plants excluding walking time, decreased from 4 seconds per plant with 10,000 ha^{-1} to 1.4 seconds per plant with 1 million ha^{-1}. Further, hand pulling would not be applicable to large farm operations in areas with low human populations.

Efficient weed control in maize

Models have been developed and evaluated for economical use of herbicides for weed control based upon weed seeds in the soil and the presence of emerged weeds in irrigated maize (8). The model was based upon data from six years of maize management experiments and was evaluated for continuous maize in a four year rotation (9,10,19). The models predicted that a flexible weed control system of pre-emergence and post-emergence herbicide usage based on weed seeds in the soil and emerged plants would reduce pre-emergence herbicide usage 13% and post-emergence use 5% of the time compared to a fixed system of pre-emergence, post-emergence, and layby herbicide usage. Seed production by the grass and broadleaf weeds present was greater, yield of maize grain equal, and the economic returns greater for the flexible system, with a high initial weed density (9). With a low initial weed density, the flexible herbicide treatment system used 45% less pre-emergence herbicide and 17% less post-emergence herbicide and gave equal yield, and a higher economic return than the fixed system

The above simulated results were generally substantiated in production maize fields over four years (10). The flexible system had a gross annual margin of $885 and the fixed system $810 ha^{-1}. Herbicide use over the four years was 3.8 kg ha^{-1} for the flexible and 26.9 for the fixed system and total weed density averaged 28,720 plants ha^{-1} for the flexible and 68O for the fixed system. Two other systems were evaluated with generally intermediate results. Further, the three less herbicide intensive systems gave a greater economic return than the fixed system in maize as part of a barley - maize - pintobear (*Phaseolus vulgaris* L.) - sugarbeet (*Beta vulgaris* L.) rotation (9).

The above models used cyanazine which only gave 60% post-emergence grass weed control and 2,4-D or dicamba for broadleaf weeds which gave 75 to 90% control(10). Sulfonylurea herbicides have been developed recently which give excellent post-emergent control of grass weeds and certain broadleaf weeds in maize (17). These herbicides alone, or in combination with other post-emergence herbicides provide an opportunity for future development of more efficient post-emergent weed control systems.

In soybeans (*Glycine max* (L.) Merr.) where many effective post-emergence herbicides for grass and broadleaf weeds are available models are being used to determine the losses from various emerged weeds (3). The model is based on the average number of various weeds in 10 metres of row. Number of an individual species is multiplied by a competitive index for that species, which is totaled for all species giving a total weed load used in the calculation of expected percent yield loss. This can easily be converted to economical loss for use in determining economic return from a post-emergence herbicide treatment. The system assumes that the weed population is low so that no competition occurs among the weeds. Further, the assumption is that when competition among weeds occurs the population is beyond the economic threshold. The high densities would justify the lowest priced effective treatment available. Models similar to those in soybeans could now be developed for maize for use with the newly available post-emergence herbicides. However, the present model does not consider environmental factors which could greatly influence field to field or year to year competition between various weeds with maize.

A model has been developed recently to estimate the yield loss from johnsongrass in corn (7). The sampling time was set by accumulated thermal units to correct the difference in early growth of the two species which affected competition. This program may be a beginning to post-emergence herbicide application according to weeds present. However, the procedure requires 50 samples at several locations which may prevent usage and is limited to only johnsongrass.

Efficient weed control with post-emergence herbicides requires consideration of crop rotation, competitive crops and proper time and method of application. Adjuvants have enhanced weed control with many post-emergence herbicides and together with application technology can greatly increase the efficiency of post-emergence herbicides. This topic is being considered in another section of this proceedings.

Maize usually is grown in rows which allows for cultivation between the rows and hoeing within the row. Further, cultivations and cultural systems vary in efficiency. Deep cultivation is thought to disrupt maize roots, bring weed seeds near the surface for subsequent emergence, and is energy intensive. Data for hoeing sugarbeet, which are also grown in rows, indicated that 5.4 h ha^{-1} was required to walk the field and 0.5 h ha^{-1} more for every 1,000 weeds present (11). Herbicides and hand hoeing are efficient compared to cultivation in the usage of petroleum energy; but in general, hand hoeing is more costly than herbicides and herbicides more costly than cultivation (4). The economic return is usually higher from the use of herbicides because cultivation does not control weeds within the maize row. Control of weeds in wheat or maize by most means generally provides an economic return because of the severe yield loss caused by weeds. The most efficient means of control depends upon available crop rotations, acceptable tillage, cost of herbicides and labour, an needed energy and soil conservation in a given situation. Information on the impact of uncontrolled weeds in a given year on future infestation and costs for control is needed for development of models for efficient weed control.

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