Weed control in cereals - Now and in the future

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Wheat, barley, and oats are important worldwide, providing food for people and livestock. In this presentation, the term small grains will be used to refer to mainly these three crops. These small seeded cereals as a plant group are grown in over 300 million ha throughout the world, more than two times the area of any other crop. Wheat occupies more area than any other crop, over 200 million ha, or nearly twice that of rice and world production exceeds rice.

The immense areas dedicated to production of wheat certainly indicates its tremendous importance to sustenance of man, and also indicates the importance of efficient weed control. Weeds in wheat, barley, and oats reduce yields and deprive man of food needed for survival. Weeding small grains by whatever means is a tremendously important task.

These crops are solid seeded; therefore, hand pulling or hoeing, and cultivation for weed control is difficult or impossible. Perhaps for this reason the earliest inorganic and organic chemical weed control practices were developed in small grains. Modern weed control utilizing chemicals began with 2,4-D in small grains about 30 years ago. The use of 2,4-D, and subsequent developed herbicides by agriculturalists in developed countries eliminated much of the drudgery of hand pulling weeds and also improved crop yields.

Tremendous progress has been made in controlling weeds which infest cereal grain crops. Since the discovery of 2,4-D, many other herbicides have been developed for control of broadleaf weeds resistant to 2,4-D, for control of grass weeds, and for greater safety to the cereals at more stages of growth.

Most major, annual broadleaf weeds are controlled adequately by herbicides or herbicide combinations available today. However, specific resistant species of minor importance still exist in localized areas and may become the major weed problems in the future. For example, false chamomile (*Matricaria maritema* L.) infects a localized area in North Dakota. Several herbicides are used successfully to control this weed in Europe, but they are not effective in North Dakota. Skeleton weed (*Chondrilla juncea* L.) which occurs in Australia and North-Western United States is another example.

Wild oats (*Avena fatua* L.) and other grass weeds have become economically important in small grains in recent years and continue as a major problem. Wild oats is a severe competitor with cereal grains and flax. In North Dakota, 100 wild oat seedlings per square meter caused a yield loss of 30% in wheat, 15% in barley, and 65% in flax. Wild oats apparently has been increasing around the world in recent years. The increases in reported infestations of wild oats may be due partly to greater awareness of the importance of weed competition in reducing crop yield. However, increases in wild oat infestations are probably real and may be primarily because of the increased use of the combine for harvest which unfortunately returns a higher proportion of the wild oat seed produced directly back to the soil as compared to other harvest methods. Less use of crop rotations in some areas and better control of other competing weeds have led to increased wild oat infestations. The introduction of short strawed crops has been reported to reduce crop competitiveness and increase wild oat seed production. The relatively high cost of herbicides has prevented their widespread use for wild oat control in crops with low infestations or where yields are low. Thus, herbicide usage is restricted to heavy infestations and has not greatly reduced areas of wild oat infestations.

The annual world losses from wild oat infestations have been estimated at nearly 13 million tonnes of wheat and barley (Nalewaja, 1977). This production loss would be enough food to feed 50 million people at the subsistence level, or 100 times the population of North Dakota or about 3 times that of Australia.

Agriculture and weed problems in Australia and North Dakota are similar in many respects, I believe. We even plant seed grains during the same calendar months. Now, I would like to briefly review the agriculture and weed problems in North Dakota and our research for weed control in small seeded cereals, mainly wild oat control.

North Dakota is a semi-arid state with 32 cm precipitation in the west and 50 cm precipitation in the east. The average farm size is 421 ha and the main crops are hard red spring wheat and durum on about 4.5 million ha, barley on 0.9, oats on 0.5, sunflowers on 0.5, and flax on 0.3 million ha. Corn, soybeans, sugarbeets, potatoes and rye are also important crops. The average wheat yield is 1814 kg/ha.

Major weeds infesting cereals in North Dakota are wild oats, green foxtail (*Setaria viridis* L.), wild mustard (*Sinapis arvensis* L.), Russian thistle (*Salsola kali* L.), redroot pigweed (*Amaranthus retroflexus* L.), wild buckwheat (*Polygonum convolvulus* L.), and field bindweed (*Convolvulus arvensis* L.).

Wild oat control effort includes research on biology, herbicides and integrated systems, and various educational efforts to inform farmers of losses caused by wild oats and of control practices.

Research on wild oat biology has provided insights into seed germination and genetic variability in the species. Most of the wild oat selections in our research originally were selected by Dr. Andersen from the University of Minnesota. He made selections by travelling through Eastern North Dakota and Western Minnesota and stopped at fields every 5 km and collected individual panicles. Wild oat selections were found to vary in susceptibility to nearly all the known wild oat control herbicides, and in many growth characteristics (Table 1). The variations in herbicide tolerance indicates a potential for the development of more tolerant populations with extensive prolonged usage of a given herbicide. Rotation of herbicides might be needed to give long term wild oat control. The selections also appeared to vary in the dormancy of seeds produced. Variable dormancy would help assure infestation over a period of years as well as aid in survival of the species.

Table 1. Variation among wild oat selections

Characteristic	Range	Mean
Plant height, cm	24 to 59	44
Tillers, no.	10 to 42	22
Heading date	28 June to 17 July	12 July
Seed production, g	1 to 36	15
Herbicide, % control		
a. barban	10 to 95[a]	
b. triallate	5 to 75[a]	
c. diclofop	12 to 98	61
d. difenzoquat	41 to 97	78
e. MSMA	1 to 80	31
f. flufenprop-methyl	31 to 100	67

[a] values from Jacobsohn and Andersen (1972).

Research on wild oat seed dormancy indicated that seed emergence was stimulated by sodium azide at 5.6 to 11.6 kg/ha in the greenhouse. However, the effectiveness was dependent upon seed source. In the field, sodium azide was only partly effective in stimulating seed germination as moisture and azide distribution in the soil influenced results. However, with thorough incorporation and favourable soil moisture as much as 50% of the dormant seeds were stimulated to germinate compared to 10% without treatment. This indicates great potential for the concept even though sodium azide may not be the ideal chemical.

Wild oat seed survival in the soil was greater with deep than shallow burial (Table 2). The loss of viability was 70% to 90% the first year, but further loss in viability was slow with no reduction in viability of seed buried 30 to 34 cm during the subsequent 3 years.

Tillage influenced the distribution of seed in the soil. Fields which had been regularly moldboard plowed had wild oat seeds distributed rather uniformly to plow depth, while fields which were chisel plowed had 50% to 60% of the seed in the top 2.5 cm of soil.

A field that initially had 18 million wild oat seeds per ha to 15 cm deep had increased levels of wild oat seed after 3 years of continuous flax, spring wheat, or barley, and lower levels of wild oat seed after 3 years of winter wheat, rye or soybeans (Table 3). Treatment with triallate caused a decrease in wild oat seed reserves in all crops over the 3 year period and the triallata was more effective when used on the more competitive crops. Three years of fallow or rye and soybeans treated with triallate, reduced the seed level to less than 1 million per ha.

Wild oat control research at North Dakota includes evaluation of new herbicides, but an effort is also directed toward improving the efficacy with presently commercial herbicides.

Table 2. Percentage wild oats remaining viable at various burial depths over 4 years

Depth (cm)	Percent viability after burial, years[a]			
	1	2	3	4
	Fargo, North Dakota			
0 to 4	11	13	6	3
12 to 16	22	19	15	9
30 to 34	26	27	26	29
	Williston, North Dakota			
0 to 4	8	7	7	4
12 to 16	16	12	14	16
30 to 34	20	17	19	19

[a] Seed was 98% viable and 80% dormant at time of burial in the fall of 1973.

Table 3. Influence of various crops grown annually and triallate used annually for 3 years on the number of wild oat seeds per ha to 15 cm deep when the starting level was 18 million wild oat seeds per ha

Crop	Wild oat seed/ha to 15 cm deep (x 10^6)	
	No control	Triallate[a]
Flax	47	15
Spring wheat	38	11
Barley	27	5
Winter wheat	10	3
Rye	3	1
Soybeans	1	<1
Fallow	<1	not treated
Wild oats	130	not treated

[a] Treated with 1.12 kg/ha a.i.

Wild oat control with barban was improved when NH_4NO_3 fertilizer (28% N w/v) was added at from 9.35 to 56 ℓ/ha to the spray mixture (Table 4). Wild oat control was improved especially where plants were growing on soil low in fertility, thus improving the consistency of wild oat control with barban as control is usually poor on fields low in fertility.

Table 4. Wild oat control and wheat yield as influenced by barban at 0.28 kg/ha a.i. applied alone or with 28 ℓ/ha of 28% N (NH_4NO_3). Results are an average of 30 locations x ? years

Additive	Wild oats control (%)	Wheat yield (kg/ha)
None	56	1492
Nitrogen + SURF[a]	73	1687
SURF[a]	59	1478
Control	0	1337

[a] A non-ionic surfactant was added at 0.05% (v/v).

Other research indicated that MSMA (monosodium methanearsonate) at 1.7 kg/ha a.i. in combination with barban (4-chloro-2 butyl m-chloro-carbanilate) at 0.28 kg/ha a.i. increased wild oat control above the control obtained with either herbicide applied alone (Table 5). Further, the combination gave good control of green foxtail and wild mustard and increased the period for effective wild oat control.

Table 5. Weed control with barban/MSMA combinations

Treatment	Rate (kg/ha)	Weed control[a]			
		wild oats (%)	Green foxtail (%)	Common lambsquarters (%)	Wild mustard (%)
MSMA	1.7	50	67	48	91
Barban	0.28	52	0	0	0
MSMA + barban	1.7 + 0.28	82	80	60	100

[a] wild oat control values are an average of four locations, green foxtail three, and common lambsquarters and wild mustard, one.

In our area with the cold winters, triallate (S-(2,3,3-trichloroallyl) diisopropylthiocarbamate) does not dissipate through the winter and fall applied triallate often gives more effective control of wild oats than spring application. Improved wild oat control from fall applied compared to spring applied triallate is possibly from better distribution of the triallate through the soil from the winter moisture.

One of the key phrases in pest control in the United States today is "integrated pest management" (I.P.M.). Pest management is new terminology for sound management practices. I.P.M. was originally conceived as a method of reducing pesticide use through cultural methods. However, I.P.M. as practised often does not cause a decrease in pesticide usage and in some cases, pesticide usage may be increased when usage has been low or where herbicides alone are effective and economical. I.P.M. in many ways may be analogous to usage of soil testing information to crop production. Now I will try to use the results just discussed relative to an I.P.M. system for weed control in small grains. Pest management, for successful implementation on weeds in small grains, requires highly qualified individuals with knowledge and ability to apply biology, agriculture, and economics into an integrated system of pest control. Areas of knowledge of primary concern to I.P.M. for weed control in small grains are as follows:

1. Weed biology
2. Soil weed seed population dynamics
3. Crop-weed-tillage-herbicide interactions
4. Post-emergence herbicide effectiveness
5. Economic implications of weed competiton, weed seed production, crop selection, and tillage practices.

Weed biology - An understanding of weed seed production, dormancy, and longevity and weed growth is needed to evaluate the potential for future weed infestations with various management practices. Maximizing weed control through integration of all known cultural and chemical control practices to reduce soil seed reserves may be impractical for weeds which produce a large number of seeds with long dormancy.

Soil weed seed population dynamics - Weed seed population in the soil is the source of infestations; and therefore, information on soil weed seed reserves is essential to an I.P.M. program. Fields with a high weed seed infestation would require the use of pre-emergence herbicides plus post-emergence herbicides and cultural control practices to maximize yields and to lower the infestation level in subsequent years.

Pre-emergence herbicides would be applied to fields with an anticipated heavy infestation to remove the weed competition early and then post-emergence follow-up treatments would maximize control. However fields with potential for only light infestation would not be given pre-emergence treatment for weed control, relying on post-emergence herbicides should weed infestation develop. Thus, a method to assay for weed seeds in the soil is needed for application of I.P.M. Our research with sodium azide was directed at depleting the seeds in the soil during a fallow year. However, sodium azide in combination with gibberellic acid appeared promising in stimulating many species to germinate in the greenhouse. Thus, soil samples could be assayed for weed seeds through germination. Soil sample assay may not be practical on a field scale because of the effort involved and variability within fields. However, a soil assay method would be applicable as a research method to correlate weed mapping over several years with soil seed reserves for use in predicting infestations.

Crop-weed-herbicide-tillage interaction - The first obvious application of integrated pest management is to maximize weed control on heavily infested fields with the objective of reducing soil weed seed reserves to a level which would not require intensive control to prevent production losses. A system could be developed with a rotation containing competitive crops combined with pre-emergence and post-emergence herbicides for use on heavily infested fields. The importance of combining a competitive crop with a pre-emergence herbicide, triallate, to reduce wild oat seed reserves was indicated earlier in Table 3. Further, tillage practices to be used should take into account their effect on weed seed survival. Moldboard plowing was shown to distribute weed seed uniformly throughout the plowing depth while chisel plowing retained the seed near the surface. Thus, moldboard plowing would prolong a wild oat infestation as seed survival increased with burial depth in the soil. However, weeds with short longevity in the soil (*Setaria, Bromus*) would be controlled better by moldboard plowing.

I.P.M. Would take into consideration the effect of control methods for one pest as it might influence other pests. In small grains, the primary consideration would involve the effects of herbicides to control weeds in place of tillage upon the development of diseases. At present, insects of small grains do not appear to be influenced by weeds or tillage.

Post-emergence herbicide effectiveness - Integrated pest management relies heavily on effective post-emergence herbicides. Post-emergence herbicides will be used to supplement pre-emergence herbicides during the first phase of reducing seed reserves in heavily infested fields. Post-emergence herbicides will be the only chemical control planned in the system for fields with low weed infestations. Further usage of the post-emergence treatment will depend on infestation and weed species and may involve only spot treatment. Thus, research on development of selective post-emergence herbicides effective under various environments is needed for use with I.P.M. systems.

Economic considerations - Economics form the basis for most decisions in agricultural production. Thus, I.P.M. will probably promote effective and economical herbicide use since herbicides are generally the most economical means of achieving effective weed control. Economic considerations should include the benefit from initial weed control inputs on subsequent weed infestations, the long term effect of seeds produced by low infestation of various weed species, the possible lower returns from competitive crops(e.g. rye) or fallow in the rotation, and costs of tillage methods and herbicides or herbicide combinations relative to the long term economic returns.

I.P.M. for small seed cereals is a means to first reduce infestation levels in heavily infested fields and second to reduce the use of pre-emergence herbicide in fields with low weed infestations assuming that infestation levels can be accurately predicted. The use of a pre-emergence herbicide in a field or area of a field without weeds is not an efficient use of energy or finances. I.P.M. will not replace herbicides for weed control in small grains. An effective and economical selection of both pre-emergence and post-emergence herbicides is essential as an addition to crop and soil management for an effective I.P.M. system for weed control in small grains.

In North Dakota, we believe that fields heavily infested with wild oats can be reduced to a low infestation in 4 years by using as many competitive crops as possible in the rotation and by applying pre-emergence herbicide followed by a post-emergence herbicide if needed.

Modern weed control in small grains has effectively controlled many weeds, improved the nutrition of mankind by increasing food production while reducing the drudgery of weeding by humans. Herbicides have increased agricultural production (energy) with a very low energy input. The return from controlling 100 wild mustard or wild oat plants per square meter in North Dakota was 39 to 143 times the energy input for herbicides and application. Energy considerations in the future will stress the use of post-emergence herbicides so that application can be related to the weed infestation.

In summary, most broadleaf weeds are adequately controlled at minimal cost by available herbicides in small grains. However, broadleaf weeds resistant to present treatments exist in localized areas and grass weeds remain of major economic importance. Herbicides are presently available for many grass species, but economics may not favour usage for light weed infestation or in areas where yields are low. Future weed control efforts need to involve research in the areas of weed biology, soil seed reserves, and development of efficient post-emergence herbicide treatments.

REFERENCES

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