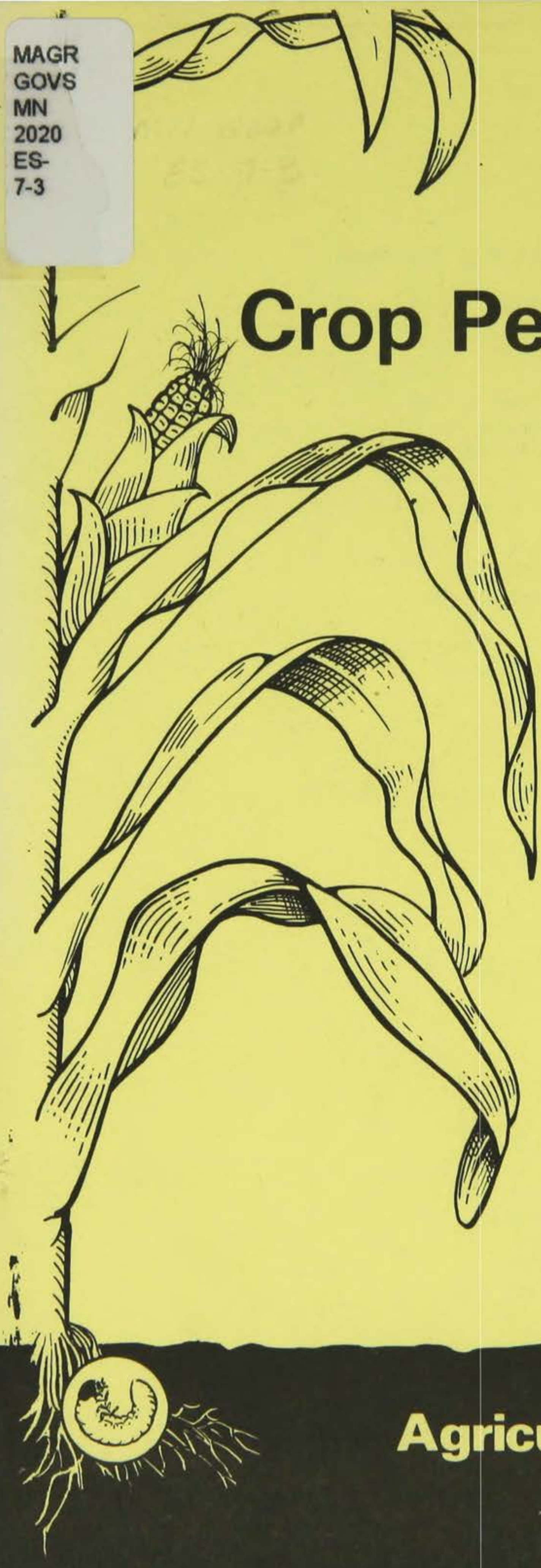

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ENHANCED BIODEGRADATION: CURRENT PROBLEMS AND FUTURE IMPLICATIONS

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INTRODUCTION

Biodegradation is a natural process. It is nature's way of recycling utilizable substances into new building materials for new living cells, obtaining energy, and riding itself of undesirable irritants or toxicants. Like most other organic molecules placed in or on soil, pesticides are subject to biodegradation by soil microorganisms. In fact, nearly all pesticides are degraded in soil through primarily microbiological processes. The importance of the microoganisms responsible for this degradation is considerable because their activity determines the persistence, and thus the agricultural use of many pesticides.

The mechanisms by which soil microorganisms develop the capacity to degrade pesticides have been discussed in detail elsewhere (Audus, 1960; Kaufman and Kearney, 1970, 1976; Loos, 1969). Enzyme induction in a microbial culture is a response to an appropriate signal in the environment. Available information indicates that it basically follows the well-known growth patterns of isolated microbial cultures initially exposed to fresh, suitable substrates under favorable environmental conditions, i.e., an initial "lag phase", followed successively by a growth phase, a stationary phase, and finally a "decline" or death phase. Although this series of responses is over-simplified the microbial degradation of many pesticides appears to be consistent with this basic sequence of events. This series of events has been observed with numerous pesticides in soil in the laboratory (Audus, 1949, 1951, 1960; Kaufman, 1964; Kaufman and Blake, 1973; Kaufman and Kearney, 1965) and in soil under both glasshouse (Kaufman, unpublished data) and field conditions (Aly and Faust, 1964; Fryer and Kirkland, 1970; Newman and Thomas, 1949; Newman, Thomas and Walker, 1952).

The significance of this phenomenon under actual field conditions appears to depend upon several factors: The pesticide's mode of action, the rate and frequency of application, the time elapsed between applications, the cropping system, the survival of an enriched population, the complexity of the metabolic reaction involved, and the physical-chemical behavior of the pesticide in soil. Certain of these factors, of course, are quite closely interrelated and subject to multiple interactions. The importance of this phenomenon in soil would be of minor consequence to the efficacy of pesticides which are primarily active as foliar or aerial contact chemicals. Pesticides which are primarily active in soil or through root absorption would have limited effectiveness. When considering the effect of pesticides on soil microbial activity, however, one can not ignore or omit the effect of residues of foliar applied pesticides which ultimately enter the soil environment by virtue of either having missed their intended application site, or were washed off the plant with rain water, or entered with the dead and decaying crop residue.

CURRENT PROBLEMS

Under certain conditions when repeated applications of the same chemical are made to the same site, microbial populations can develop to the point that succeeding applications will have progressively shorter residual times in soil. Continued application of the same pesticide to such soils will ultimately lead to a reduced or complete loss of that pesticide's efficacy in that soil. Such soils are currently referred to as "problem" soils, that is, soil in which the chemical applied failed to control the target pest (Kaufman and Edwards, 1983a). Recent reports have indicated that several soil-applied chemicals may be having problems of this nature in U.S. Midwestern corn-cropped soils and elsewhere. Rahman et al. (1979) and Obrigawitch et al. (1982a,b) reported that the herbicidal efficacy of Eradicane (EPTC (S-ethyl dipropylthiocarbamate) + antidote (N,N-diallyl-2,2-dichloroacetamide)) was reduced in certain soils which had received successive annual applications of the herbicide. Preliminary investigations suggested that the reduced activity of Eradicane was due to a more rapid microbial breakdown. Similar results were obtained by others (Gunsolus and Fawcett, 1982; Obrigawitch et al., 1982b; Schuman and Harvey, 1982; Wilson et al., 1982). Subsequent investigations (Edwards and Kaufman, 1982, 1983; Kaufman and Edwards, 1983a,b) have conclusively demonstrated that the accelerated loss of Eradicane efficacy in problem soils is due to an enhanced rate of EPTC degradation by soil microorganisms (Fig. 1). Soil sterilization by either autoclaving or gamma irradiation drastically reduces the rapid rate of EPTC degradation.

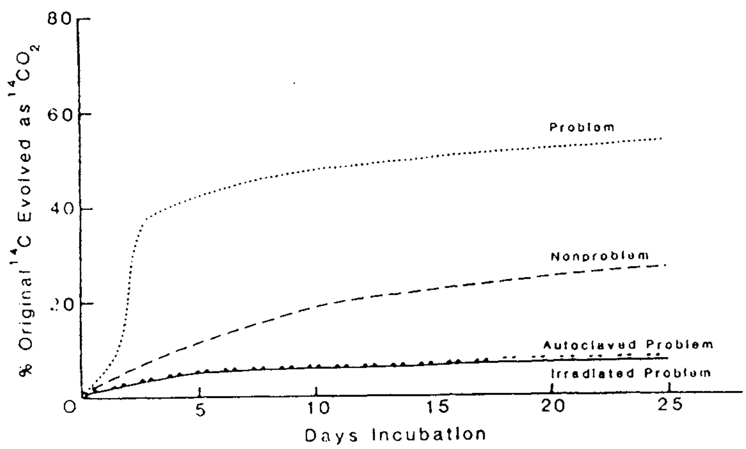

Figure 1. Degradation of ^{14}C-ethyl-EPTC in Eradicane problem (sterile and nonsterile) and nonproblem soils.

The insecticide carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate) has also experienced similar problems, Felsot, Maddox, and Bruce (1981). Felsot et al. (1982), and Gorder, Dahm, and Tollefson (1982) assessed the persistence of carbofuran in several soils with and without histories of carbofuran use. The particular history soils selected for their investigations were noted as "problem"; soils with a poor performance of carbofuran. Their results suggested that an enhanced microbial degradation occurred in the problem soils. Two other studies, however, were unable to define relationships between history of insecticide use and carbofuran persistence (Ahmad, Walgenbach, and Sutter, 1979; Gorder, Tollefson, and Dahm, 1980). Kaufman and Edwards (1983a) and Kaufman et al. (1981) examined the degradation of ^{14}C-carbonyl-carbofuran in numerous pairs of problem and nonproblem (an identical soil type with an identical cropping history, but without any known use of any chemical) soils. Degradation of carbofuran with evolution of $^{14}CO_2$ from the carbonyl position occurred far more rapidly in carbofuran problem soils than in nonproblem soils (Fig. 2). The inhibition of carbofuran degradation by addition of antibiotics added to the soil or by soil sterilization (autoclaving or gamma irradiation) confirmed the importance of an active microbial population in the degradation of these materials.

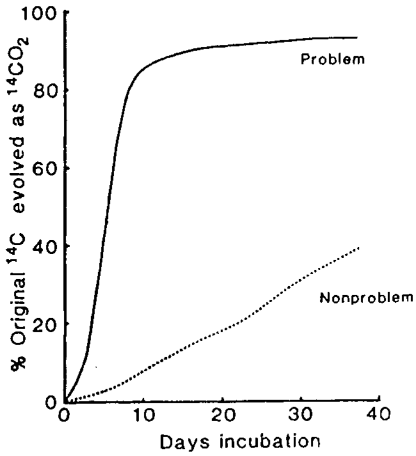

Figure 2. The degradation of ^{14}C-carbofuran in carbofuran problem and nonproblem soils.

Table 1. Comparative Degradation of ^{14}C-carbonyl Diphenamid and Carbofuran in Diphenamid History Soils

Diphenamid history	%^{14}C evolved as $^{14}CO_2$ in 5 days from soil treated with: Diphenamid	Carbofuran
1 year (3.5 lb a.i./A)	9.9	8.8
12 years (6.5 lb a.i./A)	56.2	17.1
Nonhistory	1.4	4.8

In similar experiments (Katan and Kaufman, unpublished results, 1983) we recently investigated the degradation and persistence of diphenamid (N,N-dimethyl-2,2-diphenylacetamide) in soils which had varying years of continuous diphenamid application (Table 1). The rate of $^{14}CO_2$ from $^{14}CO_2$ evolution from ^{14}C-carbonyl-diphenamid treated soils having either one or 12 previous yearly diphenamid applications was 7 to 40 times more rapid, respectively, than that from a soil which had been treated before. Again, soil sterilization by either gamma irradiation or autoclaving prevented diphenamid degradation. The ability of microoorganisms to degrade diphenamid in vitro has been demonstrated (Kesner and Ries, 1968). Our results indicate that soil microorganisms play a significant role in diphenamid degradation and that repeated, yearly application of diphenamid can and will lead to the establishment of diphenamid problem soils. It was also interesting that the rate of carbofuran degradation was similarly affected by the diphenamid history soils, even though there was no previous application of carbofuran to these soils.

The repeated application of other pesticides to the same soil may also contribute to their inability to control target pests. Although it has been reported that the nematicide ethoprop (O-ethyl S,S-dipropylphosphorodithioate) suppresses nematode populations and increases yields of many crops (Johnson, 1974; Johnson and Chalfont, 1973; Johnson and Harmon, 1974; Johnson, Harmon, and Chalfont, 1974) in monocrop (one crop per year) systems, the studies of Rohde et al.(1980) demonstrated that ethoprop would not give adequate control of Meloidogyne incognita in intensive multicrop systems. When used in multicropped systems, concentrations of ethoprop in the 0-15 cm soil layer were near 6 μg/g at application and decreased to 1 μg/g over a 30-day period during the first cropping period. Subsequent applications decreased to 1 μg/g within 5 days after application, and thus, were not effective in controlling M. incognita in either of the two subsequent crops. Entwistle (1983) noted that the fungicide iprodione (3-(3,5-dichlorophenyl)-N-(1-methylethyl)-2,4-dioxo-1-imidazolidinecarboxamide) failed to control white rot of onions in field where it had tested on land with no history of previous usage of that material.

These results indicate that a loss of efficacy of certain soil-applied pesticides may result through the development of microbial populations capable of rapidly degrading the pesticide. It is also evident that a wide variety of chemicals, that is, insecticides, herbicides, fungicides, and nematicides, may be similarly affected.

Other factors may also contribute to the development of problem soils. Soil microbial populations are known to be affected by soil organic matter content, pH, moisture content, aeration, and temperature, as well as other soil chemical-physical parameters. These soil characteristics are also known to affect the behavior of pesticides in soil. Thus, it can be questioned whether or not the effect of any one of these soil parameters on pesticide degradation occurs through its influence on the level of microbial activity, the pesticide itself, or both. Obrigawitch et al. (1982b) observed that EPTC degradation in Eradicane history soils was dependent on soil moisture from below 3% and independent of moisture above 3%, and also degraded more rapidly at 15^{o} and 25^{o}C than at 5^{o}C. These factors, however, are also known to influence the adsorption-desorption characteristics of EPTC and thus the availability of EPTC to soil microorganisms for biodegradation. Similar effects have been noted for many other pesticide-microbe interactions.

FUTURE IMPLICATIONS

As indicated in preceding discussions, enzyme induction in a microbial culture is in response to an appropriate signal in the environment. Adaptation to a given substrate generally involves adaptation to all intermediates in the breakdown chain, but it may also result in an increased ability to degrade homologous molecules as well. The ability of microorganisms to degrade other structurally related molecules after adaptation to an original structure is a well-known microbiological principle. It is also recognized from the work of Jacob and Monod (1961) that enzyme inducers are not necessarily substrates for the enzymes induced and that some inducers may also act as inhibitors of the enzymes induced. These interactions can be illustrated by the information presented in Table 2. Consider that chemicals A-E are homologous chemical structures which may interact with a soil microbial population. Chemical A may

Table 2. Microbe/Chemical Interactions at the Enzyme Level

Chemical	Chemical behavior[a] Inducer	Substrate	Inhibitor
A	x	x	o
B	o	x	o
C	o	o	x
D	x	o	x
E	x	o	o

[a]x = positive reactions; o = no reaction.

induce an enzyme for which it is a substrate. Chemical B may not induce the same enzyme, but it can be a substrate for the enzyme induced by chemical A. Chemical C may not act as either an inducer or a substrate, but it can inhibit the action of the enzyme induced by chemical A, D, or E. Chemical D may act as an inducer and an inhibitor but may not be a substrate. Finally, chemical E may be an inducer of an enzyme which acts on A, B, C, or D (or all), even though it does not serve as either a substrate or an inhibitor. All of these interactions have been demonstrated with soil microorganisms exposed to a series of homologous pesticides.

Audus (1951) was the first to demonstrate certain of these phenomena when he observed that microbial populations adapted to degradation of 2,4-D ((2,4-dichlorophenoxy) acetic acid) could also degrade MCPA ([(4-chloro-*o*-tolyl)oxy]acetic acid) and vice versa. Others (Kirkland and Fryer, 1972; Tortensson, Stark, and Goransson, 1975) have subsequently reported similar observations. Kaufman and Blake (1973) isolated several microorganisms which were each able to degrade rapidly a wide range of acetamide, acylanilide, carbamate, toluidine, and urea-based pesticides. Thus, it is apparent that there can be a cross adaptation by soil microorganisms to similarly structured molecules. In most cases, however, the rates of degradation of the alternate molecules are slower than the rates of degradation by microorganisms directly adapted to that molecule. Two alternative explanations have been suggested (Audus, 1960). Either each molecule induces its own enrichment flora, each with the capacity of degrading other molecules, but with different efficiencies, or they each encourage the growth of the same organisms by respectively inducing their own specific enzymes which incidentally possess the power to degrade other similar molecules, though less efficiently.

This phenomenon can be further complicated by the fact that some agricultural chemicals can induce microbial enzymes which are active in degrading other pesticides even though the inducer itself is not a substrate. Engelhardt, Wallnofer, and Plapp (1971, 1973) reported that the phenylurea herbicide monuron (3-(*p*-chlorophenyl)-1,1-dimethylurea) could induce an acylamidase in the bacterium *Bacillus sphaericus* which was capable of hydrolyzing the herbicide linuron (3-(3,4-dichlorophenyl)-1-methoxy-

1-methylurea) although monuron itself was not a substrate. The phenylurea herbicide chlorbormuron (3-(4-bromo-3-chlorophenyl)-1-methoxy-1-methylurea), the acylanilide herbicides monalide (4-chloro-1,1-dimethylvaleranilide) and propanil (3',4'-dichloropropionanilide) and fungicides 2-chlorobenzanilide and 2,5-dimethylfuran-3-carboxanilide, and the phenylcarbamate herbicide propham (isopropyl carbanilate) were also capable of inducing an acylamidase in B. spaericus which hydrolyzed a wide variety of phenylamide herbicides and fungicides. The specific activity of the various enzyme extracts, however, was considerably lower than that obtained from linuron-induced cells. Similarly, Blake and Kaufman (1975) noted that although both p-chlorophenyl methylcarbamate (PPG-124, or PCMC) and propanil induced acylamidase-type enzymes in the soil fungus Fusarium oxysporum that were capable of hydrolyzing a wide variety of acylanilides, PCMC itself was not a substrate of the enzymes induced. Further, PCMC also acted as a competitive inhibitor of the activity of the enzyme which it induced. These observations substantiate the potentially unique interactions that soil microorganisms may have with a series of chemically related pesticides.

In other investigations (Kaufman, unpublished results) the microbial degradation of initial applications of ^{14}C-carbonyl-labeled CDAA (N,N-diallyl-2-chloroacetamide), linuron, oxythioquinox (cyclic S,S-(6-methyl-2,3-quinoxalinediyl) dithocarbonate), Mobam (benzo[b]thien-4-yl methylcarbamate), propachlor (2-chloro-N-isopropylacetanilide), propanil, and ^{14}C-1-isobutyl-labeled butylate (S-ethyl diisobutylthiocarbamate) was examined in Eradicane and carbofuran problem and nonproblem soils (Table 3). An increased rate of $^{14}CO_2$ was noted from most, but not all, structurally related pesticides placed in these problem soils. Similar results were obtained with carbofuran (Table 1), CDAA, and other related chemicals in diphenamid problem soils (Katan and Kaufman, unpublished results, 1983). Extraction and quantitative and qualitative characterization of the ^{14}C-product distribution in these various soils further confirmed a more rapid degradation of many of these compounds in the problem soils. Similar observations were recently reported by Obrigawitch, Martin, and Roeth (1983). They observed that the degradation of both butylate and vernolate (S-propyl dipropylthiocarbamate) occurred more rapidly in soils with a prior history of EPTC applications. The rate of butylate degradation also continued to increase with each successive butylate application to the EPTC-history soil.

Harris et al. (1984) reported that degradation rates of carbofuran were greatly increased by a single 10 ppm carbofuran pretreatment of a sandy loam with no previous history of pesticide use. Increased degradation rates for a variety of aryl- and oximino-methyl carbamates were also observed in carbofuran-activated soil but this soil did not affect the degradation rates of the thiocarbamate, butylate, the phenylcarbamate, chlorpropham, or the organophosphorus insecticide, phorate.

The ultimate effect of such interactions may not be immediately obvious from the vantage point of field performance. Other environmental factors or cultural practices may preclude immediate development or recognition of potential "multiproblem" soils. It should be noted here, however, that the author is currently researching in the laboratory several "multiproblem" field soils gathered from widely different locations within the United States in which representatives of two or more chemical classes (thiocarbamate,

Table 3. Comparative Degradation of ^{14}C-pesticides in Carbofuran and Eradicane Problem and Nonproblem Soils

Chemical	Problem soil type	Original ^{14}C evolved as $^{14}CO_2$ from soil: Problem	Original ^{14}C evolved as $^{14}CO_2$ from soil: Nonproblem
Carbofuran	Carbofuran	91.2	28.2
CDAA	Carbofuran	53.3	21.9
	Eradicane	31.7	20.2
Linuron	Carbofuran	23.0	15.2
	Eradicane	18.5	18.7
Mobam	Carbofuran	48.5	9.1
	Eradicane	77.0	72.5
Oxythioquinone	Carbofuran	5.1	6.1
	Eradicane	2.5	8.5
Propachlor	Carbofuran	15.2	6.7
	Eradicane	41.2	26.1
Propanil	Carbofuran	65.3	44.5
	Eradicane	84.2	49.2
EPTC	Eradicane	65.5	37.5
Butylate	Eradicane	29.8	19.2

methylcarbamate, acid amide, or acylanilide; methylcarbamate, organophosphate) of pesticides (insecticides and herbicides) are no longer effective. These results have led us to conclude that a potentially serious problem could be developing in certain agricultural areas.

CONTROLLED BIODEGRATATION OF PESTICIDES IN SOIL

Persistent pesticides are necessary for adequate pest control in crops, but their toxicity to, or potential for contaminating, succeeding crops may restrict their use. In contrast, the rapid loss of biodegradable pesticides frequently limits their usefulness and effectiveness in some cropping systems, or requires successive applications in a single season, thereby accentuating the development of problem soils. Developing suitable methods for: (a) Regulating the rate of pesticide biodegradation in soil; (b) preventing the development of problem soils; and (c) controlling or eradicating microbial populations in problem soils once they have developed is essential for maintenance of adequate pest control with soil-applied chemicals.

At present, there is essentially no information available on how, once a problem field has developed, it can be converted back to a nonproblem field for the chemical involved. Although soil sterilization might be effective in high-cash-return crops, it would not be economically feasible for most field crop soils. Thus, new technology is needed on how to reclaim problem fields.

Rotation of chemical (Anonymous, 1981 a,b) has shown some degree of success in preventing problem field development, but the long range effectiveness of this preventive measure is not known. Crop rotation has been tentatively examined but is only successful when the pesticide complex used on one crop is suitably different from that used on the rotational crop or the pest is relatively specific for one crop and its numbers are rapidly depleted in absence of the crop. Rahman et al. (1979) noted that while Eradicane failed to give satisfactory weed control in plots where it had been used previously, it provided excellent weed control on plots which had previously received alachlor (2-chloro-2',6'-diethyl-N-(methoxymethyl)acetanilide) treatments. Similar observations has been made by others. In our own laboratory investigations (Kaufman, Katan, and Edwards, unpublished data) we have observed that the microbial degradation of carbofuran, diphenamid, CDAA, and EPTC are considerably slower in soils previously treated with alachlor, metholachlor (2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide), or both. Thus, there may be some benefit in planning pesticide applications which capitalize on this apparent inhibitory effect. The mechanism of this interaction is not presently known.

Several microbe or enzyme inhibitors which appear to be effective for extending soil persistence of pesticides have been identified for extending soil persistence of pesticides have been identified (Capper, 1982; Cohn and Monod, 1953; Dexter, 1979; Doersch and Harvey, 1979; Kaufman, 1977; Kaufman, Blake, and Miller, 1971; Kaufman and Edwards, 1983a; Kaufman et al., 1970; Martin and Roeth, 1979; Obrigawitch et al., 1982a; Roslycky, 1980). The potential use and action of these materials has been discussed elsewhere (Kaufman and Edwards, 1983a). The successful combination of such inhibitors into a pesticide formulation would be dependent upon several factors: (1) The chemical and physical compatibility of the inhibitor with all the other formulation ingredients; (2) the relative mobility in soil of the inhibitor and the pesticide; (3) the relative toxicity of the inhibitor to the soil microbes as well as the crop plants on which the formulated pesticide is to be used; (4) the environmental fate and behavior of the inhibitor itself; and (5) the mechanism by which the inhibitor works.

Factors 1, 3, and 4 are important to the introduction and use of any new chemical into the environment. Factor 2 is critical since the inhibitor must remain in the immediate vicinity of the pesticide in order to be effective. The mechanism by which the inhibitor works is also important in that it should probably not be an inducer (Chemical D, Table 2) of the same enzyme it is serving to inhibit, nor should it serve to inhibit one degradative mechanism in favor of another more rapid mechanism. Such inhibitors could ultimately serve to increase the severity of the problem rather than control it. Thus, considerable care must be taken in the selection and development of an effective inhibitor.

SUMMARY

Recent investigations have demonstrated that the unusually rapid loss of pesticide efficacy of several major pesticides and others is due to their exceptionally rapid biodegradation by soil microorganisms.

Further investigations indicate that this phenomenon can rapidly spread to other structurally related pesticides also used in the same soils, thus eliminating a significant segment of our presicide arsenal from effective use as soil-applied materials. The practical significance of these observations is of consiaerable importance to agriculture. Successful pest control is essential if we are to maintain the high level of crop production needed to sustain our food and fiber demands. Successful pest control depends upon maximum performance of our pest control chemicals. The deliberate combination of certain pesticides, or addition of microbial or enzyme inhibitors to pesticide formulations, or the rotation of certain crops and pesticides shows considerable promise for the purpose of controlled persistence of biodegradable pesticides. In the absence of adequate pest control measures, crop production will be seriously reduced.

Finally, in this and several previous publications; soils in which a loss of pesticide efficacy has been observed have been referred to as "problem" soils. This is perhaps unfortunate in that it provides an unnecessarily negative connotation to a natural phenomenon. While it is indeed a problem for the farmer who is currently experiencing a loss of pest control in his fields, it should be remembered that this is nature working at an optimum level of efficiency. If we deem it desirable to have minimal, or no pesticide resiaue remaining in a soil at the end of each crop's growing season, then this phenomenon should be viewed in a more positive light and the challenge should be to develop more efficient control measures with these chemicals in such environments which so effectively minimize their residues.

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Soil Insecticides, Microbes, and Soils

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The problem in predicting and understanding insecticide failures in the field are not new; a few of us have had first hand experience with corn rootworm control and aldrin, aldrin-parathion combinations, diazinon, BUX, dasanit, Furadan and Amaze. Common to all these situations were the first postulated reasons for failure of the chemicals: too much rain, dry soil conditions, cold soils, warm soils, eroded soils, higher rootworm populations, late rootworm hatch, poor formulations, and improper calibration and application techniques. No one can deny that these factors can have an impact on soil insecticide performance, however, none of the above cited insecticides were removed from the market or had their marketing emphasis changed because of weather related factors. It is interesting to note that few comments are made on the impact of good weather conditions on insecticide performance. When the same compounds are used in dryland and irrigated corn, from the western ton substantially higher rainfall areas of the eastern cornbelt; annual and local weather fluctations seem less important as major criteria in performance.

Aldrin resistance has been documented with the western and a few northern corn rootworm populations. Enhanced microbiological degradation has been shown with diazinon in other than midwestern soils, with Furadan from across the cornbelt and in a few with Amaze. The time interval necessary for Amaze to be dropped from the market was much shorter than for Furadan. This curosity indicates a preconditioning of the soils prior to Amaze application. Field failure patterns of these insecticides were not adequately predicted in university tests except for Amaze, which failed in the University of Wisconsin trials in 1982. Aldrin, parathion, diazinon, BUX, dasanit and Furadan showed initial failures in the western cornbelt whereas Amaze had significant first failures in the eastern cornbelt. The risk of performance uncertainity by corn rootworm insecticides is a major concern wtih registered compounds and certainly raises the anxiety level for those companies developing experimental soil insecticides.

Root ratings have not been adequate indicators of yield or future performance of insecticides, especially those affected by enhanced biodegradation. Plots need to be established on areas with four annual applications of a given insecticide as the primary criterion and subsequently treated with at least two applications to establish cross-reactivity of soils.

The performance parameters of the registered insecticides in South Dakota are listed in Table 1. The comparative performance among the treatments is relatively steady with minor deviations between years.

Table 1
1980-1984
Corn Rootworm Insecticide Evaluations

Insecticide	1980 %[1] R.P.	1981 %[1] R.P.	1982 %[1] R.P.	1983 %[1] R.P.	1984 %[1] R.P.	1980-84 Avg.
Counter 15G	69	84	84	77	77	78
Thimet 20G	66	80	81	62	68	71
Furadan 15G	58	71	68	58	57	62
Dyfonate 20G	60	74	72	68	62	67
Mocap 15G	60	76	67	66	56	65
Lorsban 15G	55	64	70	64	63	63
Broot 15G	58	72	73	60	59	64

[1] % R.P. - Percent Root Protection = % 100 - $\frac{\text{(root rating of treatment) -1}}{\text{root rating of UTC}}$

The disappearance of the major registered insecticides are shown in Table 2 in soil that had no previous insecticidal history.

Table 2

Days Post App.	PPM Residue, Dry Soil Weight ± Standard Deviation (1.1 kg. AI/ha)				
	Carbofuran	Fonofos	Chlorpyrifos	Phorate	Terbufos
0	6.0 ± 0.31	5.8 ± 0.4	6.0 ± 0.3	6.3 ± 0.08	6.0 ± 0.4
14	5.4 ± 0.5	5.0 ± 0.5	4.0 ± 0.6	3.0 ± 0.12	1.5 ± 0.3
28	5.0 ± 0.5	4.0 ± 0.1	3.0 ± 0.4	2.0 ± 0.2	1.0 ± 0.12
42	5.0 ± 0.3	3.0 ± 0.2	2.5 ± 0.2	0.8 ± 0.05	0.4 ± 0.06
49	4.0 ± 0.4	2.0 ± 0.02	2.4 ± 0.1	0.4 ± 0.02	0.1 ± 0.02
56	2.3 ± 09.1	2.5 ± 0.4	2.0 ± 0.4	0.1 ± 0.01	0.03 ± 0.005
70	1.9 ± 0.6	1.4 ± 0.1	1.4 ± 0.1	0.02 ± 0.003	0.015 ± 0.001

Performance of soil insecticides also has an additional aspect, that of toxicity of the insecticides to the target insect. The data in Table 3 shows this relationship between the different insecticides and places the compounds in an inverse relationship to their longevity in the soil.

Table 3.

Larval Topicals

Insecticide		1977 Mean Larval Topicals LD_{50} ug/g insect tissue
Counter		0.55
Amaze		0.85
Lorsban		1.06
Thimet		1.59
Dyfonate		4.09
Furadan	Range 6.3-33.4	16.79

We have carried out pesticide degradation studies both in the laboratory and in the field, chiefly with the carbamate and phosphate insecticides. In addition to determining the rate of degradation on soils with and without a history of prior pesticide use, the microbiolgoical characteristics of the soils were examined. There is evidence for cross-reactivity of some soils between insecticides; application of one carbamate has led to the rapid degradation of a different carbamate sooner than in a control soil. A microbial taxonomic study is currently underway to determine the identity of some of the organisms responsible for the degradation of pesticides in soil. Perhaps the most striking observation has been the changes in microbial population diversity in soils with a pesticide use history. One problem soil, for example, contained relatively fewer species of bacteria than controls and was dominated by Gramnegative rods and actinomycetes.

Table 4

Days Post Application	Furadan (pppm) Furadan History	Furadan (pppm) Furadan Non-History	Lance (ppm) Furadan History	Lance (ppm) Furadan Non-History
0	4.85	4.25	4.29	4.45
7	3.68	4.89	5.58	3.18
14	3.41	5.33	4.24	2.14
21	1.77	3.95	4.79	1.24
28	0.50	1.64	3.19	3.39
35	ND	ND	1.88	1.23
48			1.52	2.64
70			2.97	2.62
84			0.47	2.04
		Second Application		
0	4.61	4.95	6.23	8.01
7	0.68	0.32	0.60	5.44
14	0.21	0.08	0.30	2.86
21	ND	ND	0.22	4.0
28			0.17	3.16
42			0.15	2.77
56			ND	1.98

	Broot Residues (ppm) Furadan Active Soil	Broot Residues (ppm) Lance Active Soil
0	4.18	4.92
7	4.10	2.55
14	4.42	2.28
21	4.41	0.80
28	4.40	0.80
35	3.65	0.52

HERBICIDES AND INSECTICIDES IN SOILS,

REDUCED PERSISTENCE, CARRYOVER AND INTERACTION

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Some soil applied herbicides dissipate faster with repeated annual applications and these results can be observed with herbicides used to control wild proso millet (Panicum miliaceum L.). This is a difficult to control annual grassy weed because germination occurs over an extended period resulting in seedling establishment after herbicides have dissipated. Two studies will be discussed that relate to repeated annual applications of Eradicane (EPTC+) and Eradicane Extra ($EPTC^{+}$ + Extender).

Some herbicides do not completely dissipate in the year of application and therefore persist into the next year and may affect susceptible crops in the following year. It is common knowledge that high rates of AAtrex (Atrazine) will carryover to susceptible crops in the following years on soils with high pH in west central Minnesota. It is also known that rates of Treflan (Trifluralin) applied above the recommended rate caused by overlapping, mis-calibration, etc. will also affect corn during the following year. Two studies will be discussed that relate to persistence of Banvel (dicamba) and Glean (chlorsulfuron) the year after application and the affect on succeeding crops.

One study was initiated on the John Dosdall farm near Morris, Minnesota, in 1981 to determine effectiveness of repeated applications of Eradicane and Eradicane Extra for control of wild proso millet in corn in a field that had 4 consecutive years of Eptam (EPTC) or Eradicane repeated use prior to this experiment. During the course of this experiment, Eradicane and Eradicane Extra were applied at 6 lb/A during each year of the study.

Evaluation of percent control of wild proso millet in 1983 (Tables 1 and 2) showed that control was reduced as the evaluation date was delayed, This is primarily due to an extended period of germination for wild proso millet. Percent control of wild proso millet is also dependent on the herbicide that was applied in 1983 and the previous use in 1981 and 1982 of that applied herbicide. Percent control of wild proso millet with Eradicane was reduced with repeated use in the previous 2 years. Percent control of wild proso millet with Eradicane Extra was also reduced with repeated use of Eradicane Extra in the previous 2 years.

Percent control of wild proso millet in 1982 and 1983 with Eradicane and Eradicane Extra with 1981 use of Eradicane, Eradicane Extra and a check are given in Table 3. The least effective sequence is an application of Eradicane Extra in 1981 followed by Eradicane in 1982 and 1983.

Table 1. 1983 percent control wild proso millet with Eradicane and with various years of repeated Eradicane use.

		Years of Eradicane History			
			1981		1981
				1982	1982
Herbicide	Evaluated	1983	1983	1983	1983
		- - - % Control WPM - - -			
Eradicane	6/26	72	66	50	45
Eradicane	8/15	20	18	0	6

Table 2. 1983 percent control wild proso millet with Eradicane Extra and with various years of repeated Eradicane Extra use.

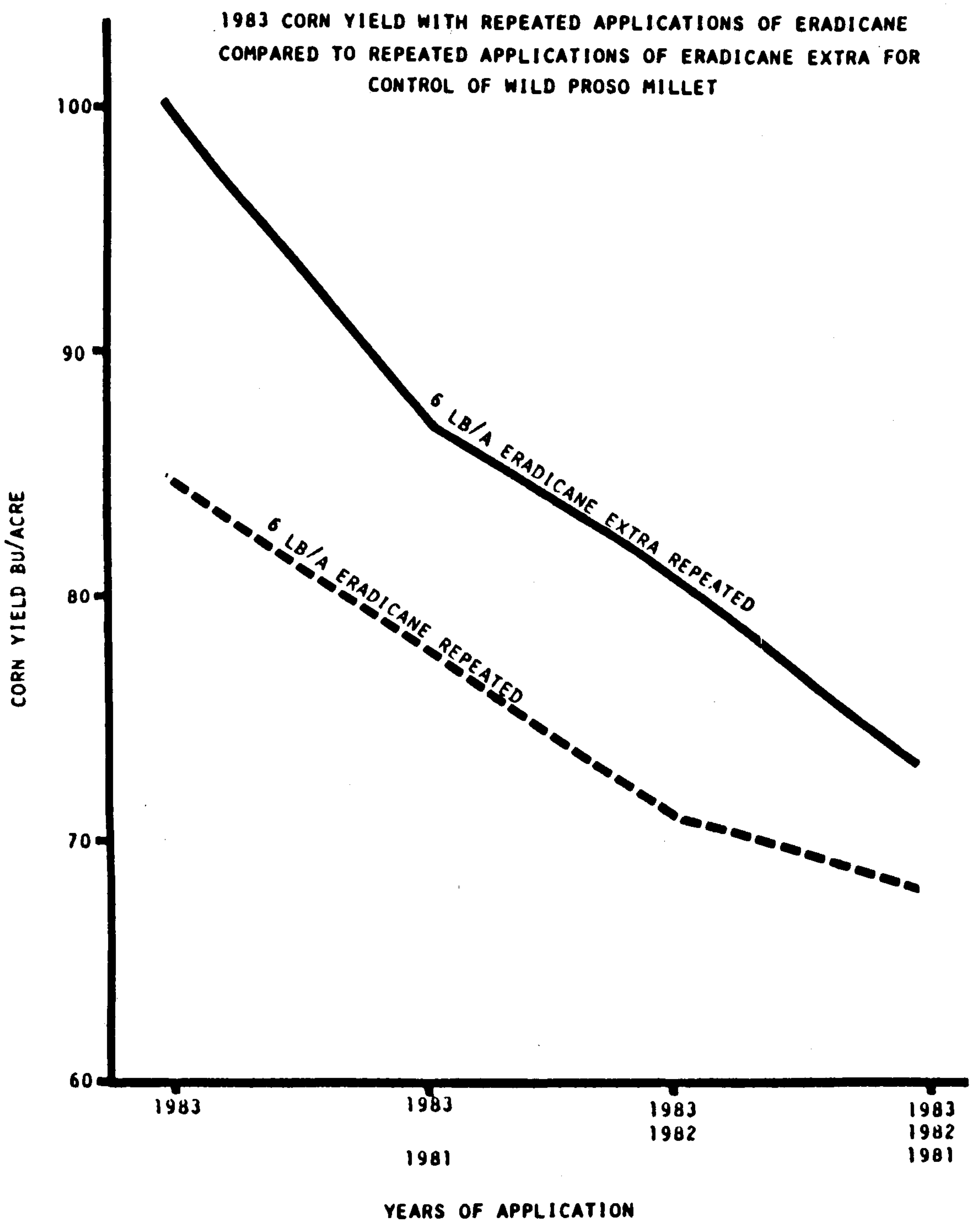
		Years of Eradicane Extra History			
			1981		1981
				1982	1982
Herbicide	Evaluated	1983	1983	1983	1983
		- - - % Control WPM - - -			
Eradicane Extra	6/26	82	60	65	33
Eradicane Extra	8/15	50	30	37	10

Table 3. Early evaluation of percent control wild proso millet with Eradicane and Eradicane Extra applications in 1982 and 1983 with various herbicide applications in 1981.

	Eradicane		Eradicane Extra	
1981 Treatments	1982	1983	1982	1983
	- - - - % Control WPM - - - -			
Check	73	72	77	82
Eradicane	53	66	70	80
Eradicane Extra	7	27	67	60

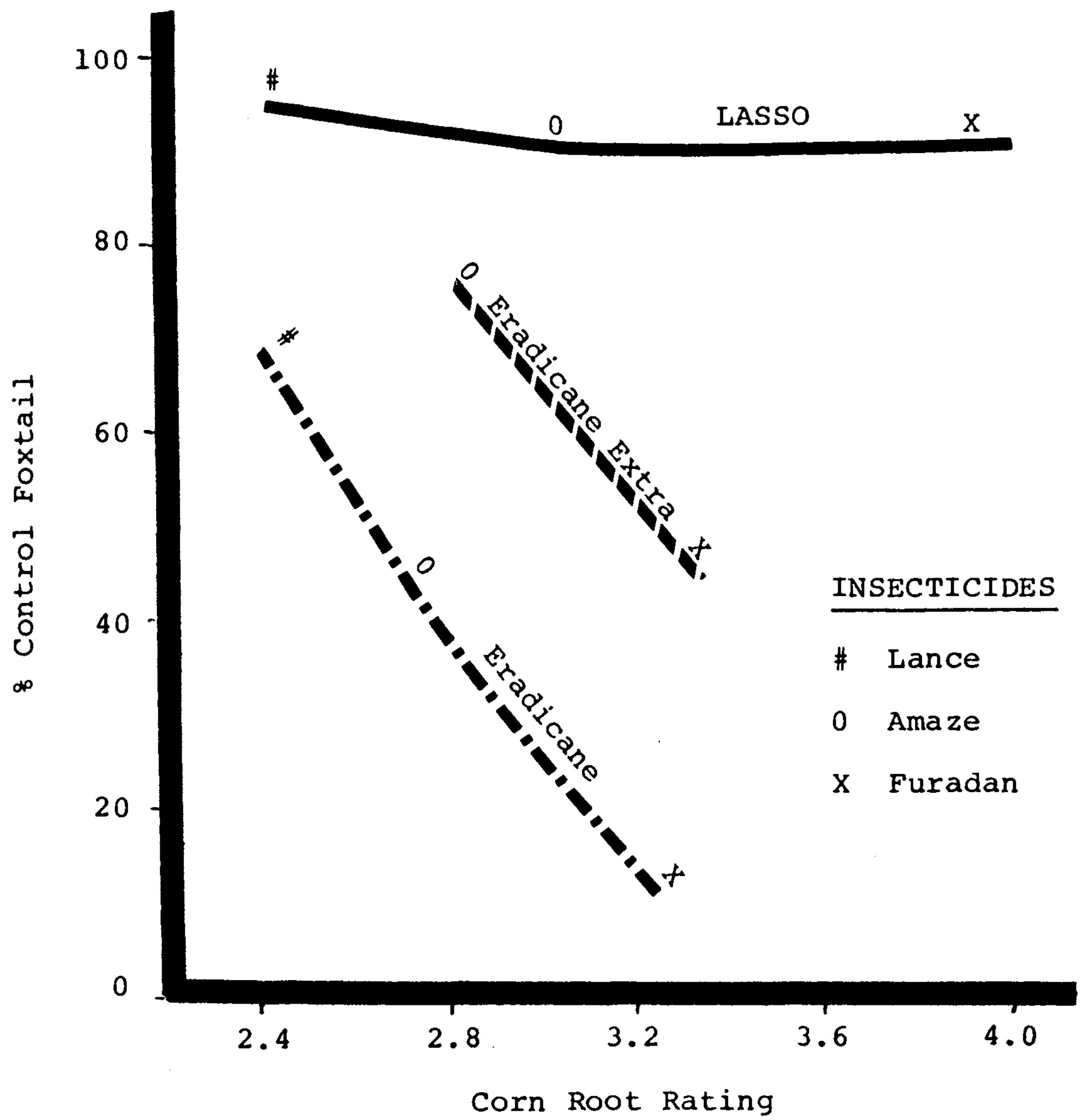
The following figure presents the corn yield with repeated applications of Eradicane compared with repeated applications of Eradicane Extra for control of wild proso millet. Eradicane Extra used for control of wild proso millet resulted in higher corn yields than Eradicane in all repeated use combinations. Use of both herbicides for control of wild proso millet resulted in reduced corn yields with increased repeated use of each of the herbicides.

The second study was designed to determine effectiveness of repeated annual applications of herbicide and insecticide combinations on weed control and control of corn rootworm larvae. This study was initiated in 1980 at the West Central Experiment Station at Morris, Minnesota, and repeated on the same plots in 1981 and 1982 in a field with a history of reduced effectiveness of carbofuran. Thirteen treatments in a randomized complete block design with 6 replications included check plots and combinations of a herbicide [Lasso (alachlor), Eradicane (EPTC + R-25788), or Eradicane Extra (EPTC + R-25788 + R-33865)] and an insecticide [Amaze (isofenphos), Furadan (carbofuran), Rotate (bendiocarb), or Lance (cloethocarb)]. Corn root damage ratings, percent corn lodging and corn yields were used all three


1983 CORN YIELD WITH REPEATED APPLICATIONS OF ERADICANE
COMPARED TO REPEATED APPLICATIONS OF ERADICANE EXTRA FOR
CONTROL OF WILD PROSO MILLET
CORN YIELD BU/ACRE
100
90
80
70
60
6 LB/A ERADICANE EXTRA REPEATED
6 LB/A ERADICANE REPEATED
1983
1983
1981
1983
1982
1983
1982
1981
YEARS OF APPLICATION

The third study was initiated in the fall of 1983 with Banvel (dicamba) rates of 0, 1, 2, and 4 lb/A applied on September 29, 1983, and October 27, 1983. Fall tillage treatments were fall chisel and fall plow. Treflan (trifluralin) at 1 lb/A was applied on May 24, 1984, and the soybean and sunflowers were planted on May 24. Corn was planted May 24 with Lasso applied at 3 lb/A preemergence. Handweeding was used to control any surviving weeds.

Figure 2. COMPARISON OF 1982 ROOT RATING AND 1982 % CONTROL FOXTAIL WITH TREATMENTS REPEATED 3 YEARS



Crop injury ratings and crop yields were used to evaluate the effects of Banvel residue on sunflowers, soybeans and corn (Tables 5, 6 and 7). Increased rates of fall applied Banvel gave increased soybean and sunflower injury and reduced soybean and sunflower yields. The two dates of injury ratings for soybeans are similar; however, for sunflowers the later date had a much higher injury rating suggesting that the sunflower root system was in contact with Banvel leached during a heavy precipitation period in June and early July. The highest rate of Banvel also reduced corn yields.

Table 5. The effect of rates of Banvel applied in fall 1983 on sunflower injury and yield at Morris, MN in 1984.

Banvel Rate	% Injury Ratings July 2	% Injury Ratings Aug. 18	Sunflower Yield
lb/A			lb/A
0	0	0	1820
1	4	1	1311
2	8	40	187
4	34	75	27
LSD_{05}	13	13	285

Table 6. The effect of rates of Banvel applied in fall 1983 on soybean injury and yield at Morris, MN in 1984.

Banvel Rate	% Injury Ratings July 2	% Injury Ratings Aug. 18	Soybean Yield
lb/A			bu/A
0	0	0	42
1	13	13	38
2	32	29	24
4	62	66	10
LSD_{05}	11	11	6

Table 7. The effect of rates of Banvel applied in fall 1983 on corn yield at Morris, MN in 1984.

Banvel Rate	Corn Yield
lb/A	bu/A
0	100
1	101
2	96
4	55
LSD_{05}	12

The fourth study was initiated in the spring of 1983 with .01, .03 and .06 lb/A rates of Glean (chlorsulfuron) applied to wheat as a postemergence herbicide. The area was fall plowed. On May 24, 1984, the area was sprayed with Lasso at 3 lb/A and incorporated twice with a cultivator. Evans soybeans were planted on May 24. Soybean injury ratings and soybean yield were used to evaluate the effects of Glean residue (Table 8). Increased rates of Glean delayed soybean maturity and decreased soybean yield.

Table 8. The effect of rates of Glean applied in spring 1983 on the maturity and yield of soybeans grown in 1984.

Glean Rate	Date Mature in September	Soybean Yield
lb/A		bu/A
Check	28	37
.01	28	47
.03	28	39
.06	32	32
LSD_{05}	2	8

Conclusions:

1) Later dates of evaluation of percent control of wild proso millet resulted in lower percent control ratings for both Eradicane and Eradicane Extra.

2) Percent control of wild proso millet was reduced and corn yield was reduced with increased use of both Eradicane and Eradicane Extra.

3) The least effective herbicide sequence was an application of Eradicane Extra in 1981 followed by an application of Eradicane in 1982 or 1983.

4) Under laboratory conditions, repeated use of Eradicane or Eradicane Extra reduced the percent of herbicide remaining in the soil sample after 4 and 7 days.

5) With repeated annual application, Amaze--a phosphate insecticide--and Lance--a carbamate insecticide--were the most effective in controlling corn rootworm larvae while Furadan and Rotate--both carbamate insecticides--were the least effective in control of corn rootworm larvae.

6) Eradicane and Eradicane Extra had reduced foxtail control with Furadan as the repeated insecticide compared to Lance or Amaze as the repeated insecticide. Less corn root damage was associated with hgher populations of foxtail weeds which may have diverted some larval feeding away from the corn roots.

7) Increased rates of Banvel applied in fall of 1983 resulted in increased crop injury and reduced soybean and sunflower yields.

8) Increased rates of Glean applied in spring of 1983 resulted in reduced soybean yields in 1984.

9) Grateful that pesticides do break down over time in our soils. We do not want to use any very persistent pesticides. The only problem is that some pesticides break down faster in some situations than would be expected and some pesticides persist longer in some situations than would be expected.

Application of Herbicides Through Irrigation Systems

Alex J. Ogg, Jr., C. C. Dowler,
A. R. Martin, A. H. Lange, and P. E. Heikes

In 1981, there were approximately 61 million acres of irrigated farmland in the United States. Of this total, about 21 million acres were irrigated with sprinkler systems and 40 million acres were irrigated with gravity systems. Sprinkler systems include center pivots, solid-set systems, hand moves, tow lines, wheel lines, traveller systems, and drip or trickle systems. Gravity systems include gated pipe, open-ditch/siphon tubes, underground systems with valves, and flooding from ditches.

Weeds are a serious problem on nearly all of these lands, and each year more than half of the 61 million acres are treated with herbicides. Traditionally, tractor-mounted and aircraft sprayers have been used to apply these herbicides. With the rising costs of fuel, labor, and equipment, however, interest in using irrigation systems to apply herbicides has increased. Because irrigation systems already are being used to apply fertilizers, very little additional equipment is needed to apply herbicides.

The application of herbicides in irrigation water is a relatively new development in weed control technology. Herbicides can be applied through irrigation systems provided that the herbicide is labeled for the crop and provided the label does not prohibit the application.

Advantages and Disadvantages of Applying Herbicides Through Irrigation Systems

Before deciding to use an irrigation system to apply herbicides, a farmer must carefully consider the advantages and disadvantages of this technology. The type of irrigation system—sprinkler versus gravity or center pivot versus solid set, for example—can affect the level of advantage or may change an advantage to a disadvantage.

Advantages

1. **Reduces the cost of herbicide application.** Applying herbicides through an irrigation system usually will save 50 percent or more in application costs.
2. **Reduces energy consumption.** Applying herbicides through irrigation systems can reduce energy consumption for herbicide application by 90 percent.
3. **May reduce labor costs.** Where center pivots are used, one man can supervise the treatment of two to four center pivots, thus reducing the labor needed to operate sprayers.
4. **Reduces equipment needs.** Applying herbicides through irrigation systems saves wear on tractors, sprayers, and in some cases soil incorporation equipment.
5. **Reduces soil compaction.** Because vehicle travel for spraying is eliminated, soil compaction is reduced.
6. **Reduces operator hazards.** Because the operator does not have to be in the field near the application, and because the herbicide is much more diluted in the irrigation water, actual exposure to the operator is reduced.
7. **Can reduce environmental hazards.** Because herbicides are more diluted in irrigation water than in conventional sprays, and because there is less drift from sprinklers than from sprayers, hazards to nontarget organisms are reduced. Also, herbicide residues on crop foliage are reduced.
8. **May increase herbicide activity.** In some cases, herbicides applied to the soil through irrigation systems are more active than when applied conventionally.
9. **Allows more uniform application.** Properly designed and operated center-pivot sprinkler systems can apply herbicides more uniformly than aircraft and as uniformly as ground sprayers.
10. **Insures timely applications of herbicides.** Herbicides can be applied at the proper time with the irrigation system, even if the field is too wet for tractors or when an aircraft is unavailable. Also, applying the herbicide with the irrigation water places the herbicide in the weed seed zone when conditions are ideal for herbicide action.
11. **Is compatible with reduced or no-till farming.** Because the irrigation water substitutes for mechanical incorporation, herbicides can be applied without soil tillage.
12. **May reduce crop phytotoxicity.** When herbicides are applied after crop emergence, there is less herbicide left on the crop from an irrigation application than from conventional sprays.

Disadvantages

1. **Requires greater management input.** Applying herbicides in irrigation water requires more management input to insure that personnel in charge of the treatment fully understand the calibration of injection equipment, the operation of the sprinkler system, and the operation of the check valves, anti-siphon valves, and other safety devices.
2. **May require some additional equipment.** If herbicides formulated as wettable powders are to be applied, the solution tank should be equipped with some form of agitation. Mechanical agitation is preferred. For maximum utilization, injection equipment and solution tank should be

one unit that can be easily transported from field to field. Antisiphon valves, check valves, and vacuum break valves must be installed in the sprinkler system to prevent contamination of the water source.

3. **Can increase environmental hazards.** If proper safety measures are not used, water sources or the irrigation drainage system can be contaminated with herbicide-treated water.
4. **Increases application time compared to aircraft application.** Applying herbicides through an irrigation system to large fields takes many hours compared to 1 or 2 hours for an aircraft. Because more time is needed for the application, environmental conditions such as wind or rain may interfere with applications made through irrigation systems.
5. **May require unnecessary irrigation.** Irrigation to apply herbicides may have to be made when water is not needed by the crop; for example, a preemergence application of an herbicide in irrigation water when the soil already is moist.

Factors Affecting the Application of Herbicides in Irrigation Water

Herbicide Properties

Solubility in water, adsorption onto organic matter and clay, and volatility affect the behavior of herbicides whether they are sprayed conventionally or applied in irrigation water.

Solubility

Different herbicides have different solubilities in water. The amount of an herbicide that dissolves in water is one of the factors that determines the depth that the herbicide will move into the soil. Generally, herbicides with high water solubilities are carried to a deeper depth than are those with low solubilities. Solubility also affects the amount of herbicide available for absorption from the soil solution by plants. The more herbicide there is in the soil solution the more toxic the herbicide will be to plants. Movement of herbicides in soil water often is the key to herbicide activity and crop selectivity.

Volatility

Volatility refers to the tendency of a liquid to become a gas and is dependent on the vapor pressure of the herbicide. The higher the vapor pressure the more likely the herbicide will become a gas. If an herbicide with a high vapor pressure is applied through a sprinkler irrigation system, an excessive amount of the herbicide may be lost as a gas before it reaches the soil. Furthermore, herbicides with high vapor pressure can evaporate more rapidly from moist soil surfaces by codistillation with water. The main importance of codistillation is the loss of herbicide activity, but occasionally crops may be injured by the vapors.

Adsorption

Adsorption is important to the activity and persistence of herbicides in soils. Herbicides are adsorbed on organic matter and clay in the soil. Because soils vary in amounts of organic matter and clay, and because herbicides vary in their tendency to be adsorbed, adsorption of herbicides varies among herbicides and soils.

Adsorption removes herbicides from the soil solution and reduces the activity of the herbicide. Soils low in organic matter and clay do not adsorb herbicides readily; therefore, herbicides are less selective to crops grown in these soils compared to crops grown in soils high in organic matter and clay. Some herbicides are adsorbed so tightly they are ineffective, whereas others are so weakly adsorbed that they move readily with the soil water and can be carried deeply into the soil, where they don't control weeds and sometimes can injure crops.

Generally, herbicides that are adsorbed on organic matter and clay are not readily decomposed and therefore are more persistent.

Movement in Soil

Herbicides applied with irrigation water are carried by the water into the soil. The extent of the movement of herbicides into the soil is a function of solubility, adsorption, and volatility. Estimating how far the herbicide will move into the soil during an irrigation is very important. Generally, a herbicide will move only a proportion of the distance that the water moves.

Most weed seeds germinate in the top 1 to 2 inches of soil. To control weeds most effectively, the herbicide must be concentrated in the zone of weed seed germination. If too much water is applied, the herbicide may be carried below the weed seed germination zone. If too little water is applied, the herbicide will remain near the soil surface, where it may be lost by volatilization or decomposition by ultra-violet light from the sun. Also, the soil dries rapidly near the surface and herbicides are less active in dry conditions.

To control perennial weeds, some herbicides have to be moved deeply into soil to kill rhizomes and roots.

Environmental Conditions

Climatic Conditions

Wind velocity is the most important environmental factor affecting the application of herbicides through sprinkler irrigation systems. Wind distorts the water application pattern, causing the herbicides to be distributed unevenly. Disruption of the sprinkler pattern is least with continuously moving systems and greatest with solid-set systems. Spacing sprinklers closer together, reducing the height or angle of water trajectory, increasing nozzle size, and reducing water pressure will help to minimize the effects of wind. Herbicides should not be applied if wind velocities exceed 12 to 15 miles per hour for continuously moving systems and about half that (6 to 7 miles per hour) for other systems.

Wind also increases evaporation and can increase the loss of volatile herbicides. If volatile herbicides are applied when temperatures are high and relative humidity is low, excessive amounts of water and herbicide may be lost to the atmosphere. Also, the vapors of some herbicides may injure crops and other nontarget organisms. High temperatures increase water loss and herbicides may not be moved to the desired depth in the soil.

Soil Factors

Soil properties must be considered in herbicide selection, regardless of the application method. Soil texture (sand, silt, and clay composition) and organic matter influence the performance of soil-applied herbicides and are especially important with herbicides used in irrigation water. Organic matter and to a lesser extent clay particles tend to bind herbicides, retarding their movement with water. Generally, herbicides are most mobile in sandy soils low in organic matter and require small amounts of water for adequate incorporation. Excessive irrigation water may move soluble herbicides below the zone of germinating weed seeds in sandy soils and weeds will not be controlled.

Soil moisture influences the penetration of irrigation water and therefore influences the movement of herbicides into the soil. On dry soil, water penetration and herbicide movement are less than with moist soil. Soil moisture is an especially important factor with volatile herbicides. The ability of wet soils to bind and hold these herbicides is greatly reduced and vapor losses increase. Volatile herbicides applied in irrigation water to wet soil may volatilize excessively and weeds will not be controlled.

Amount and Rate of Water Application

Determining the amount and rate of irrigation water to be applied is very important for the successful application of herbicides in irrigation water. Most soil-active herbicides can be applied effectively through sprinklers in 0.2 to 1.0 inch of water. Where furrow-irrigation is used, 1.5 to 2.0 inches of water is the practical minimum.

Where sprinkler systems are used the water should not be applied faster than it can be absorbed by the soil. If the application rate is too high, water will accumulate in low areas and herbicides will be applied unevenly.

Equipment

Herbicides applied through irrigation systems will be distributed only as uniformly as the irrigation water. An overapplication in one area could injure the crop, while an underapplication in another area may not control weeds. Before herbicides are applied through any irrigation system, the uniformity of water application throughout the system should be checked. The uniformity coefficient should be at least 80 percent and preferably 90 percent or more. Irrigators should consult irrigation authorities for instructions on how to determine the uniformity coefficient of their irrigation system. Also, worn or improperly operating nozzles, gaskets, valves, and other fittings should be replaced or repaired.

The basic system for delivering an herbicide into an irrigation system includes a chemical supply tank, an injection system, and the appropriate safety and anti-siphon devices that prevent potential contamination of the water source.

Design and Safety Features

The typical design for an herbicide delivery system with injector pump and proper safety devices powered by an internal combustion engine source is diagrammed in figure 1. Figure 2 is a diagram of a delivery system using electricity as the sole power source.

With an internal combustion engine as the power source, the chemical injection pump (figure 1a) can be belted to the drive shaft or an accessory pulley of the engine (figure 1b). This insures that the injection pump will stop when the motor on the irrigation pump stops. Constant monitoring of the belt and pulleys is necessary. Stretched and worn belts will result in variable injector pump outputs. With an electric-motor-driven irrigation pump, a separate ⅓ or ½ horsepower electric motor is needed to power the chemical injection pump. In the electric-driven system, the injector pump motor (figure 2a) must be interlocked into the electrical control panels (figure 2b) so that it stops when any section of the electrical system malfunctions.

The anti-siphon device that prevents contamination of the water source (figures 1c and 2c) is a **priority safety element** on irrigation systems used to apply agricultural chemicals. The

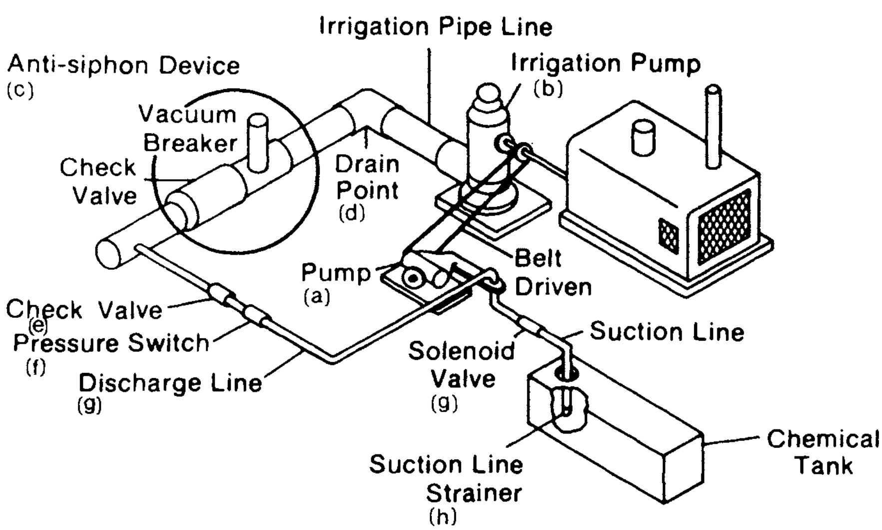


Figure 1. Herbicide delivery system with safety devices for irrigation powered by internal combustion engine. (Figure by P. E. Fischbach, University of Nebraska, modified by E. D. Threadgill, University of Georgia.)

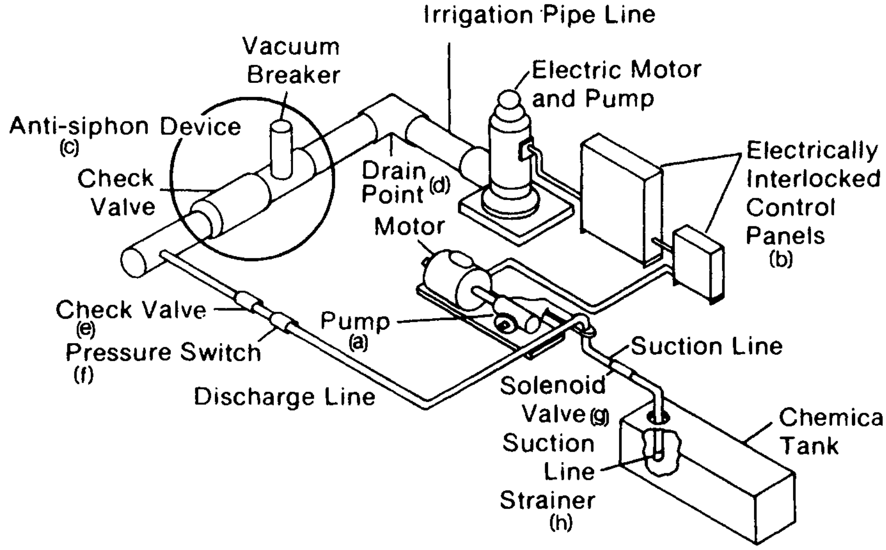


Figure 2. Herbicide delivery system with safety devices for irrigation powered by electricity. (Figure by P. E. Fischbach, University of Nebraska, modified by E. D. Threadgill, University of Georgia.)

device consists of a check valve and a vacuum breaker. These valves keep the water or a mixture of water and chemical from draining or siphoning back into the irrigation well or other water source. Both of these valves are located between the irrigation discharge pump and the point where the chemical is injected into the irrigation pipeline. In addition, a drain point (figures 1d and 2d) is located between the anti-siphon device and the irrigation well or water source as an additional safety factor.

A check valve in the chemical injection discharge line (figures 1e and 2e) is necessary to stop the flow of water from the irrigation system into the chemical supply tank. If this check valve is omitted and the injection pump stops, irrigation water could flow back through the chemical line into the chemical supply tank, overflowing the tank and causing a spill around the irrigation well or water source. The chemical could eventually seep down into the ground water.

A small, normally closed solenoid valve (figures 1g and 2g) located in the suction line between the chemical supply tank and the injection pump is desirable for chemical injection systems. The automatic solenoid valve is electrically interlocked with the electrical source or the engine that drives the injection pump. This feature provides a positive shut-off on the chemical injection line. Therefore, neither the chemical nor the irrigation water can flow in either direction if the chemical pump stops. Do not place the solenoid valve on the discharge side of the injection pump. Under certain situations, excessive pressure buildup caused by the injector pump can create a hazardous condition.

A pressure switch located in the chemical discharge line between the check valve and the injector pump (figures 1f and 2f) is desirable for completely automated control. The switch is electrically interlocked with the safety panel on the irrigation system. The switch will provide automatic shutdown of the entire irrigation system and the injector pump if pressure is lost in the injection discharge line. Running out of chemical in the chemical line is a primary cause of pressure loss.

A strainer placed on the suction line of the injector pump in the chemical supply tank (figures 1h and 2h) is necessary to prevent clogging or stoppage of the injection pump, safety switches, check valves, or sprinklers in the irrigation systems. The strainer should have a 50-mesh screen and be constructed of materials resistant to agricultural chemicals.

Figure 3 shows a closeup of the important safety and anti-siphoning devices required for injecting herbicides into an irrigation system. Also shown is a gate valve, which is necessary if the same water source serves more than one irrigation system.

Equipment Construction

All equipment, hoses, and accessories that come in direct contact with herbicide mixtures must be resistant to all formulations of agricultural chemicals being applied, including emulsifiers, solvents, and other carriers in addition to the active material. Hoses, seals, gaskets, etc., should be constructed of polypropylene, polyethylene, EPDM, EVA, teflon, hypalon, or viton. In general, products that contain PVC, neoprene, butadiene, or styrene butadiene rubber are not satisfactory for many agricultural chemicals.

Supply Tanks

A chemical supply tank must be constructed of materials that will withstand the corrosive action of agricultural chemicals. Stainless steel, fiberglass, nylon, and polyethylene are common construction materials. Iron, steel, copper, and brass should be avoided. The capacity of the supply tank should be large enough so that a single mix will treat the irrigated acreage. This reduces the possibility of accidental spills and repeated mixing errors. Allow at least 1 gallon of water for each pound of wettable powder added. Liquid or flowable formulations will require less water. Agitation in the chemical supply tank is required when wettable powders, dry flowables, flowables, or any other suspended formulation is being used. Mechanical and hydraulic agitation are the two most common types. Experience has shown that mechanical agitation is highly desirable. Both types of agitation require a separate power source.

Injection Pumps

Herbicides are most commonly applied through center pivot, solid set, wheel, or cable tow irrigation systems. These systems normally operate between 25 and 100 pounds per square inch. Positive displacement piston or diaphragm injection pumps

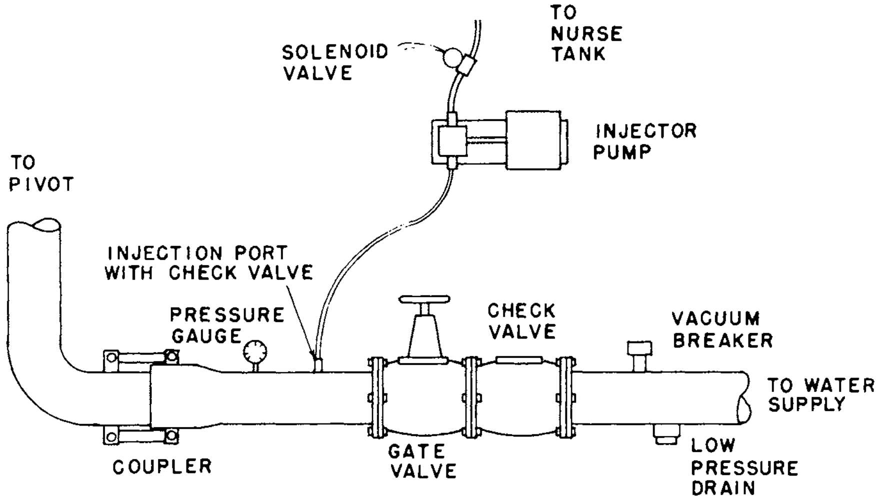


Figure 3. Cross-section diagram of minimum safety devices for injecting herbicides into center pivot irrigation systems. (Figure by E. D. Threadgill, University of Georgia.)

generally are used as the metering device for applying herbicides into pressure irrigation systems. These injection pumps can be either electric motor or belt-driven from the irrigation pump, depending on the installation.

Injection pump capacity and calibration are very critical. Pump capacity must be compatible with the capabilities of the irrigation system and the projected uses. Injection pump calibration must be precisely matched with the calibration of the irrigation system. Generally, injector pump markings on the calibration shaft are not adequate for precise calibration purposes, especially for low volume outputs. Each time the injector pump output is changed, the pump should be recalibrated. Once calibrated, the pump can be expected to remain accurate for several weeks. Frequently, it is more convenient and advantageous to change herbicide concentration by dilution to match the output of a precalibrated injection pump. Frequent calibration checks of all injection pumps are highly desirable. Injection pumps are most accurate and dependable when operating from 40 to 100 percent of their specified capacity.

Other Injection Systems

Other systems that deliver chemicals to pressurized irrigation water are pressure differential and venturi (vacuum) systems. In the pressure differential system, the chemical tank is under pressure (usually the main line water pressure). The difference in pressure between the tank connections caused by the constriction in the flow pipe is sufficient to create a flow through the sealed airtight pressure supply tank to the reduced water pressure on the outlet side of the supply tank. The venturi method is based on a rapid change in velocity. This velocity change creates a reduced pressure (vacuum) that forms a suction on the chemical supply tank, which then feeds the chemical into the main irrigation water flow. The pressure differential and venturi injection systems are most commonly used in drip irrigation. Precise control valves are necessary to control the chemical injection rate.

In nonpressurized or gravity irrigation systems (furrow and flood), a constant head siphoning device (figure 4) can be used instead of an injection pump to meter the appropriate herbicide into the irrigation water source. This siphon device consists of a valve or petcock and an appropriate metering orifice attached to an appropriate length of pipe and air control valve that can be plumbed directly into a chemical container such as a 5-gallon can or 55-gallon drum. Through physical placement or with proper tubing to the constant head siphoning device, the chemical is allowed to drip into the main stream of water. Changes in chemical flow rate are made by changing the metering orifice size.

Injector Calibration

Equipment calibration is an extremely important step in applying chemicals through an irrigation system.

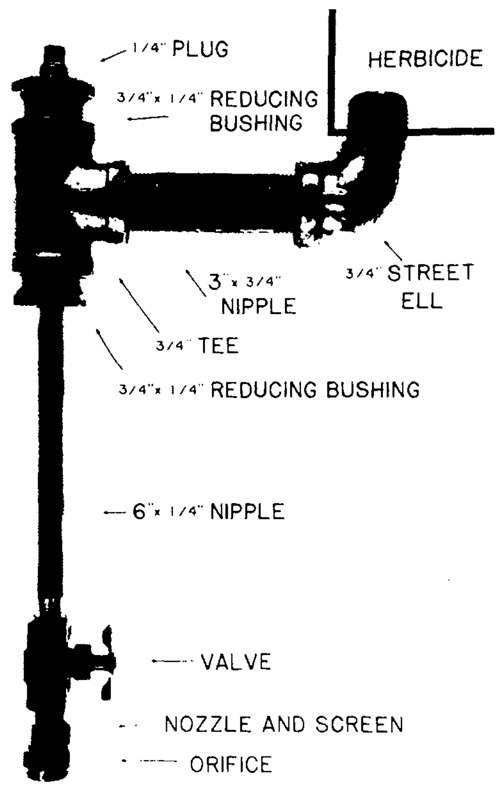


Figure 4. Constant head siphoning device for metering herbicides into nonpressurized or gravity-flow irrigation systems. (Figure by Stauffer Chemical Company, Mt. View, California, modified by A. G. Ogg, Jr., USDA-ARS, Prosser, Washington.)

Calibrate the irrigation equipment and injection pump yourself rather than relying on the manufacturer's or dealer's recommendations. The manufacturer's suggestions eliminate the need for much trial and error in calibration. But you still need to determine the exact irrigation water output and injector pump setting because conditions at your worksite will not be the same as they were at the factory.

An accurate timing device such as a stop watch or wrist watch with a second hand and a collection container with easy-to-read units such as a graduated cylinder can be used to calibrate the injection pump. The injection pump should be calibrated with the irrigation system running and the chemical tank placed as it will be during actual operation. Instead of operating the irrigation pump, a back-pressure regulating system can be attached between the check valve and the irrigation line. The back-pressure is adjusted to the operating pressure of the irrigation system and the injection pump is calibrated by collecting output per unit of time.

Monitoring the complete system (irrigation and herbicide injection) at regular intervals is the most effective way of insuring accurate and uniform application. Calibration tubes have been designed to check injection output during operation and are useful if they are constructed of the correct material and are accurately marked. Experience has shown that close monitoring of the supply tank also is an effective and accurate way of checking injector pump calibration.

Methods of Applying Herbicides Through Irrigation Systems

Sprinkler, gravity flow, and drip are three general types of irrigation systems that can be used to apply herbicides. Sprinklers are the most widely used irrigation system for applying herbicides. The injector equipment and safety devices required for applying herbicides through all irrigation systems are similar (figures 1-3).

Sprinkler Systems

Continuously Moving Sprinkler Systems

Farmers who have center pivot and continuously moving systems have shown the most interest in applying herbicides in irrigation water. Properly calibrated and operated, these systems have a high degree of uniformity for applying water and subsequently herbicides. They can apply as little as 0.1 inch to as much as 1.0 inch of water in a single irrigation. These systems may irrigate as few as 10 acres up to 240 acres or more. Generally, most center pivots have a radius of about one-fourth mile and will irrigate about 125 acres.

Center pivots have a high instantaneous rate of water application near the outer portions of the circle. If the water infiltration rate of the soil is exceeded, the herbicide-water solution will run from the high areas to the low areas. If this happens, weeds may not be controlled in the high areas and crops may be injured where the water collects. For this reason, the use of center pivots for applying herbicides should be restricted to soils with relatively high water infiltration rates.

To calibrate a continuously moving sprinkler system and injection pump:

1. Determine the number of acres irrigated by the system. Example: Center pivot, including area covered by end gun = 1,320 feet long = 126 acres.
2. Determine the amount of formulated herbicide needed per acre (consult product label). Example: 3 quarts per acre.
3. Determine the total amount of herbicide needed. Multiply step 1 by step 2. Example: 126 acres × 3 quarts per acre = 378 quarts or about 94 gallons of formulated herbicide.
4. Partially fill the solution tank with water, leaving room to add the herbicide. Start the tank agitator and add the herbicide to the tank. Example: Add 100 gallons of water, start agitator, then add 94 gallons of herbicide. Add more water to bring total volume up to 200 gallons.
5. Determine the water application rate for the irrigation and set the speed of the sprinkler. Example: Need 0.5 acre-inch of water, and center pivot will take 18 hours to make a revolution applying 0.5 inch of water.
6. Determine injection rate by dividing the total gallons of solution in the tank (step 4) by the hours required to irrigate the field (step 5).
   Example: $\frac{200 \text{ gallons}}{18 \text{ hours}} = 11.1$ gallons per hour.
7. Calibrate the delivery rate of the injection pump to make certain the rate is correct. In some cases, it may be necessary to first determine the range of flow rates of the injection pump and then to calculate the total volume of herbicide-water solution that can be applied during the irrigation. The herbicide can then be diluted accordingly.
8. Allow the irrigation system to operate for a sufficient time after the injection is finished to completely flush the herbicide from the system (usually about 5 minutes).

The application of herbicides through travelling big guns is not recommended because the application of water with these systems is too uneven.

Stationary Systems

Solid set, hand lines, and wheel lines are examples of stationary irrigation systems that can be used for applying herbicides. These systems differ from center pivots or continuously moving laterals in that they are set on a given area of the field and do not move during the irrigation. Herbicides can be applied throughout the period of the irrigation or at any preselected interval during the irrigation. Stationary systems can apply almost any amount of water desired.

The greatest limitation with stationary systems is the distortion of the water distribution by wind. Herbicides should not be applied through these systems if wind velocities exceed 7 miles per hour.

To calibrate a stationary sprinkler system and injection pump:

1. Determine the acres to be irrigated in one set. Multiply the lateral spacing along the main line by the length of the lateral and divide by 43,560 (square feet per acre). If more than one lateral is being operated simultaneously, also multiply by the number of laterals. Example: 10 laterals 800 feet long spaced 40 feet apart.

   $$\frac{800 \times 40 \times 10}{43{,}560} = 7.3 \text{ acres.}$$

2. Determine the amount of formulated herbicide needed per acre (consult product label). Example: 4 pounds of wettable powder herbicide per acre.
3. Determine the total amount of herbicide needed. Multiply step 1 by step 2. Example: 7.3 acres × 4 pounds per acre = 29.2 pounds.
4. Determine the amount of water to be applied during the application. Follow recommendations on herbicide label. Example: Herbicide label recommends that 1.0 acre-inch of water be applied and that the herbicide be injected during the first half of the irrigation period.
5. Determine the rate of water application by the irrigation system. Attach a short piece of hose to one nozzle outlet, start irrigation system, and measure flow for 1 minute. With information on sprinkler head spacing and nozzle flow in gallons per minute, consult irrigation tables to determine the water application rate in acre-inches per hour. Adjust the duration of the irrigation to apply the amount of water necessary for proper herbicide application. Example: Nozzle flow = 4 gallons per minute. Sprinkler head spacing is 40 by 40 feet. According to irrigation tables, a sprinkler system with these characteristics will apply 0.24 acre-inch of water per hour.
6. Determine how long to irrigate. Divide the amount of water to be applied (step 4) by the rate of water application (step 5).

   Example: $\frac{1.0 \text{ acre-inch}}{0.24 \text{ inch/hour}}$ equals about 4 hours

   for the length of the irrigation. Herbicide label recommends that the herbicide be applied during the first half of the irrigation or during the first 2 hours.
7. Partially fill the solution tank with water, leaving room to add the herbicide. Start the tank agitator and add the herbicide to the tank. Example: Add 30 gallons of water (1 gallon water for each pound of wettable powder) to solution tank, start agitator, and add 29.2 pounds of formulated herbicide. Add more water to bring total volume to 50 gallons.
8. Determine the injection rate by dividing the total gallons in the tank (step 7) by the hours required to apply the herbicide (step 6).

   Example: $\frac{50 \text{ gallons}}{2 \text{ hours}} = 25$ gallons per hour.
9. Calibrate the delivery rate of the injection pump to make certain the rate is correct.
10. If herbicide solution is to be applied throughout or during the last part of the irrigation, allow the irrigation system to operate for sufficient time after the injection to completely flush the herbicide from the system (usually about 5 minutes).

Gravity Flow Systems

Application of herbicides in gravity flow systems is adapted to bed planted and to furrow and flood irrigated crops. Very sandy soils are not well adapted. Herbicides can be applied immediately after planting or as a later layby application. The irrigation water serves to incorporate the herbicide and stimulate weed seed germination—ideal conditions for herbicide performance. A limited number of herbicides are suitable for application in gravity flow systems.

Herbicides applied in the irrigation water will control weeds in the irrigation furrow or flooded area but will not control weeds on top of the bed or ridge. Usually some other weed control practice will be required to control weeds on the bed or ridge. The later layby herbicide applications prevent weed growth that may interfere with irrigation and compete with short-statured crops. Layby applications should be considered a secondary rather than a primary weed control effort.

The herbicide application will only be as accurate as the water application. A minimum grade of 0.2 percent is required to achieve uniform water application. Maximum length of irrigation run should be limited to ¼ mile to maintain uniform water application. Usually these applications are made during the first irrigation of the field. If the herbicide is applied in later irrigations, weeds already may have germinated and become established and may be impossible to control.

In the case of furrow irrigation, the herbicide application usually is made during the first irrigation. The condition of the furrow is important because it influences the rate of water flow, the amount of water applied, and the uniformity of distribution. A furrow slicking or packing device is useful for reducing water intake during the first irrigation. Furrow or bed forming machines that result in a smooth, firm, clod-free furrow are very helpful in controlling the water application during the first irrigation.

A water application of 1.5 to 2 inches should be the goal when applying herbicides using this method. The 1.5- to 2-inch water application is the practical minimum for first irrigation with furrow or flood irrigation. A reuse pit to collect tailwater is a requirement when applying herbicides under furrow or flood irrigation. Tailwater must be collected, recirculated, and used in the same field or used on other crops where the herbicide is registered.

To calibrate a gravity flow irrigation system and injection pump:

1. Determine the acres to be irrigated in one set.
   Example: 100 rows on 30-inch (2.5 feet) spacing that are 1,000 feet long.

   $$\frac{100 \times 2.5 \times 1{,}000}{43{,}560} = 5.7 \text{ acres.}$$

2. Determine the amount of formulated herbicide needed per acre (consult product label).
   Example: 2 quarts of herbicide per acre.

3. Determine the total amount of herbicide needed. Multiply step 1 by step 2. Example: 5.7 acres × 2 quarts per acre = 11.4 quarts.
4. Partially fill the solution tank with water, leaving room to add the herbicide. Start the agitator and add the herbicide to the tank. Example: Add 25 gallons of water to the solution tank, start agitator, and add 11.4 quarts of herbicide. Add more water to bring total volume up to 40 gallons. In some cases, undiluted liquid herbicide can be injected into the irrigation system.
5. Determine the time required for the irrigation. Example: Assume 4 hours will be required to apply 1.5 inches of water.
6. Determine the injection rate by dividing the total gallons in the tank (step 4) by the number of hours required for irrigation (step 5).

   Example: $\frac{\text{40 gallons}}{\text{4 hours}}$ = 10 gallons per hour.
7. Calibrate the delivery rate of the injection pump to make certain the rate is correct. In some cases, a constant head siphoning device (figure 4) can be used instead of an injection pump to meter the herbicide into the water source.

Drip or Trickle Systems

Drip or trickle irrigation is described as the frequent, slow application of water to soils through emitters or orifices located at selected points along the water delivery lines. Most emitters are placed on the ground, but they also can be buried or suspended above the ground. Since the area wetted by each emitter is a function of the soil hydraulic properties, one or more emission points per plant may be necessary. Emitters can be of many types. The "dripper" type emitters usually deliver 1 to 2 gallons per hour. The "jet" types usually deliver more water.

Applying herbicides through drip irrigation systems usually will not control all of the weeds, so other methods also have to be used. Most herbicides will move only a portion of the distance that the water moves, and a fringe of weeds usually will grow in the wetted areas not treated with herbicides. Also, herbicides degrade rapidly around the emitters and weeds will invade these areas soon after the initial treatment. To control the weeds in the fringe areas and around the emitters, conventional preemergence or postemergence applications of herbicides also have to be used.

Injection of herbicides through drip irrigation systems can pose a health threat to field workers unless safety measures are taken to prevent workers from drinking water from the ends of the drip lines.

To calculate the amount of herbicide to apply per acre through a drip irrigation system, the lateral movement of water from the emitter must be measured. But, because the pattern of water movement often is irregular, it is difficult to calculate the area irrigated.

A more workable method is to apply solutions of a known herbicide concentration for a definite period of time. The amount of herbicide in solution is expressed in parts per million (ppm). For deep-rooted perennial crops, herbicide solutions of 20 to 100 ppm applied for 2 to 4 hours have controlled weeds selectively. For selective weed control in annual row crops, concentrations usually are lower.

To calibrate a drip irrigation system and injection pump (assume that a 20 ppm solution applied for 4 hours will be needed to control weeds):

1. Determine how many gallons of water are being delivered per hour per acre by the drip system. Collect the water from 10 randomly selected emitters for 1 minute, calculate the average flow per emitter, multiply by 60 to get the amount of water per hour per emitter, and then multiply by the number of emitters to get the amount of water delivered per hour per acre by the drip system. Example: Average flow for 10 randomly selected emitters was 2 ounces per minute. 2 ounces × 60 minutes = 120 ounces per hour or about 1 gallon per hour. If there are 1,000 emitters per acre and each emitter delivers 1 gallon per hour, the system delivers 1,000 gallons per hour.
2. Determine the weight of the water applied. Each gallon of water weighs 8.3 pounds. Multiply the number of gallons delivered per hour per acre by the drip system (step 1) by the weight of 1 gallon of water (8.3 pounds). Example: 1,000 gallons × 8.3 pounds = 8,300 pounds per hour. Multiply the weight of the water applied per hour by the number of hours the system runs. Example: 8,300 pounds × 4 hours = 33,200 pounds of water in 4 hours.
3. Determine the pounds of active herbicide required. A 20 ppm solution equals 20 pounds of herbicide per 1,000,000 pounds of water. Multiply the ppm required by the total weight of the water applied during the irrigation period and then divide by 1,000,000.

   Example: $\frac{20 \times 33{,}200}{1{,}000{,}000}$ = .66 pound of active herbicide per 4 hours.
4. Determine the amount of formulated herbicide required. Example 1: Herbicide is formulated as 2 pounds active ingredient per gallon.

   $\frac{\text{0.66 pound}}{\text{2 pounds/gallon}}$ = 0.33 or ⅓ gallon per 4 hours.

   Example 2: Herbicide is formulated as a 50 percent wettable powder.

   $\frac{\text{0.66 pound} \times 100}{.50}$ = 1.32 pounds per 4 hours.
5. Partially fill the solution tank with water, leaving room to add the herbicide. Start the agitator and add the herbicide to the tank. Example: Add 15 gallons of water, start agitator, and then add ⅓ gallon of herbicide. Add more water to bring total volume to 20 gallons.
6. Determine injection rate by dividing the total gallons of solution in the tank (step 5) by the hours the drip system runs.

   Example: $\frac{\text{20 gallons}}{\text{4 hours}}$ = 5 gallons per hour.
7. Calibrate the delivery rate of the injection pump to make certain the rate is correct. If the herbicide moves rapidly in the soil, it is best to inject it during the last 4 hours of irrigation. If the herbicide does not move readily in the soil, it should be injected earlier in the irrigation.
8. Allow the irrigation system to operate for a sufficient time after the injection is finished to completely flush the herbicide from the system (usually about 15 minutes).

CURRENT AND FUTURE POSSIBILITIES FOR POSTEMERGENCE HERBICIDE USE

George Kapusta, Professor
Southern Illinois University

The use of selective, postemergence herbicides for soybeans has been increasing substantially over the past ten years. It is anticipated that their use will continue to grow dramatically during the next decade. There are several reasons for the great increase and interest in the use of these herbicides. First, manufacturers continue to discover and develop outstanding candidates and introducing them to the market. Second, crop production is a dynamic industry with many changes having occurred during the past decade, changes that force new approaches to weed control. These changes include less primary and secondary tillage, less thorough incorporation of herbicides, long-term use of the same soil herbicides resulting in changes in the weed spectrum, earlier planting, the use of narrower row spacing, an increase in the size of farm units and in rented vs. operator-owned land, and some increase in herbicide carryover and in the incidence of resistant weeds. These factors generally result in an increase in weeds not controlled by soil-applied herbicides and/or mechanical means. The most obvious control method becomes the use of postemergence herbicides.

BEST FIT FOR POSTEMERGENCE HERBICIDES.

What is the "best fit" for postemergence herbicides? Currently, postemergence herbicides best fit as a component of a total weed control program that includes soil-applied herbicides and mechanical control. They also could serve a very useful purpose as part of a herbicide rotation program to decrease the incidence of weeds tolerant or resistant to soil-applied herbicides. A continuous total postemergence herbicide program also might fit situations where soil-applied herbicides do not perform consistently or fit a specific grower's operation. High level management of all farming operations is imperative for this program to be successful consistently.

SITUATIONS REQUIRING SOIL PLUS POSTEMERGENCE HERBICIDES.

There are several situations where soil-applied herbicides should form the backbone of your weed control program, with postemergence herbicides used to control escapes. These situations include no-till soybean production and fields that have a broad spectrum of grasses and broadleaf weeds or a very high density of weeds. Also, soil herbicides should be used on fields where repeated weed emergence may occur over several weeks or throughout the season and where weed species tolerant to available postemergence herbicides occur. The need for soil-applied herbicides in drilled soybeans (10 inch or less spacing) is less distinct since the early canopy may reduce the weed problem so that the use of only postemergence herbicides may suffice. Great care should be taken in selecting the postemergence herbicides since cultivation is not possible.

BEST SITUATIONS FOR TOTAL POSTEMERGENCE PROGRAMS.

Weed control programs consisting of postemergence herbicides only are suitable or may be preferred for several situations. Alkaline soils (high pH) may preclude the use of metribuzin (Lexone/Sencor) because of the possibility of excessive soybean injury. Some soil herbicides may not be suitable for use on sandy soil because of excessive leaching. Very high organic matter soils usually require excessively high rates of soil-applied herbicides, which may preclude their use. A total postemergence program also would be preferred on soils where uniform incorporation is hard to achieve, such as on gumbo soils, in areas where low rainfall reduces the effectiveness of preemergence herbicides, and on fields where a high level of mulch may intercept too much of the soil herbicide. Additionally, total postemergence programs would be an advantage in fields infested with weeds more susceptible to postemergence herbicides. Late planted fields would be another likely situation for a total postemergence program since several flushes of weeds would have been controlled by tillage.

FACTORS INFLUENCING THE EFFICACY OF POSTEMERGENCE HERBICIDES.

The efficacy of a postemergence herbicide largely depends on the specific weed to be controlled, assuming the appropriate rate has been used. However, several other factors influence the control one might achieve. Applying the herbicide when the weeds are small (two inches or less) and actively growing greatly favor optimum control. Unusually low temperatures the night preceding application may decrease control substantially. Less complete control may be achieved where the weed stand is very dense compared to a lighter stand. Uniform coverage of the foliage is necessary when contact herbicides such as Basagran, Blazer, or Dyanap are used. Flat fan or hollow cone tips should be used with at least 40 PSI. These features are somewhat less crucial with herbicides such as Poast and Fusilade that translocate within a plant. Be certain to use the appropriate additive such as a surfactant or crop oil.

ADVANTAGES OF POSTEMERGENCE HERBICIDES.

Postemergence herbicides are insensitive to soil type, organic matter, and pH, providing great flexibility for growers where these aspects may restrict the use of soil herbicides. Since postemergence do not need incorporation, growers can save time and money and reduce potential soil erosion. Further, cloddy soils and those with a high level of residue do not decrease the efficacy of postemergence herbicides. They also generally are less dependent than preemergence herbicides on timely rainfall for optimum control. The use of postemergence herbicides also allows you to defer application from the busy planting season to one or two weeks later. Growers using only postemergence herbicides are able to defer the selection of a herbicide until they determine the weed problem in each field. This would preclude the application of a herbicide that might afford little control of the weeds infesting a field.

DISADVANTAGES OF POSTEMERGENCE HERBICIDES.

Postemergence herbicides generally cost more per acre than soil-applied herbicides. The currently available products have little or no soil residual, thus more than one application may be needed some years. Weather conditions may affect the performance of postemergence herbicides adversely. Wet fields may delay application until the weeds get too large for effective control. Conversely, extended drought conditions also reduce the effectiveness of postemergence herbicides. Several broadleaf weeds are at least partially tolerant to all of the currently available products, especially if the weeds exceed three to four inches in size. Tank mixes of most of the postemergence grass and broadleaf specific herbicides results in a reduction in grass control. Consequently, either the rate of the grass herbicide has to be increased or sequential applications must be used.

Chemical trespass (drift) may be a greater problem since most crops are emerged. This especially might be a problem where the postemergence grass herbicides drift onto highly susceptible corn. Fields bordering residential areas also could be serious problems. Generally, a high level of management is needed for a total postemergence program to be successful. Weeds must be identified within a week of emergence, the proper herbicide selected and applied, and control monitored about a week later to determine if a repeat application is needed.

BASIS FOR ADOPTION OF A TOTAL POSTEMERGENCE PROGRAM.

The primary reason to consider a total postemergence program is dissatisfaction with soil-applied herbicides. The probability of achieving acceptable control of all weeds in a field must be evaluated critically. Further, the grower must arrange his schedule to assure timely application and be ready to accept repeat applications if necessary. Finally, the acceptance of a total postemergence program should be based on the premise that the cost might be higher than where soil herbicides are used.

DESIGNING A SUCCESSFUL TOTAL POSTEMERGENCE HERBICIDE PROGRAM.

Know your customer/client! Initially, recommend a total postemergence program only to the better farm managers. It is likely that they will have a less serious weed problem--and know what weeds infest their fields. Further, they are most likely to be using other "best management practices" that will give their crop a competitive edge. Also, they are most likely to be timely with their postemergence applications. Know your weeds! It is imperative that the grower or his advisor be able to identify weeds within one week of emergence. The most effective control can be achieved only when the application is made no later than two weeks after emergence. Know your herbicides! One advantage of a postemergence program is the flexibility of selecting the herbicide to match the weed problem. This advantage can be lost entirely if the wrong herbicide is selected, or if an unreasonably low rate is used for the weed problem. Reduce the row spacing! Early canopy development is critical for consistent, season-long weed control with postemergence herbicides. Use other best management practices! Proper fertility, soil pH, adapted varieties, optimum planting dates, and other practices can be very influential in giving your crop a competitive edge over weeds. Apply your herbicides correctly! Calibrate your sprayer, use flat fan or hollow cone tips, a minimum of 40 PSI, the recommended additive and adequate carrier volume for uniform coverage. Be timely with the application! Applying the postemergence herbicide 7 to 10 days after weed emergence (no later than two weeks) greatly enhances optimum weed control--even at the low label rates. Split your applications! Apply the broadleaf herbicide first followed by the grass herbicide several days later to assure optimum grass control. If this is impractical, increase the rate of your grass herbicide. Monitor your control! One week following the application, check your fields to observe broadleaf weed control. Ten to fourteen days may be needed to ascertain grass control. Make a repeat application if necessary. Rotary hoe and cultivate! If your row spacing is 15 inches or wider, help your herbicides with timely rotary hoeing and cultivation.

SELECTING THE POSTEMERGENCE HERBICIDE.

Each herbicide has specific strengths and weaknesses. By knowing the weeds that each herbicide controls most completely, optimum weed control can be achieved.

A combination of two herbicides may be necessary to control all broadleaf weeds in fields that are infested with a broad spectrum of weeds such as velvetleaf, pigweed, morningglory, and lambsquarters.

USE PROFESSIONAL CONSULTANTS.

Consistent, high level control of weeds demands considerable training and expertise. The increasing availability of professionally trained consultants adds a valuable dimension that should be exploited. Make use of them to identify and map your weed problems and select the most effective herbicide program for your weeds. Depend on them to advise on the rate and additive that should be used, the time and method of applying the herbicides, and on monitoring the control. Adoption of a total postemergence herbicide program requires a high level of management skills that might be best obtained from professionally trained people.

FUTURE OF POSTEMERGENCE HERBICIDES.

The use of postemergence herbicides will continue to increase rapidly, primarily as a component of a total weed control program that includes one or more soil-applied herbicides. Adoption of total postemergence herbicide programs will be less rapid. Initially, it will be adopted most rapidly by the best farm managers, on fields where soil-applied herbicides have not given consistent control. Other likely situations for the rapid adoption of total postemergence programs is in fields infested with weeds highly susceptible to these herbicides and where weed densities are relatively low.

CURRENT AND FUTURE USE OF POSTEMERGENCE HERBICIDES IN CORN AND SOYBEANS IN MINNESOTA

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Postemergence herbicide treatments have both advantages and disadvantages when compared to soil applied herbicide treatments. Advantages include: 1) no treatment is made until you are sure that you have a weed problem, 2) you need to treat only the areas of a field where the weed occurs, 3) you have the opportunity to identify the specific weeds and select the most appropriate herbicides before application. Disadvantages include: 1) spray drift is rarely a problem with soil applied treatments while it oftimes is of concern with postemergence treatments, 2) many postemergence herbicides are active only through the foliage and will provide little or no residual weed control, 3) rainfall soon after foliar applications may wash the herbicide from the foliage and reduce weed control effectiveness, 4) weeds may not all be emerged and in the best stage for treatment at the same time.

Postemergence herbicide applications frequently serve as back-up treatments when soil herbicide treatments fail. However, if postemergence treatments are used as the primary weed control measure, back-up treatment alternatives are much more limited.

Current usage of postemergence herbicide treatments in corn is very extensive with over 60% of the corn acreage treated postemergence in 1983. The herbicides used postemergence are effective on most broadleaf weeds. However, only atrazine and cyanazine (Bladex), used postemergence on about 12% of the corn acreage, have the potential for control of annual grasses. Presently available herbicides provide acceptable postemergence broadleaf weed control and should do so in the future. It seems possible that future use of 0.5 lb/A of dicamba (Banvel) on corn up to 5 inches tall may increase. This treatment provides both effective control of emerged broadleafs and residual control of those that germinate later. Early postemergence treatments with dicamba will reduce the potential for drift injury to nearby soybeans or other sensitive crops. The prediction of future increases in dicamba early postemergence usage on corn is made on the presumption that dicamba tolerance of the numerous hybrids used in Minnesota will be sufficient to avoid significant corn injury under the wide range of environmental conditions that are possible.

Presently available herbicides, cyanazine or atrazine plus oil, provide only marginal postemergence control of small grassy weeds, 1 to 3 inches tall, in corn. Future increases in usage of postemergence treatments for grass control in corn depend upon the development of more effective treatments. The addition of tridiphane (Tandem) has given improved grass control performance of cyanazine or atrazine plus oil on grassy weeds. Also, cyanazine plus pendimethalin (Prowl) applied to corn at the spike to 2-leaf stage has been very effective on small grasses. However, as the grasses become larger, control becomes poorer. Studies now under way using sequential treatments with cyanazine or atrazine plus oil combined with tridiphane appear promising on larger grasses. Drop nozzle treatments may be necessary to minimize corn injury from sequential applications of atrazine-oil or cyanazine combination treatments with tridiphane. Also, label clearances will be required before these sequential treatments can be used on corn.

Current usage of postemergence weed control treatments is much less extensive in soybeans than in corn. Less than 20% of the soybean acreage was treated postemergence in 1983. Most of this acreage was treated for broadleaf weeds with bentazon (Basagran). However, recent clearances of several new postemergence herbicides, acifluorfen (Blazer) for broadleaf weeds and sethoxydim (Poast) and fluazifop (Fusilade) for grasses, should soon result in substantial increases in the use of postemergence treatments in soybeans. In addition to these cleared herbicides, there are at least twelve new postemergence herbicides being developed that are promising for the control of broadleafs or grasses. It seems likely that clearances of some of the large number of new postemergence herbicides for soybeans will result in increases in their use in the future. This may result in substantial changes in soybean production methods with reliance on postemergence applications for primary weed control treatments rather than their use as back-up treatments for soil applied herbicide treatments.

CROP INJURY AND ANTAGONISM PROBLEMS

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With the recent development of several herbicides for postemergence weed control in soybeans, growers have additional tools to add to their weed control program. Each of these herbicides have strong points as well as weaknesses. The postemergence grass compounds have provided excellent control of annual grasses. When combined with postemergence broadleaf soybean herbicides, the potential exists for total postemergence weed control programs. However, this type of program presents some problems that need to be considered. One problem is soybean injury where Blazer is applied to soybeans to control certain broadleaf weeds. Injury has generally not been associated with applications of Basagran, Poast or Fusilade. The second problem is antagonism between the broadleaf herbicides and the grass compounds applied as tank mixtures.

Herbicide Injury as Influenced by Blazer Rate and Additive

Because of the potential for soybean leaf damage with Blazer, experiments were designed to evaluate the influence of rate of Blazer application and the type and rate of additive on weed control and soybean injury. These two-year studies were conducted at Waseca, Minnesota. In 1983 the soil type was a Webster clay loam containing 6% to 7% organic matter. A Nicollet clay loam soil with 5% to 6% organic matter was the site selected for the 1984 study. These studies were designed as randomized complete block experiments with three replications in 1983 and four replications in 1984. The data were analyzed as factorial experiments with appropriate BLSD values listed in the tables. Both years 'Evans' soybeans were planted in 30-inch rows. Planting dates were June 10, 1983 and May 21, 1984. All postemergence herbicide treatments were applied as tank mixtures of Basagran, Blazer and Poast on July 12, 1983 and June 20, 1984 using a sprayer calibrated to deliver 20 gallons/A at 30 psi.

When the herbicides were applied on July 12, 1983, air temperature ranged from 81^{o} to 86^{o}F with 45% to 60% relative humidity. At this time soybeans were 8 to 10 inches tall (fourth trifoliolate leaf stage). Redroot pigweed and foxtail species were 4 to 10 inches tall when herbicides were applied in the weedy study. Soybeans were 6 inches tall when herbicides were applied on June 20, 1984; the air temperature was 84^{o}F with 60% relative humidity, broadleaf weeds were 3 to 6 inches tall (4 to 8 leaves) and giant foxtail was 6 inches tall. No rainfall occurred for at least 48 hours following herbicide applications in either year.

Two studies were conducted each year. One study was conducted on weed-free soybeans to evaluate crop injury. In this study Treflan (.75 lb/A) was applied and incorporated before planting and Amiben (2.0 lb/A) was applied preemergence each year to control weeds in this weed-free study. Hand-weeding was also done to prevent weeds from reducing soybean yields. A second study was conducted to evaluate weed control and crop injury where Basagran, Blazer and Poast were applied as tank mixtures. This will be referred to as the weedy study.

In both studies Basagran (0.75 lb/A) and Poast (0.2 lb/A) were applied as a tank mixture with either 0.125, 0.25, or 0.50 lb/A of Blazer (2L). Three additives were used in these studies: 0.25% (0.4 pt/A) surfactant (Ag98) and crop oil concentrate (Atplus 411F) at either 0.63% (1 pt/A) or 1.25% (1 qt/A) of the total spray volume. The additives were always added last after the herbicides were dispersed in the water carrier.

Rate of Blazer application influenced soybean injury in weed-free soybeans (Table 1). Early visual injury ratings (leaf burn and stunting) averaged over the two years were 9%, 12%, and 19%, respectively, for the 0.125, 0.25 and 0.50 lb/A rates of Blazer. Plant height on July 11 and July 26, 1984 was reduced by Blazer application. Compared to the plots not receiving Blazer, plant height on July 11, 1984 was reduced 1 to 2 inches where Blazer was applied; a reduction in plant height of 2 to 3 inches was observed on July 26, 1984. There were no significant effects of Blazer on plant height at harvest. Similar observations were observed in the weedy study (Tables 2 and 3).

Compared to the checks that received no Blazer, applying Blazer without a surfactant reduced yields in 1984 (Table 1). A similar trend was observed in 1983, however, this difference was not statistically significant. Plots receiving no Blazer application in 1984 yielded 44.7 bu/A while yields for the 0.125, 0.25 and 0.50 lb/A Blazer rates were 42.4, 41.1 and 40.6 lb/A, respectively, with a least significant difference ($P > .05$) of 1.4 bu/A. Therefore, the injury obtained from applying Blazer in combination with Basagran and Poast in 1984 was sufficient to reduce yields of weed-free soybeans. In 1983 there was little difference in soybean yields among the three rates of Blazer application.

Not only was rate of Blazer important, but the additive used with the Blazer, Basagran and Poast tank mixture also influenced yields in weed-free soybeans (Table 1). Compared to applying Blazer without surfactant, there was a general trend toward reduced yields as the additives were changed from surfactant to 1 pt/A of oil concentrate and then to 1 qt/A of oil concentrate. Although all of these differences were not significant ($P > .05$), the trend was evident both years. The 1 qt/A rate of oil concentrate significantly reduced yields both years as compared to applying the Basagran, Blazer and Poast tank mixture without any additives.

There was a significant Blazer x Additive interaction for yield in weed-free soybeans in 1984. This was primarily the result of yields declining steadily as Blazer rate increased where 1 qt/A of oil concentrate was added. There was little difference in soybean yields among the other additive treatments as Blazer rate increased.

Control of pigweed, a mixture of redroot pigweed and Powell amaranth, was improved as rate of Blazer application was increased (Tables 2 and 3). However, the degree of pigweed control at harvest only ranged from 58% to 80% in 1983. Early season pigweed control in 1984 ranged from 67% for the 0.125 lb/A rate of Blazer to 90% for the 0.50 lb/A rate. However, pigweed control at harvest in 1984 was poor with no differences among Blazer rates (Table 3).

Pigweed control in 1983 was similar for the surfactant and both rates of oil concentrate for the July 19 rating; these additives gave better pigweed control than where no additive was used (Table 2). On June 27, 1984, there were no differences among the additive treatments for pigweed control. (Table 3). Although there were some significant differences among additives for pigweed control at harvest in 1984, the level of control was poor (36% to 57%) and these differences probably are not meaningful.

One of the most significant effects of herbicide additive was observed for control of giant foxtail (Tables 2 and 3). Grass control at harvest with the Basagran, Blazer and Poast tank mixtures was similar where no additive and the surfactant was used. These treatments gave poor control of foxtail. Control of foxtail was significantly better where either 1 pt/A or 1 qt/A of oil concentrate was used as the additive. The oil concentrate treatments generally provided 90% or better grass control. Over the two years, treatments applied without additive or with surfactant gave only 43% to 82% grass control at harvest. These findings are not new since the benefits of using oil concentrate with Poast has been demonstrated several times.

Control of velvetleaf and common lambsquarters was generally not influenced much by either the rate of Blazer or the type of additive (Tables 2 and 3).

In both years in the weedy study, the rate of Blazer application did not influence soybean yields (Tables 2 and 3). However, the effect of additive was significant in 1984. Although greater soybean injury was associated with the use of oil concentrate as the herbicide additive, yields were highest in the weedy study with these treatments. This is primarily the result of improved grass control where oil was the additive.

In summary, both rate of Blazer and type and amount of additive influenced soybean injury, yield, and weed control in these studies. In the weed-free study, soybean yields were reduced 3 bu/A over two years when comparing the yields of plots not receiving Blazer with the average yield across all three rates of Blazer and all additives. The rate of Blazer did not appear to be an important factor; all rates effectively lowered yields compared to the weed-free checks not receiving the Blazer, Basagran and Poast tank mixture. The greatest yield reductions were associated with the 1 qt/A rate of oil concentrate.

Increasing the rate of Blazer from 0.125 to 0.25 lb/A generally increased control of pigweed more than increasing the rate from 0.25 to 0.50 lb/A. Rate of Blazer had little effect on all other weed species. As compared to no additive or surfactant, use of oil concentrate greatly improved foxtail control with the Basagran, Blazer and Poast tank mixture.

Because of the risk of soybean injury where oil concentrate is used at 1 qt/A, it is recommended that the rate of oil concentrate be reduced to 1 pt/A when Poast and/or Basagran are tank mixed with Blazer. Since the oil concentrate was the superior additive for annual grass control, it is not recommended that a surfactant be substituted for the oil where Poast is involved in the tank mixtures. In these studies, lack of weed control had a greater effect on soybean yield than soybean injury resulting from Blazer application.

The best approach would be to split the application of postemergence broadleaf and grass herbicides. Applying the Basagran plus Blazer first and delaying the application of Poast for 1 to 7 days would allow greater discretion in the use of additives with the broadleaf herbicides. If common lambsquarters or velvetleaf are among the target weed species, the use of 1 to 2 pt/A of oil concentrate with Basagran or Basagran plus Blazer is recommended to improve the consistency of control. When applications of these herbicides are made under hot (85°F) and humid conditions, oil concentrate should be applied at no more than 1 pt/A to reduce the risk of serious soybean injury. If pigweed or nightshade are the only target species, use of surfactant with Blazer should provide adequate control. Oil concentrate should always be applied with Poast to provide the best opportunity to control annual grasses.

Antagonism Between Postemergence Grass and Broadleaf Herbicides

The problem of antagonism when postemergence grass and broadleaf herbicides are combined in tank mixtures has been reported by most weed researchers. Antagonism is defined as one compound interfering with the activity of another. The most consistent antagonism has been that of broadleaf herbicides interfering with the activity of the grass herbicide. In other words, when Poast or Fusilade are tank mixed with Basagran, Blazer, or Basagran plus Blazer, control of grass species has been reduced.

Studies conducted at the Southern Experiment Station at Waseca, Minnesota and studies conducted at North Dakota State University by Dr. Alan Dexter illustrate some of the problems and solutions to these problems. The study done at Waseca in 1983 was designed to evaluate tank mixtures and split application of Basagran or Basagran plus Blazer and Poast. The following table gives the data on control of giant foxtail at Waseca.

Days after Basagran + Blazer[1]	Poast (lb/A) .1	Poast (lb/A) .2
	--% Giant Foxtail Control[2]--	
Tank Mixture	88	97
1 Day	100	100
3 Day	97	100
17 Day	98	95

[1]Basagran .75 lb/A + Blazer .25 lb/A

[2]Ratings taken 9/6/83

In this study 1 qt/A of oil concentrate was added with each herbicide application--split application received a total of 2 qt/A of oil concentrate. Where Poast was applied at .1 lb/A in a tank mixture with Basagran plus Blazer control of giant foxtail was 88%. All split applications where the .1 lb/A rate of Poast followed the application of Basagran plus Blazer by 1, 3 or 17 days resulted in nearly complete giant foxtail control. In this study there was no antagonism observed for the .2 lb/A rate of Poast in tank mixture with Basagran plus Blazer. Also there was no antagonism observed for control of pigweed, common lambsquarters, or velvetleaf with any of the treatments.

A study involving both Fusilade and Poast was conducted in 1984 to further evaluate the problem of antagonism. In this study two tank mixtures were evaluated. One tank mixture was formulated by adding all herbicides to water, then adding oil concentrate (1 qt/A) after all herbicides were dispersed in the water. The second tank mixture was formulated by first dispersing Basagran or Basagran plus Blazer in water. Then the grass herbicide was mixed with the oil concentrate prior to adding it to the broadleaf herbicides dispersed in water. The following table gives the results for giant foxtail control on September 17, 1984.

Method of Application[1]	Fusilade (lb/A)		Poast (lb/A)	
	.13	.25	.1	.2
	--% Giant Foxtail Control--			
Tank Mix	55	72	61	86
Tank Mix (oil)	59	81	60	90
1 Day Split	52	81	76	94
2 Day Split	62	79	76	88
13 Day Split	80	89	81	92

[1]Tank mix = all herbicides added to water before adding oil concentrate. Tank mix (oil) = Fusilade or Poast premixed with oil concentrate before adding to Basagran plus Blazer dispersed in water. Basagran .75 lb/A + Blazer .25 lb/A applied with Fusilade or Poast. The broadleaf herbicide was applied first with all split application. Each application included 1 qt/A of oil concentrate.

The .13 lb/A rate of Fusilade only gave 50%-60% giant foxtail control for both tank mixtures and the 1 and 3 day split applications. Activity on giant foxtail was increased to 80% where Fusilade (.13 lb/A) was applied 13 days after the Basagran plus Blazer. Antagonism was also observed where .1 lb/A of Poast was applied as a tank mixture with Basagran plus Blazer. Tank mixtures only gave 60% control while all split applications of Poast (.1 lb/A) gave 76% to 81% giant foxtail control. Sequence of mixing made little difference in control obtained with tank mixtures involving the low rate of Fusilade or Poast. The greatest antagonism with tank mixtures involving the higher rates of Fusilade and Poast was observed with Fusilade. The tank mixture where oil concentrate was added after dispersing all herbicides in water gave the poorest control of giant foxtail. Adding the grass herbicide to oil concentrate prior to adding to the broadleaf herbicides dispersed in water resulted in better control of giant foxtail than where oil was added last in the tank mixture. This difference was greatest for Fusilade which exhibited more antagonism than Poast. Best control of giant foxtail with Fusilade was obtained with the 13 day split application. Poast generally gave better giant foxtail control than Fusilade. With Poast (.2 lb/A), delaying application one day following the application of Basagran plus Blazer was sufficient to eliminate any antagonism observed with tank mixtures. The antagonism with .2 lb/A rate of Poast was relatively small--less than 10% reduction in giant foxtail control.

No antagonism was observed with any of the applications for control of pigweed, common lambsquarters and velvetleaf. However, there was a trend toward antagonism for common ragweed control with tank mixtures. All split applications gave equal control of common ragweed with either Fusilade or Poast in combination with Basagran plus Blazer. The standard tank mixture with oil added after dispersing all herbicides in water gave the poorest control of common ragweed. Adding the grass herbicide to oil before adding to the broadleaf herbicides and water reduced antagonism slightly in most cases.

Work done by Dr. Alan Dexter (NDSU) points out the importance of several factors that relate to antagonism. First, the herbicides involved influence the degree of antagonism. In these studies, Basagran was more antagonistic than Blazer or Betanex where Poast or Fusilade was used for giant foxtail control. Where oats was the target species Betanex and Blazer were more antagonistic to Fusilade than was Basagran. Basagran was again the most antagonistic in tank mixtures with Poast where oats was the target species. Thus, the particular grass herbicide and the target grass species influence antagonism. This emphasizes the importance of evaluating each herbicide combination on each weed species in question to determine the level of antagonism anticipated.

Yet another factor that complicates the antagonism question is weather and growing conditions. Under ideal growing conditions, antagonism may be reduced or even go unnoticed if labeled rates are applied to actively growing weeds. Add a little drought stress, cool temperatures, larger grasses or less susceptible species and the antagonism may be quite severe.

Work done by Dexter and Burnside would also indicate that carrier volume influences antagonism. In work at Fargo and Crookston, Dexter observed that 8.5 gallons/A spray volume resulted in less antagonism than 17 or 25 gallons/A. One thing that needs to be kept in mind in this respect is the need for good coverage with contact broadleaf herbicides (Basagran and Blazer). Reduced carrier volume may result in reduced broadleaf weed control if coverage is not adequate.

In summary, most data indicates that split applications of postemergence grass and broadleaf herbicide reduce antagonism and give the most consistent performance. With Poast it appears that split applications 1 to 3 days after the broadleaf herbicide is applied is adequate. Our data would indicate that a 3 day delay between application of Basagran plus Blazer and the application of Fusilade is not sufficient to eliminate antagonism where giant foxtail is the target. In this case, it appears that the grasses need to begin regrowth following Blazer applications before the Fusilade will give adequate grass control. This time interval will depend on growing conditions but will range from 7 to 14 days.

Increasing the rate of the grass herbicide when applied as a tank mixture with broadleaf herbicides has generally improved grass control. The problem is to determine what rate of grass herbicide will be needed to give adequate control. The herbicides involved in tank mixtures, the target species, the weather, and the growing conditions all interact to influence whether or not antagonism will be severe enough to cause sufficient loss of activity. This makes it nearly impossible to suggest a blanket policy for increasing rates for tank mixtures. In many cases, at least with Poast on giant foxtail, the .2 lb/A rate may be sufficient since this herbicide has excellent activity on foxtail species. However, the label states that the rate for Poast should be increased by 50% (to .3 lb/A) when applied as a tank mixture with broadleaf herbicides. This rate seems excessive in many cases but may be necessary for certain weed species or when the grasses are under stress.

Split application provides the best opportunity to select the best additive to use with a particular application. Oil concentrate should always be added with the postemergence grass herbicide. However, adding oil to Blazer may result in significant soybean injury. It may be possible to eliminate or at least reduce the rate of oil concentrate where Basagran and/or Blazer are applied separately from the grass herbicide. This will provide the greatest flexibility with respect to additive selection and will also provide the most consistent performance of grass herbicides. Where possible, split applications should be encouraged.

Table 1. Influence of Blazer and herbicide additive on weed-free soybeans at Waseca in 1983 and 1984.

		1983				1984					Average 1983-84	
		% Injury			Bu/A	% Injury	Plant Height (inches)			Bu/A	Early[b]	Bu/A
Blazer[a] (lb/A)	Additive (%)	7/14	7/19	9/12	13.5%	6/27	7/11	7/26	9/17	13.5%	Injury	13.5%
Basagran .75 lb/A + Poast .2 lb/A tank mixed with each of the following:												
.125	None	1	8	2	41.9	5	17	29	33	43.2	5	42.6
.25	None	1	7	0	41.9	11	16	29	32	44.2	7	43.0
.50	None	7	13	2	40.6	14	18	29	32	41.2	12	40.9
.125	Surf.(.25)	1	7	0	38.6	8	17	29	33	40.8	6	39.7
.25	Surf.(.25)	3	8	0	42.1	10	17	29	32	40.3	7	41.2
.50	Surf.(.25)	5	13	2	39.6	14	16	28	33	42.9	11	41.2
.125	Oil Conc.(.63)	4	7	0	40.3	14	17	29	33	42.9	10	41.6
.25	Oil Conc.(.63)	9	12	3	38.7	20	16	28	32	40.0	15	39.3
.50	Oil Conc.(.63)	24	18	10	38.3	25	15	28	33	40.8	23	39.5
.125	Oil Conc.(1.25)	18	18	5	37.2	16	16	29	32	42.9	17	40.1
.25	Oil Conc.(1.25)	18	13	0	39.0	20	16	28	31	40.1	18	39.5
.50	Oil Conc.(1.25)	40	25	5	36.6	25	15	26	30	37.4	29	37.0
Check:												
Treflan .75 lb/A + Amiben 2 lb/A		0	0	0	42.2	0	18	31	32	44.7	0	43.4
Means for Blazer Rates:												
.125		6	10	2	39.5	11	17	29	33	42.4	9	41.0
.25		8	10	1	40.4	15	16	28	32	41.1	12	40.8
.50		19	17	5	38.8	20	16	28	32	40.6	19	39.6
BLSD .05		3	3	2	NS	2	1	1	NS	1.4	2	NS
Means for Additive:												
None		3	9	1	41.5	10	17	29	32	42.9	8	42.2
Surf.(.25)		3	9	1	40.1	10	17	28	33	41.3	8	40.7
Oil Conc.(.63)		12	12	4	39.1	20	16	28	33	41.2	16	40.1
Oil Conc.(1.25)		25	19	3	37.6	20	16	28	31	40.1	21	38.9
BLSD .05		3	4	2	2.6	2	1	1	2	1.6	2	1.5
Significance Level for Rate x Additive:												
		99	51	99	28	44	91	76	67	99	94	83

[a]Herbicide formulations: Basagran=4S; Blazer=2L; Poast=1.53EC
[b]Average of 7/14/83 and 7/19/83 and the 6/27/84 rating.

Table 2. Influence of Blazer rate and herbicide additive on soybeans and weed control in weedy soybeans at Waseca, MN in 1983.

		% Injury			% Control[c]				
					Ftsp		Rrpw		Bu/A
Blazer[a] (lb/A)	Additive(%)[b]	7/14	7/19	9/12	7/19	9/12	7/19	9/12	13.5%
Basagran .75 lb/A + Poast 0.2 lb/A tank mixed with each of the following treatments:									
.125	None	1	3	5	35	73	40	50	24.6
.25	None	3	7	2	55	82	45	62	27.9
.50	None	4	5	5	57	80	63	78	25.8
.125	Surf.(.25)	0	3	2	43	85	52	75	32.4
.25	Surf.(.25)	5	7	0	57	87	62	82	32.0
.50	Surf.(.25)	3	7	8	58	74	65	78	27.0
.125	Oil Conc.(.63)	4	10	5	43	97	43	52	26.3
.25	Oil Conc.(.63)	7	12	5	55	95	53	57	30.9
.50	Oil Conc.(.63)	20	13	3	73	97	73	73	31.2
.125	Oil Conc.(1.25)	6	15	15	52	85	50	55	24.1
.25	Oil Conc.(1.25)	10	13	3	58	95	62	67	27.8
.50	Oil Conc.(1.25)	18	15	0	77	100	77	91	31.0
Weedy Check		0	0	0	0	0	0	0	22.3
Hand-Weeded		0	0	0	100	100	100	97	36.5
Means for Blazer Rate:									
.125		3	8	7	43	85	46	58	26.8
.25		6	10	3	56	90	55	66	29.6
.50		11	10	4	66	88	69	80	28.7
BLSD .05		3	NS	NS	12	NS	9	11	NS
Means for Additive:									
None		3	5	4	49	78	49	63	26.1
Surf.(.25)		3	6	3	53	82	59	78	30.5
Oil Conc.(.63)		11	12	3	57	96	57	61	29.5
Oil Conc. (1.25)		11	14	5	62	93	63	71	27.6
BLSD .05		3	4	NS	NS	11	11	13	NS
Significance for Acifluorfen Rate x Additive:									
		99	8	94	12	48	19	53	40.0

[a]Herbicide formulations: Basagran=4S; Blazer=2L; Poast=1.53EC.

[b]Additive: Surf.=Ag98; Oil Conc.=Atplus 411F. % on a V/V basis with a total spray volume of 20 gpa.

[c]% Control: Ftsp=mixture of green and giant foxtail; Rrpw=redroot pigweed.

Table 3. Influence of Blazer rate and herbicide additive on soybeans and weed control in weedy soybeans at Waseca, MN in 1984.

		% Injury	Plant Height (inches)			% Control[c]								
						Gift		Rrpw		Vele		Colq		Bu/A
Blazer[a] (lb/A)	Additive (%)[b]	6/27	7/11	7/26	9/17	6/27	9/17	6/27	9/17	6/27	9/17	6/27	9/17	13.5%
Basagran .75 lb/A + Poast 0.2 lb/A tank mixed with each of the following treatments:														
.125	None	10	14	24	23	51	35	75	55	81	58	59	51	19.2
.25	None	10	14	25	25	55	54	85	56	90	66	66	48	20.7
.50	None	15	14	23	25	58	64	91	55	95	79	71	59	21.6
.125	Surf.(.25)	10	15	23	24	50	43	70	58	84	66	69	51	18.2
.25	Surf.(.25)	11	14	23	23	53	31	85	55	88	60	65	43	17.0
.50	Surf.(.25)	22	13	22	24	61	55	89	59	90	56	73	36	20.2
.125	Oil Conc.(.63)	13	14	23	24	55	89	60	30	93	70	68	41	22.2
.25	Oil Conc.(.63)	15	14	24	26	56	88	85	43	84	76	65	54	24.3
.50	Oil Conc.(.63)	24	13	23	25	58	87	89	35	89	75	74	36	22.5
.125	Oil Conc.(1.25)	13	14	23	24	58	89	61	33	85	75	58	49	21.5
.25	Oil Conc.(1.25)	24	14	21	25	60	90	86	34	85	59	76	35	22.0
.50	Oil Conc.(1.25)	31	13	22	27	68	91	90	54	94	76	79	43	23.6
Weedy Check		0	15	24	20	0	0	0	0	0	0	0	0	9.8
Hand-Weeded		0	18	29	32	100	100	100	100	100	100	100	100	28.9
Means for Blazer Rate:														
.125		11	14	23	24	53	64	67	44	86	67	63	48	20.3
.25		15	14	23	25	56	66	85	47	87	65	68	45	21.0
.50		23	13	22	25	61	74	90	51	92	71	74	44	22.0
BLSD .05		3	NS	NS	NS	5	8	4	NS	6	NS	9	NS	NS
Means for Additive:														
None		12	14	24	24	55	51	84	55	89	68	65	53	18.5
Surf.(.25)		15	14	23	24	55	43	81	57	87	61	69	43	20.5
Oil Conc.(.63)		17	14	23	25	56	88	78	40	89	74	69	44	23.0
Oil Conc.(1.25)		23	14	22	25	62	90	79	36	88	70	71	42	22.4
BLSD .05		4	NS	NS	NS	6	8	NS	13	NS	NS	NS	NS	3.4
Significance for Acifluorfen Rate x Additive:		91	11	27	24	15	96	89	38	65	22	50	62	9.0

[a] Herbicide formulations: Basagran=4S; Blazer=2L; Poast=1.53EC.

[b] Additive: Surf.=Ag98; Oil Conc.=Atplus 411F. % on a V/V basis with a total spray volume of 20 gpa.

[c] % Control: Gift=giant foxtail; Rrpw=Redroot pigweed; Vele=Velvetleaf, and Colq=Common lambsquarters.

TROUBLE SHOOTING CROP DAMAGE - QUESTIONS TO ASK

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There is little question that herbicide damage to crops does occur. It is particularly likely when using herbicides with a narrow range of selectivity between weeds and crop plants. Furthermore, any herbicide treatment is capable of causing crop damage under some set of circumstances. However, one must also appreciate that herbicide damage is often suggested as a "convenient diagnosis" of the problem. Your challenge is to determine whether or not a herbicide was in some way associated with the observed crop production problem and to formulate suggestions for minimizing a reoccurrence of that problem.

Plant growth is continuously influenced by the interactive effects of a variety of environmental, biological, chemical and physical forces. An imbalance among these forces can have rather drastic effects on plant growth. Among these effects is the potential for increased susceptibility of crop species to herbicide damage. On the other hand, the symptoms you observe may be merely mimicking herbicide damage. So keep an open mind, unswayed by pre-conceived notions or the convenient diagnosis of others. Gather all of the relevant facts regarding the problem. Any one of them may be the clue that unravels the entire puzzle as to what happened and why it happened.

The following are guidelines that I've found useful in investigating crop growth problems and alleged herbicide injury complaints. The list is not intended to be all inclusive. Nor will each of the items be relevant to every investigation. But never dismiss any information as unimportant or unrelated to the issue until your complete investigation has proved it so.

--Respond to the inquiry as soon as reasonably possible. Symptoms may disappear or intensify without remedy if you delay too long. Listen to the grower's version of what happened. A neighbor's off-the-cuff impression might also be helpful. Don't commit yourself until you're sure of what happened.

--Are the symptoms characteristic of those you'd expect from the herbicide that was used? Is injury from the use of this herbicide fairly common or is it extraordinary? When was the injury first noticed? Have the symptoms changed? Remember that plants have roots as well as topgrowth.

--What non-herbicide factors might have caused symptoms similar to those alleged to have been caused by the herbicide? Does the injury follow any pattern relative to topography, soil texture or soil organic matter content? Is there an area in the field that was untreated (herbicide) which might be used for comparison? Are neighboring fields similarly affected? Note the crop variety(s) involved.

--What rate of herbicide was applied at what stage of crop growth? Does this use pattern agree with application guidelines as set forth on the herbicide product label? How many acres were treated vs how much herbicide was used vs how much herbicide was left? Were any other products such as oils, surfactants, compatibility agents or liquid fertilizers included in the spray mixture? Did the applicator experience any herbicide mixing difficulties?

--Consider the possibility of herbicide drift, sprayer contamination or carryover damage from a previous herbicide treatment. What herbicide treatments might have drifted from neighboring fields or roadsides? What was the sprayer last used for? What is the past cropping and herbicide use history?

--Have there been unusual weather conditions such as frost, excessive moisture, drought, etc? Check local weather records. What is the possibility of the problem being caused by air pollution?

--What is the plant nutrient availability in the field? If no recent soil test results are available, take a representative soil sample from the affected area as well as one from an unaffected area in the same field. Taking such samples is a good idea even when soil test results are available. The previous sampling may have been too general to detect the problem. Does the area have a history of either major or secondary nutrient deficiencies? What is the physical condition of the soil? Is there evidence that the area was worked wet? Did intense rains cause excessive soil crusting, erosion or sedimentation?

--How much fertilizer was applied to the crop and how was it applied (amount broadcast vs band vs pop-up vs spray, etc)? Is there a possibility that too much fertilizer came in contact with the seed? What fertilization program was used the previous year and the year before that? Were any other soil amendments used?

--Might the symptoms be related to a disease or insect problem? If you suspect a disease problem, submit the affected plants to a plant pathology laboratory for diagnosis. Search both above and below ground for insects and evidence of insect feeding. Have this verified also. Is there a possibility that the damage might have been caused by birds, rodents, deer or other wildlife?

--Does the problem repeat itself within the field on a regular or semi-regular basis? Familiarize yourself with the size of implements used to fertilize the field, prepare the seedbed, plant the crop and apply the herbicide. Could the problem be caused by faulty fertilizer distribution? What about ridging or compaction during seedbed preparation? Does the injury follow the planter pattern (one or more planter shoes reacting differently than the others)? Is a sprayer pattern apparent? Planter and sprayer tracks will generally be visible in a field for some time after planting. If necessary, pay a visit to the machine shed checking the adjustments of the fertilizer spreader, planter, sprayer, etc.

--Was the herbicide up to standard potency? Off grade herbicide is not very likely, but counterfeit herbicide containing reduced levels of active ingredient has occasionally been confiscated. Does the grower have any of the herbicide left or any emptied containers bearing serial numbers of production lots?

--Maintain an air of neutrality throughout your investigation. This may be difficult since you often become involved at one party's request. Verbal conclusions or impressions that you leave during your analysis will be tallied by whomever of the contesting groups gains the most from the comment. So don't share any conclusions until you've gathered all the facts possible.

--What is the "reliability" of the various sources from which you've gathered your facts? You alone can best judge who is telling the whole truth and who is "handing you a convenient line" for his/her own protection. Also, remember that there are instances where certain facts have been lost forever, not willfully, but because they were never recorded. Always carry a camera and a note pad when trouble shooting crop damage. A colored photograph of the problem and its pattern, and a brief written summary of your observations may prove quite useful at some later date if you're asked to describe your observations and impressions to an insurance adjustor or attorney. Your memory will fade substantially with time so keep a good photographic and written record of your impressions.

It has not been the objective of this discussion to make you an expert crop diagnostician. The objective has been to make you more aware of the variety of factors that influence crop growth and to make you appreciate that these factors are constantly interacting. Herbicide use and weed control is one of these factors and, in the case of legitimate herbicide damage, it's obviously a dominate factor. Remember that occasionally even the previously thought impossible can happen. But before you declare so to the world, make sure you have your facts straight and that there's little doubt about your conclusion. Don't go off half cocked! Keep an open mind. Don't stretch your expertise too far. And lastly, don't hesitate to seek the help of others.

01/03/85

IRRIGATION IN MINNESOTA

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INTRODUCTION

Although early records show that some irrigation of fruit and vegetable crops occurred in the Twin Cities area as early as the 1920's, no significant growth occurred until the 1970's. Of major significance to the growth was the introduction into the market of low labor automated distribution equipment that permitted full production type irrigation as opposed to insurance (save the crop) type irrigation. Other factors contributing to the growth rate were the favorable economic period of the early 70's and the drought of the mid 70's.

IRRIGATED ACREAGE GROWTH

Table 1 shows the growth of irrigated acreage in the State for the 15 year period beginning in 1969.

Table 1. Growth of Irrigated Acreage in Minnesota 1969-83

Year	Acreage	Growth Over Previous Year In Acres	Percent
1969	35,000	-	-
1970	44,000	9,000	26
1971	55,000	11,000	25
1972	64,000	9,000	16
1973	86,000	22,000	34
1974	111,000	25,000	29
1975	174,000	63,000	57
1976	222,000	48,000	28
1977	387,000	165,000	74
1978	433,000	46,000	12
1979	450,000	17,000	4
1980	470,000	20,000	4
1981	489,000	19,000	4
1982	498,000	9,000	2
1983	503,000	5,000	1

The absolute growth and growth rate both were the smallest of the 15 year period in 1983. Preliminary indicators are that both of those declined even further in 1984.

The geographic area where most of the development has occurred is in the glacial outwash sand plains of central Minnesota. Counties with 10,000 acres or more irrigated are (listed alphabetically) Dakota, Hubbard, Morrison, Otter Tail, Pope, Sherburne, Stearns, Stevens, Swift, Todd and Wadena.

In the southern part of the State, the counties of Brown, Mower and Freeborn lead in irrigated acreage.

CROPS BEING IRRIGATED

Although irrigation provides the opportunity for the production of specialty crops, the acreage produced of those crops remains small. Corn continues to dominate the list of irrigated crops accounting for 315,500 acres in 1983 which was 63% of the total. Soybeans, potatoes and dry edible beans together account for another 125,000 acres or 25% of the total. The remaining 12% of the acreage includes a wide variety of agronomic and horticultural crops.

IRRIGATION SYSTEMS

An irrigation system consists of a water supply, pumping plant and distribution equipment plus the necessary pipe and fittings to tie them into a unit and any auxiliary equipment to enhance the systems effectiveness.

The most common water supply is a screened well in a shallow surficial sand and gravel aquifer. Depths of these wells range from 30 to 100 feet. Some areas, most notably Dakota County, are using rock aquifers which in Dakota County require a well depth of 300 to 400 feet. A relatively small percentage of the irrigation systems in the State use surface waters. There are several reasons for this, but the two main ones are limited accessibility and State policy which discourages the use of surface water for irrigation.

A deep well turbine pump driven by a hollow shaft electric motor is the most common pumping plant used in Minnesota. Diesel power units are also very popular and may predominate in some areas.

The center pivot dominates the distribution system category even more than corn dominates the crop category. In 1983, center pivots irrigated an estimated 338,500 acres of the total of 503,000 or 67%. Traveling guns irrigated another 135,000 acres or 27% of the total leaving 6% of the acreage to be irrigated by all other systems including drip/trickle systems, hand move systems, solid set systems, etc.

Chemical injection pumps are the most common pieces of auxiliary equipment supplied with irrigation systems. Estimates are that 75 to 80% of the systems in Minnesota have the capability of injecting chemicals. The principal use of these injection pumps is to inject nitrogen fertilizer generally 2 to 4 times during the season. Only in the past couple of years has there been injection of pesticides. Herbicide injection was tested by a few irrigators several years ago, but did not prove satisfactory. The injection of insecticides or fungicides may prove to be more successful than the early herbicide efforts.

SUMMARY

The rapid growth of irrigation in the seventies has decreased dramatically in the past few years. What this growth will be in the future is unknown but considerable potential for increased acreage exists. A return of the favorable cost-price ratio of the early 70's combined with another prolonged dry spell would certainly cause another surge in growth.

Improved management will dominate irrigators concerns over the next few years. The interactions of the changes they make in their management in one area with changes in another area are of increasing concern. Using their irrigation systems as not only a water management tool but also for fertility management and pesticide management is highly desirable if effective and safe.

APPLYING INSECTICIDES THROUGH CENTER PIVOTS[1]

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Applying insecticides through center pivot irrigation systems can be an effective alternative to more conventional forms of chemical application. Reasons for using this method include 1) relatively uniform chemical distribution (it may be desirable to check the irrigation system water application uniformity before chemical injection); (2) flexible timing of chemical applications, (3) possible economic advantage and (4) insecticide effectiveness. <u>However, this method requires specialized equipment, specific application conditions, accurate calibration, and use of critical safety precautions.</u>

The major concern in applying insecticides through center pivots is potential contamination of the groundwater. The insecticide water mixture can be backsiphoned into the well if proper check valves are not in place and functioning. Additional concerns include drift and/or runoff of the insecticide onto non-target areas, and personal exposure to the insecticide during the mixing and application process.

THE INSECTICIDE LABEL:

Any insecticide can be applied through a center pivot if so stated on the product label. Lorsban 4E, Pounce 3.2 EC, Pencap-M and Sevin 80S are currently labeled for center pivot application (see Tables 2 and 3). However, watch for any statement that specifically prohibits application through an irrigation system. The Furadan 4FL label specifically states it CANNOT be applied through a center pivot irrigation system. Injecting an insecticide through a center pivot when the labeling does not specifically identify or prohibit such use is legal if the insecticide is registered for the intended site. Extreme caution is urged in this regard however; pesticide application in a manner consistent with the label, including calibration is the responsibility of the person who actually applies the insecticide.

SAFETY EQUIPMENT:

Insecticides should only be applied through center pivot systems equipped with proper check valves (back-flow prevention devices) to prevent backflow of the insecticide/water mixture into the well if an unexpected shutdown occurs. (See NebGuide G73-43 (Revised, August 1984), "Anti-Pollution

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[1]Some statements in this write-up are based on current interpretations of the federal law (FIFRA) and the rules, regulations and policies thereunder. In the future these could change. Therefore, always consult the labeling which currently accompanies the product being used for complete directions and precautions.

Devices for Applying Chemicals Through the Irrigation System.") Install the check valve in the irrigation pipeline between it and the well. Also place a check valve in the injection line between the point of injection into the irrigation pipeline and the injector pump (normally placed at the injection point). Another necessary feature is an interlock between the power system of the injection unit, the irrigation pumping plant and the pivot. This allows the entire system to be shut down simultaneously in the event of a malfunction. If the irrigation system shuts down, the irrigation pumping plant and injection system shuts down, and vice versa. There are various ways to interlock the system components to cause simultaneous shutdown; consult an electrician or those who service your irrigation or injection system. See table 1 for a list of required and recommended safety devices. <u>All safety devices must be adequately maintained and routinely inspected to assure they will perform as desired.</u>

<u>THE INJECTION UNIT:</u>

For safety and application accuracy, use a separate system apart from that used for injecting liquid fertilizer for applying insecticides. This system should consist of: (1) a nurse tank with agitator, (2) a calibration tube, (3) a positive displacement injector pump, and (4) an inline strainer between the nurse tank and the injector.

Nurse tank specifications, such as size and the material used in its construction (fiberglass, stainless steel, etc.), vary according to the label requirements of the insecticides registered for center pivot application. Consult the insecticide label for specific equipment requirements.

The injection pump can be any positive displacement pump such as a piston or a diaphragm metering pump. At a minimum, the pump must be accurate and all seals made of nonreactive material (viton, teflon, etc.) to withstand chemical breakdown by insecticide carriers.

The calibration tube should be clear, unbreakable and graduated in ounces, pints or milliliters. Its capacity should be sufficient for a minimum of 5 minutes injection time in order to properly calibrate and monitor the application process.

<u>PERSONAL, ENVIRONMENTAL, AND OPERATIONAL PRECAUTIONS</u>:

Always read the label and follow all directions specifically applicable to the insecticide bieng used. In addition, the following categories of safety concerns are associated with chemigation.

<u>PERSONAL</u>

1. Always wear rubber boots, gloves and other appropriate protective equipment at the injection site.

2. Plug the two nozzles outward from the pivot point so sprinklers do not wet down the injection site.

3. Consider identifying the field with a suitable warning sign that states "chemigation is in progress".

4. Use "good housekeeping practices" at the injection site.

ENVIRONMENTAL

1. Do not apply when weather conditions favor insecticide drift from treated areas. Usually this means shutting down when wind speeds exceed 10 mph.

2. Discontinue chemigating if significant rainfall occurs.

3. In the event of accidental well contamination, shut off the injection system and continue pumping water for several hours.

4. Chemigation equipment should not be left unattended. Monitor continuously.

5. Avoid injecting insecticides through center pivots on those fields with permanent or semi-permenant surface water areas, as it could harm wildlife and other non-target plants and animals.

OPERATIONAL

1. Ensure that all equipment (i.e., sprinkler nozzles, end gun shut-offs, check valves, vacuum breaker, hoses, hose clamps, and electrical interlocks) is in working order.

2. If possible, always set the pivot at a high rotational speed when injecting an insecticide. The longer it takes to complete the treatment, the more likely adverse weather conditions will affect the success of the application (Read the label, it will usually specify the preferred amount of water for chemigation).

3. Inject insecticide only when the irrigation system is running.

4. When the chemigation is completed, turn the insecticide injector off and flush the system with water for at least 10 minutes. Drain away from injection site.

CALIBRATION:

Accurate calibration of injection units is essential for proper application. Minor differences in delivery projected over extended periods can cause either excessively high or low application rates and, most likely, unsatisfactory results.

Consideration of several factors is essential for proper calibration, including (1) circumference of the last tower wheel track, (2) acres to be treated, (3) travel speed of the last tower, and (4) application rate of the insecticide delivered by the injection pump. All factors except the last are usually given in the instruction booklet that comes with the center point system. However, one of the most important aspects of proper calibration is to determine the speed of travel as the pivot completes a full circle. Book values of speed at the various settings are usually not accurate enough for chemigation. Therefore it is essential that the actual travel speed (feet/minute) of the system be determined by checking the time it takes for the outside tower to travel a measured distance. Measure this time with a stopwatch while the system is operating at the speed and pressure to be used during the actual chemigation process. A system running dry may travel faster than a system traveling wet. Check this distance per unit of time at several locations in the field if topography is rolling. Use the averaged value.

The rate at which the insecticide is delivered by the injection pump can be calculated in several ways. The metering rate is best determined by using a calibration tube in line between the nurse tank and the injection pump. The calibration tube is filled, the line from the tank is closed, and the material is pumped only from the calibration tube for a specified time period. This method is superior to pumping into a catch basin or container because pressure is maintained against the pump. Coarse adjustments are usually based on one minute time checks. Make a final check over an extended time period (at least 5 minutes). Additional checks during the application process are advisable.

An example of calibration is as follows.

1. Circumference of last wheel track

Calculate the circumference by the formula:
circumference = $2 \times \pi \times r$

Where r = distance in feet from pivot point to last wheel track and $\pi = 3.1416$

Example: r = 1250 ft, so the circumference =
2 x 3.1416 x 1250 ft = 7854 ft

2. Area irrigated

If an end gun or end sprinkler is to be operated intermittently, calculations in this step need to be modified to correctly determine the area to be irrigated. (This is because the system will irrigate a greater area while the end gun or end sprinkler is on than when it is off).

If the calculations consider the end gun running continuously, an over application will result when it is not running; if the additional throw is not considered and it is allowed to function at predetermined locations, under application will result when it is operating. However, if the resulting percentage error in either case is minimal, (less than 2 to 3%), continue your calculations with the assumption that the end gun or end sprinkler is off and allow either to operate. Most likely the resulting percentage error will be greater than 3%, and special calculations and separate calibration adjustments need to be made. Alternatives include: (1) do not allow the end sprinkler or end gun to operate intermittently during the chemigation process and calculate accordingly, or (2) Calculate two insecticide injection rates, a rate when the end sprinkler or end gun is operating and a separate rate when both are not operating, and manually adjust to the correct injection rate coinciding with the on/off operation of the end sprinkler or end gun. See your operators manual to determine acres irrigated when the outside border of the irrigated circle is not continuous.

ASSUMING THE END GUN IS OFF, THE CALCULATION CONTINUES AS FOLLOWS.

Calculate treated acres by the formula:

$$\text{Acres} = \frac{\pi \times r^2}{43{,}560}$$

Where r = distance from pivot point to last wheel track plus length of overhang.

Example:

If r = 1250 ft + 30 ft = 1280 ft

$$\frac{3.1416 \times 1280 \times 1280}{43{,}560} = 118 \text{ acres}$$

3. Rate of travel

Calculate the rotational speed of the pivot by measuring the distance traveled (at the last wheel track) by the pivot while irrigating for at least ten minutes. As stated earlier, check the rotational speed at several locations if the field topography is rolling. Use the averaged value.

Example: 60 feet/10 minutes = 6 feet/minute.

4. Revolution time

Calculate time to complete a revolution by:

$$\text{Time/revolution} = \frac{\text{Circumference in feet}}{\text{feet/minute}}$$

Example:

$$\frac{7854 \text{ ft}}{6 \text{ ft per minute}} = 1309 \text{ minutes}$$

5. Acres treated per minute

Calculate acres treated per minute by:

$$\text{Acres treated/min} = \frac{\text{Number of acres treated}}{\text{minutes per revolution}}$$

Example: $$\frac{118 \text{ acres}}{1309 \text{ minutes}} = 0.09 \text{ acres/minute}$$

6. Application rate

Calculate the amount of material to be pumped per minute by:

Volume of formulated insecticide per acre X acres irrigated per minute.

Example: 1 qt/acre = 946 milliliters/acre
(946 ml/A) x (0.09 A/min) = 85.1 ml/min

The amount of insecticide solution is the working factor necessary to calibrate the injector pump. Proper application depends on exact calculations and an adequate system to calibrate the pump (a calibration tube). CALIBRATION IS STRAIGHTFORWARD BUT TIME CONSUMING; HOWEVER, IT IS ABSOLUTELY NECESSARY. Time spent in calibration is a good investment from a control, environmental, economic and safety standpoint.

Table 1. Safety devices for chemical injection into irrigation systems.

Required

1. Mechanical device to protect underground water supply. (Nebraska Revised Statutes ¶ 46-612.01). A check valve on the irrigation pipeline between the irrigation water source and chemical injection point should satisfy this requirement. The check valve should contain an automatic, quick-closing and tight sealing mechanism to prevent backflow of water when flow in the normal direction stops.

2. Conform to the pesticide label with respect to any special equipment or safety requirements.

Recommended to Provide Minimum Safety Protection

1. Vacuum relief valve on irrigation pipeline between check valve and irrigation water source. This can also serve as an inspection port to check for leakage past the check valve.

2. Interlock chemical injection pump with irrigation system and irrigation pumping plant.

3. Electrical wiring must meet National Electrical Code requirements.[1/]

4. Spring loaded, chemical resistant check valve (minimum opening pressure of 10 psi) on chemical injection discharge line between injection pump irrigation pipeline.

5. Strainer on chemical suction line.

6. Automatic low-pressure drain on the irrigation pipeline with drainage to a point at least 20 feet and sloping away from the irrigation well.

7. All hoses, clamps, and fittings must be chemical resistant and in good repair.

8. Easy access to irrigation pipeline to observe check valve operation and make repairs.

Table 1. continued

Additional Protection

1. Normally closed, chemical resistant solenoid valve in chemical suction line between chemical supply tank and injection pump.

Management Practices

1. Flush injection system after use.

2. Flush the irrigation system after injection is complete and after any shutdown.

1/The National Electrical Code has been adopted by the State of Nebraska, however, inspection of irrigation systems is not normally required. Some power districts do require state inspection prior to providing service.

Table 2. A comparison of insecticides applied through a center pivot irrigation system to control 1st brood European corn borer larvae. Nebraska, 1983-84.

Treatment	mean cavities/plant 1983	mean cavities/plant 1984
Lorsban 4E at 1.0 lbs ai/A plus 1 qt oil	0.8	0.00
Lorsban 4E at 0.5 lbs ai/A plus 1 pt oil	1.7	0.23
Pydrin 2.4 EC at 0.10 lbs ai/A	1.0	NR[1]
Pydrin 2.4 EC at 0.15 lbs ai/A	NR	0.25
Untreated	4.0	2.40

[1]NR = Not represented in text.
All applications with minimal irrigation water.

Table 3. A comparison of insecticide applied through a center pivot irrigation system to control 2nd brood European corn borer larvae. Nebraska. 1983-84.

Treatment	1983		1984	
	Larvae/plant	Yield (bu/Acre)	Larvae/plant	Yield (bu/Acre)
Lorsban 4E @ 1.0 lbs ai/A plus oil	1.4	119	2.99	113
Lorsban 4E @ 1.0 lbs ai/A without oil	1.2	107	NR[1]	NR
Lorsban 4E @ 0.50 lbs ai/A plus oil[2]	NR	NR	2.21	118
Untreated	4.1	94	7.71	80

[1] NR = not represented in text.
[2] Two applications, seven days apart.
All application with minimal water.

COMPARATIVE PERFORMANCE OF CENTER PIVOT, GROUND AND AERIAL PESTICIDE APPLICATIONS

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The utilization of center pivot irrigation systems as delivery mechanisms for pesticides (chemigation) on vegetable crops has received increasing attention in recent years (Chalfant and Young 1982). The choice of foliar pesticides to be used in chemigation is restricted to those materials that are water insoluble, since water soluble materials will not adhere to leaf surfaces (Young et al. 1981). However, chemigation offers several advantages over conventional application methods (Harrison and Stinner 1981), including increased environmental and applicator safety, and reduced cost.

Studies designed to determine the efficacy of various insecticides, fungicides and herbicides applied to potatoes via a center pivot irrigation system and conventional tractor mounted boom sprayer were conducted at the Hancock Experiment Station, Hancock, Wisconsin, from 1979 to 1982. These studies demonstrated that weeds could be successfully controlled with either application method. Fungicide efficacy was slightly better when materials were applied with the conventional tractor mounted boom, but differences in efficacy were usually minimal and no reduction in yield was associated with the center pivot application method. Although the mounted boom provided slightly better insect control than center pivot application of insecticides, the type of material injected into the irriragtion system greatly influenced the level of control obtained with the center pivot method. High levels of insect control were obtained with the pyrethroid materials regardless of application method chosen. However, Orthene provided poor insect control when applied through the center pivot due to its high water solubility. Sevin and Monitor proved to be less effective when applied through the center pivot system compared to ground application; however, the use of an oil to counteract the effects of the emulsified formulation of Monitor may have increased its effectiveness (Young 1980).

To compare the effectiveness of ground rig and center pivot irrigation application methods to the more commonly used aerial application method, studies were conducted in 1982 and 1983 in a 160 acre commercial potato field in the Central Sands area of Wisconsin. In 1982, both fungicides (Duter) and insecticides (pyrethroids) were more effective when applied with a tractor mounted boom than through the center pivot irrigation system, while aerial application was least efficient. However, all application methods provided acceptable levels of pest control as no yield differences were apparent. In 1983, aerial applied Pydrin and Pounce provided slightly better control of tarnished plant bug populations than did center pivot application, but again yield differences were not detected.

The three methods of applying pesticides to potatoes examined in these studies all provided acceptable levels of pest control. Although each method exhibits distinct advantages and disadvantages, the cost effectiveness the center pivot irrigation system as a pesticide delivery system makes it an attractive alternative. However, certain questions regarding chemigation remain to be answered; most importantly the potential for drift and infiltration into the groundwater.

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A CONSULTANT'S VIEW OF CHEMIGATION

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Efficiency is a key word in today's agriculture, particularly in "irrigation country". Equipment and pumping costs, added to the more normal costs of crop production, make it imperative for growers to make every possible use of efficient methods. A $50,000 piece of equipment that can be used for several purposes, should not be used for just one. Center pivot irrigation equipment is such an example.

Over the past 20 years, the center pivot irrigation system has been replacing gravity (ditch, gated pipe) irrigation as a means of applying water to the crop. It has also been installed on lands too rolling for gravity irrigation systems. In Nebraska we now have approximately 4 million acres of crop land irrigated by such systems. Nation-wide there are approximately 12 million acres watered in this way.

Fifteen to 18 years ago, the first chemigation efforts proved successful. Liquid nitrogen applications through the pivot made more efficient use of nitrogen, with much less labor. Then other fertility elements were proven practical through the pivot. Now, approximately half of the pivot systems are used to apply some or all of the fertilizer needed for a particular crop year.

Shortly after fertigation was shown to be practical, herbicide applications were tried through pivots. These, too, proved successful, but to a lesser degree. Herbigation has not taken over as a means of weed control to the extent that fertigation has moved in.

In 1975 I first tried applying an insecticide through the pivot system. It was successful. Since that time, the center pivot, as a field sprayer and chemical applicator, has seen increased use for insecticides, and of recent years, fungicides. It is the application of all these different agricultural chemicals through the overhead irrigation system that has been called CHEMIGATION.

For the most part, both fertilizers and herbicides need to reach the soil to be effective. Generally speaking, fungicides and insecticides need to remain on the plant, except for a very few situations. This requirement is what makes fungigation and insectigation different from fertigation and herbigation. In today's discussion I will largely discuss the use of insecticides through the irrigation system. What I say in that regard, also will generally apply to the use of fungicides through the system.

From 1975 through 1978, my trials with insectigation utilized the insecticide Sevin. During those years, experimental use permits

(EUPs) had to be obtained from the EPA, to use an application method that wasn't on the label of a product. Sevin was chosen because it provides a rapid knockdown of key corn pests and ranks low in toxicity to birds, fish and mammals when compared to many other corn insecticides in use. It also breaks down quickly in the environment, and was readily available.

During those first 4 years of trials, we applied Sevin in 29 separate tests through 10 different center-pivot irrigation systems, to control a variety of corn pests. Early testing included residue studies because we wanted to be sure that the application of Sevin in this way was uniform from the center of the field to the perimeter of the circle. Chemical analyses carried out by Union Carbide Corporation on plant and water samples taken before application, just after application, and at harvest showed a uniform pattern of residues along the entire length of the center pivot boom.

Let me summarize the results of those 29 trials:

FIRST BROOD EUROPEAN CORN BORER: Center pivot applications controlled the borer as well as the standard granule applications made by air.

SECOND BROOD EUROPEAN CORN BORER: Center pivot applications were more effective than standard granule applications.

WESTERN CORN ROOTWORM BEETLES: Center pivot applications were as good in providing initial control as Sevin 4-Oil. Later, beetles migrating into treated fields after rainfall or irrigation with the pivot were controlled by aerially applied Sevin 4-Oil but not by pivot applications. Sevin applied by pivot applications was apparently washed off by the additional moisture, while the Sevin 4-Oil was not.

WESTERN BEAN CUTWORM: Control with the pivot applications was as good as aerial applications.

CORN EARWORM: One center pivot application of Sevin Sprayable gave 44% control of corn earworm larvae already in the silks, compared to an aerial application of 2 quarts of Sevin 4-Oil per acre which controlled 18% of the larvae.

GRASSHOPPERS: Center pivot applications gave from 95% to 97% control of grasshoppers in treated fields.

ALFALFA INSECTS: Center pivot applications were more effective in reducing pest populations of pre-bloom alfalfa than aerial applications.

BENEFICIAL INSECTS: Lady beetle adults were reduced approximately 70% by the pivot applications; but eggs, larvae and pupae appeared to be unaffected. Lady beetle populations returned to pre-treatment levels within two weeks after treatment.

Both lacewings and nabids appeared unaffected by the carbaryl applications. Honeybees did not appear in any of the fields during the tests. Apparently they were frequenting pollen and nectar sources elsewhere during the tests.

Changes in the FIFRA law in 1978 allowed application of insecticides by methods that were not on the label, provided the insecticide was labeled for the crop to be treated and the label did not prohibit such application methods. Since then we have had thousands of acres treated by irrigation water injection, with satisfactory results. Insecticides used include dimethoate, pyrethroids, malathion, chlorpyrifos (Lorsban), and toxaphene as well as several Sevin formulations.

Research by Dr. John Young and his colleagues at Tifton, Georgia, begining about 1977, showed a method of overcoming one of the problems of depending on irrigation systems for insecticide application. Our early work proved that we had to apply chemicals, that were to remain on the plant, in minimal amounts of water. If water application exceeded 1/3 inch, efficacy began to fall off. Dr. Young's work showed that the use of an oil solution, rather than a wettable powder or emulsifiable concentrate, caused the insecticide to remain on the plant, even when higher rates of water were used. Since that information came out, we have generally mixed liquid formulations of insecticide with an equal part of non-emulsifiable oil (either mineral or vegetable) to make an oil solution, prior to injecting the material. Efficacy has been enhanced.

As an independent crop consultant the use of overhead irrigation systems for chemical application provides definite benefits to my clients. It helps amortize some of their very expensive equipment; it gives them control of chemical application timing; it allows them to choose the chemical rather than leaving it to to a commercial applicator, and it provides uniform application throughout the field. If the chemical is being applied when water is needed by the crop, cost is reduced to chemical cost.

Equipment needed for insectigation need not be more than is needed for fertilizer application, depending upon the type of insecticide to be applied. However, many potential insecticides for this use may require explosion proof wiring and steel tanks. Therefore, an initial investment of about $3000-$4000 in additional equipment is desirable. This also makes the system much more flexible in its use. Equipment may be trailer-mounted and used on several pivots.

Environmental and human safety must be considered. It is my opinion that within the next 1 to 5 years, most states will pass legislation making certain requirements mandatory. These will probably include a valve in the main water line to prevent backflow of water and chemical into the water source, interconnecting valves or electrical shutoffs that will shut the pumping system down if the chemical injection unit stops and will shut the chemical injection unit down if the pumping system stops. Regulation may also include a vacume relief valve and placement of the chemical injection port on the vertical water line above the chemical tank, rather than in the horizontal water line at or below the level of the chemical tank.

There is some agitation for EPA to again regulate against using application methods not currently on the label of insecticides. In my view this would be a disadvantage. Rather than that approach, I would support regulation that would place NOT APPROVED METHODS of application on the label.

As a crop consultant, my responsibility is to my client, the grower, to help him be as efficient as possible. This includes adopting those techniques that fit his situation, as soon as possible. Certainly chemigation is one of those that hold much promise. It may not fit all producers because of location, soil type, or other reasons, but it should be considered if the producer uses overhead irrigation.

ENHANCED BIODEGRADATION IN MINNESOTA

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At the consultant level there are two aspects of the problem. One is the technical determination of the phenomenon. The other is the response of grower, consultant, researcher and chemical company to even the potential, let alone real, existence of the problem.

Enhanced biodegradation is merely the extreme of normal soil events. That is to say that along with abiotic breakdown of a chemical, biotic factors are involved as well. And these biotic factors appear to be speeded up as a result of the use of a given chemical.

The consultant, or anyone closely monitoring a crop, is apt to observe the failure immediately. They should right away ask the question "Does this form a pattern?" Two failures of a product are more convincing, of course, than one and so on.

In practice the consultant could be caught in the insecticide "failure" squeeze. At the same time they should singly or collectively attempt to determine the reasons for the failure.

In resolving the problem of "failures" of soil pesticides one immediately runs into the consideration of market. A 3% market share of corn soil insecticide in Minnesota is at least a million dollars. Some of you have clients who spend more on corn rootworm insecticides alone than you earn in annual net income. Such a consideration is going to have an effect on problem resolution as market loss can be simply enormous.

On the other hand a product which performs in an outstanding manner, which is consistent and economically competitive largely sells itself. In that process it establishes a standard for control against which it is itself measured. The better the performance the more notable the failure(s).

In Minnesota beginning in the early 60's we experienced soil insecticide (Aldrin) failures. These were gradual and multiple site phenomena. Toxicity measurements against adults showed resistance to be present. Most chlorinated compounds began to fail as well.

Diazinon (a phosphate) and Bux (a carbamate) replaced aldrin, heptachlor and chlordane. Bux performed especially well and obtained a large share of the corn rootworm market. Neither product, however, held the market for long due to failures. These failures were examined from the standpoint of the resistance failures we had seen earlier. Failures occurred despite no change in adult LD_{50}'s.

Before this problem was completely resolved, Thimet and Furadan entered the market. One performed well, the second outstanding. The use of Bux collapsed.

In 1974 Furadan failed dramatically on a specific site at the Southern Experiment Station - Waseca. Subsequent trials with Furadan and other carbamates demonstrated failures on the same site. Bux, which had never been applied to the site, failed the first time it was tried. Beetles captured from the site were not resistant to any phosphate or carbamate. Carbamates performed well at other sites on the Experiment Station. Sit or field related microbial breakdown appeared the only explanation.

Soil was removed from the site and sent to several labs. Conflicting data developed, probably as a result of lack of uniformity in handling the soil samples.

In 1979 a similar site appeared at Morris with exactly the same apparent cause (i.e. Furadan history) and the same effects (i.e. carbamate failures). During the 1979-80 educating season John Lofgren and I suggested this to be microbial breakdown and a site related phenomena. With other evidence that was available we suggested other carbamate products would fail on these sites. Work by Kaufman, Warnes and others have shown this to be true and that multiple failures (e.g. between different chemistry) are possible as well.

The consultants role in the future will include early definition of failures that are almost sure to appear. They should educate growers about these potential problems. They should communicate among themselves and with researchers to properly define the problem and permit sound explanation.

From the practical standpoint the consultant may want to suggest rotations of soil chemicals that do not enhance biodegradation. Information as to which rotations are best seems desirable.

When the same microbe (or group of microbes) is known to "consume" both an insecticide and herbicide one should probably attempt to prolong the effectiveness of the herbicide. Herbicides generally provide a higher net return to the grower, and their conservation should take precedence over conservation of insecticides.

With corn rootworm control we have the option of crop rotation. When this is the most profitable option it is clearly the first choice in insect control. Crop rotation may be necessary to prolong the effectiveness of soil chemicals.