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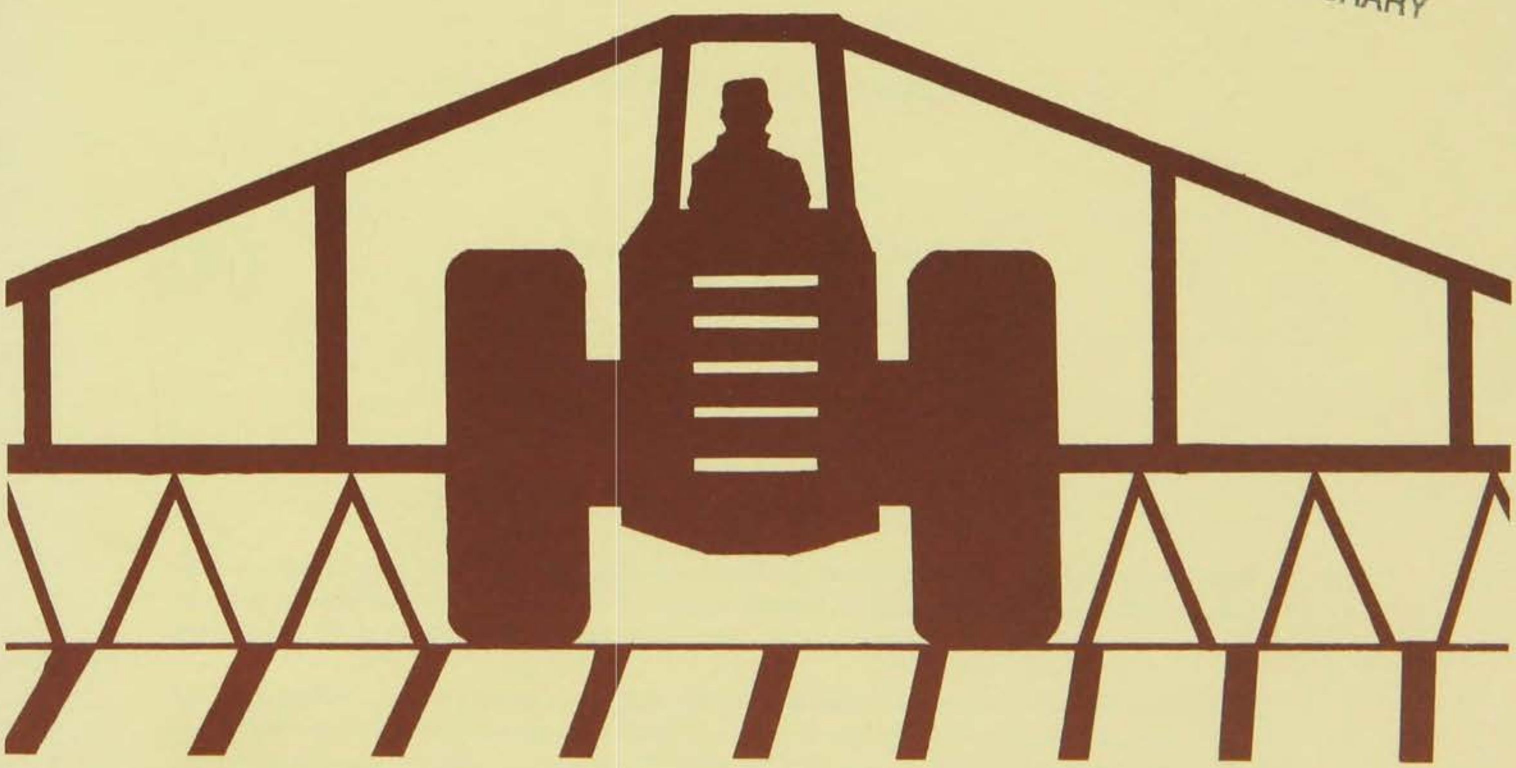

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PROCEEDINGS

SOILS, FERTILIZER AND AGRICULTURAL PESTICIDES SHORT COURSE

December 15-16, 1987
Minneapolis Auditorium

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INTEGRATED CONTROL OF CORN STORAGE MOLDS

D. G. White, B. J. Jacobsen, J. W. Shriver and R. W. Sholtis

INTRODUCTION

Every year, farmers in the Midwest harvest grain crops of exceptionally high-quality. These crops, however, do not always stay in a high-quality condition and are often of poor quality by the time they reach the end user. In general fungi and insects are responsible for deterioration after harvest and a basic understanding of the biological basis for deterioration of grain is necessary to make intelligent decisions and to prevent quality deterioration after harvest. The fungal kernel rots of corn can be divided into those caused by field fungi and storage fungi. Those fungi classified as field fungi are organisms that require high moisture (above 18%) in order to grow and reproduce. These fungi are responsible for causing ear rots on the crop in the field. Losses from ear rots are rarely severe in the Midwest except in years when wet conditions prevail after pollination or where drought and/or insect damage occur. Storage fungi grow below 18% moisture and the two most important storage fungi are in the genera *Penicillium* and *Aspergillus*. These fungi may occasionally be found as ear rot pathogens in the field; however, they are not normally associated with the crop until after harvest. These fungi are found associated with dead plant material, soil, and in other places where moisture levels are relatively low. Spores of these fungi from dead plant materials and soil are spread during the mechanical combining of the grain crop. The grain becomes coated with additional spores during the drying process as air with spores is passed over the grain. More spores become coated onto the grain during loading and unloading, and the blending of fines and/or badly contaminated lots of grain into good grain lots. In our experience, a high percentage of corn kernels are infected with *Aspergillus* or *Penicillium* sometime by the summer following harvest. In 1983, we found 80 to 100% of the corn kernels infected with *Aspergillus* in bins in central Illinois by December. The 1983 year, however, was exceptional for contamination of grain by *Aspergillus*. In 1984, we found 10-40% of the kernels were infected by *Aspergillus* and/or *Penicillium* in December with 60-90% of the kernels infected with *Aspergillus* and/or *Penicillium* by August, 1985. After a kernel is infected by a storage fungus, the fungus starts to rot the kernel any time that moisture and/or temperature conditions become favorable for fungal growth. In general, under favorable temperature conditions, *Aspergillus* species can grow at moistures as low as 13.1% with rapid growth above that moisture level. *Penicillium* species will grow at moistures exceeding 16%. As these fungi grow they produce metabolic heat and moisture which create conditions ideal for field fungi thus speeding the decay process. Therefore, deterioration of grain during drying, shipment and storage is caused by fungi and prevention of deterioration during shipment and storage is for all practical purposes a disease control problem.

[1] First and second authors are Associate Professor and former Professor of Plant Pathology, University of Illinois, presently Head, Department of Plant Pathology, Auburn University, Auburn, Alabama. Third and fourth authors are Senior Research Biologist and Account Supervisor, MSD AGVET, Division of Merck and Company, Inc., respectively.

Currently our control of storage molds relies on the integration of three controls. (1) Prevention of mechanical damage during harvest and transportation of grain. An intact kernel of corn is much more resistant to penetration by fungi than a kernel that has been cracked or broken. (2) Keep moisture levels below those that are optimum for fungal growth. (3) Where possible, keep the grain temperatures below 40°F particularly in much of the Midwest, when temperatures during the winter months are below optimum levels for fungal growth. This allows for safe storage at 15 to 16% moisture.

Mechanical damage. Mechanical damage is done at different times in the handling of grain. The first opportunity comes during harvest when corn kernels are removed from the ear. When corn is harvested at a high moisture, or the combine is in poor adjustment, damage is much greater. Additional damage is done as corn is moved during drying and shipment. It is important to realize that kernels with cracks or exposed starch surfaces are much more susceptible to penetration by storage fungi.

Low moisture. The major control of storage fungi is to dry corn below the moisture at which fungi will grow. The most common practice in use today is the use of high temperature drying where corn is harvested at an average of 20-25% moisture and dried at a high temperature to a moisture of 15 to 16%. High temperature drying has a major advantage in that it is very rapid and can be done in wet weather. A major disadvantage is that it requires a relatively large energy input, in the form of propane or natural gas, and as corn is heated and cooled very rapidly, stress cracking occurs. Stress cracking is the occurrence of very small cracks in the kernel caused by rapid heating and cooling. Stress cracking is a problem in corn because as grain is handled during shipping the kernels with stress cracks have a tendency to break. Stress cracks also act as sites for penetration by fungi.

An alternative to high temperature drying is some type of low temperature drying where moisture is removed with ambient air or air with very little heat. This procedure is not as widely used as it could be because drying is slow and fungi have an opportunity for growth at the higher moisture during drying. The effectiveness of the drying process depends upon ambient air conditions and during falls with warm moist conditions, grain that is undergoing low temperature drying will often spoil due to the growth of fungi in the slow-drying grain. Low-temperature drying, however, has two major advantages. (1) It requires less energy, and (2) little or no stress cracking occurs. Grain successfully dried using low temperatures does not break as easily during transportation, contains fewer broken kernels, and thus is of higher quality. Such corn has better storage life and yields more in some types of processing.

Cool temperatures. Cool temperatures are used to control of storage fungi in much of the upper Midwest. It is well known that cool temperatures have long been used in the preservation of high moisture commodities such as fruits and vegetables. The value of a grain crop, however, is not high enough to warrant refrigerated bins. During the winter months cool air is blown through the grain and the grain mass then becomes cold enough to prevent the growth of fungi. Therefore, cold temperatures can only be used when the outside air temperature is cool enough to allow its use.

Integration of current controls. With these three controls available, the common practice is to use high temperature drying to dry corn to 15-16% moisture and then maintain this moisture as long as temperatures are cool. We are able to store corn in much of the Midwest from harvest through the spring with a combination of cool temperature and moistures of 15 to 16.0%. During the spring, some kernels which have higher moisture due to moisture migration or uneven drying may begin to decay due to fungal growth at warmer temperatures. Additional moisture and heat are produced by fungal metabolism, thus allowing for their favorable growing conditions in very large areas of the grain mass. To prevent this, corn to be kept through the summer is often dried to 13.5 to 14% moisture, therefore moving to moisture levels less conducive for fungal growth. Drying to 14% moisture or below, however, is not desirable because of shrink discounts and because corn at low moisture, particularly with stress cracks, is more subject to breakage than corn of higher moisture corn.

How fungicides fit into an integrated system of control of storage molds. Another potential control of storage molds in grain would be the use of chemicals. A number of different methods to chemically control storage fungi have been tested over the last 40 years. In 1947, Milner et al. (12) tested over 100 compounds for their fungicidal activity on stored wheat. Some compounds slowed the rate of fungal growth, but they did not find a compound which was consistently effective and safe.

Propionic acid has been used as a preservative in stored corn (3, 8, 9, 10, 11, 12, 22), sorghum (10, 18, 22) barley, oats, wheat (10) and forages (8). Although propionic acid treated grain may enhance feeding efficiency in cattle (9), it also destroys grain germinability (18), is corrosive to bins (1) and treated grain is not suitable for direct human consumption (18).

Ammonia has also been tested as a grain preservative in corn (2, 8, 20) and forages (8). While it is an effective control method, ammonia treatment results in discolored grain with a residual ammonia odor (2).

Formaldehyde (17), sulfur dioxide (5, 6) and sorbic acid (4, 22) have also been considered as potential grain protectants. While all show some degree of effectiveness, each has particular disadvantages. Formaldehyde treatment of wheat destroys the baking quality of wheat flour and results in a depressed growth rate, feed intake and feed efficiency ratio in chicks (17). Sulfur dioxide reduces grain germinability and is corrosive to galvanized steel (5, 6). Sorbic acid, while very effective in laboratory tests (4, 22), was not effective in actual storage tests with wheat (4). Sorbic acid is also water insoluble and more expensive than propionic acid.

Within the last 15 years, systemic benzimidazole fungicides that have the potential to inhibit storage molds have been developed and marketed (7). Benomyl and thiabendazole have activity against *Aspergillus* spp. and *Penicillium* spp. while having low mammalian toxicity. Laboratory experiments by Niles with barley samples treated with different fungicides suggested that several compounds, particularly benomyl, may be effective as grain protectants (19). Niles also suggested that these compounds may be much more effective with improved application methods. Recent work has shown that several fungicides prevented infection by storage fungi and effectively protected seed germinability (14, 15, 16). Preliminary experiments with benomyl, thiabendazole and A9248 treated corn stored at 90% RH and 26°C confirm the effectiveness of these compounds as potential grain protectants (24). Since storage mold fungi do not usually invade kernels prior to harvest (21, 23), fungicides applied at harvest may be useful as grain protectants during ambient air drying and storage of corn grain.

During the past four years the University of Illinois, Department of Plant Pathology has developed facilities for testing fungicides to prevent spores of fungi from germinating and penetrating individual kernels of corn. This type of control is used in the preservation of a number of high-moisture commodities such as fruits and vegetables. With high-moisture commodities, low temperatures are a major control of decay producing organisms. For the last twenty five years, temperature and fungicides have been used together to prevent storage diseases in fruits and vegetables. Experiments at the University of Illinois have combined the use of fungicides and low temperature drying to result in better quality grain. This research has been funded by a number of chemical companies as well as the Illinois Corn Marketing Board, Quaker Oats, and the Anderson Research Fund. These studies have resulted Section 18 emergency exemption for Illinois under the provisions of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) to the Illinois Department of Agriculture for the use of MERTECT 340-F to suppress growth of Aspergillus species and Penicillium species on corn grain. MERTECT 340-F should have a full Federal label by the summer of 1988 and hopefully other fungicides will be labeled soon.

The advantages of fungicides in an integrated system to control storage fungi are not completely clear at this time. Care should be taken to understand the limitations of fungicide use so their advantages will not be overstated. A number of potential questions and answers concerning the use of fungicides in the preservation of stored grain are discussed below.

Propionic acid. A question that usually occurs when explaining the use of fungicides as preservatives of stored corn is how MERTECT 340-F is similar or dissimilar to propionic acid or mixtures of related acids. Acids are corrosive to bins and cause off-flavor of grain. The major advantage of propionic acid is that it can be used with corn at high moisture and that grain will stay in good condition. Acid treatment is presently used mainly for corn to be used for animal feed. The use of MERTECT 340-F, on the other hand, is intended to preserve grain during drying and storage where grain moistures will eventually reach 16% moisture or below. MERTECT 340-F is not effective in preservation of grain at high moisture and should not be considered comparable to propionic or other related acid. The major advantage of MERTECT 340-F is that it is not corrosive to bins, is less expensive, and does not change the color or taste of the grain.

How should MERTECT 340-F be used in combination with natural air drying? For low temperature drying the recommendations are: (1) combines should be adjusted to reduce mechanical damage, (2) grain should be harvested at 25% moisture or less, (3) each bushel of corn should be treated immediately with .03 fluid ounces of Mertect 340-F in three ounces of water carrier, (4) fans should be turned on immediately to achieve one CFM air flow and (5) drying should continue until grain moisture is 16%. These recommendations are not much different than those without fungicide use. In many years these recommendations without fungicides would result in kernels damaged by

Aspergillus spp and *Penicillium* spp. With fungicide treatment, the damage is greatly reduced but may not be eliminated. The fungicide is most effective when combined with reduced mechanical damage, good air flow in drying bins, cool temperatures in winter, and a moisture content below 16%. The fungicide may compensate for (1) some damage done in harvest, (2) slightly lower than 1 CFM air flow, and (3) moistures during the winter of more than 16%. It will not compensate if any of the other three methods of control of storage molds is completely neglected.

Can MERTECT 340-F be used before moving corn through a high temperature dryer? During the last two years we have done experiments where corn is treated before high temperature drying and after high temperature drying to determine if there is any loss in effectiveness of the fungicide. The physical characteristics of the active chemical ingredient in MERTECT 340-F and the efficacy indicates that no breakdown occurs at temperatures of 200°F or less. Experimental results show that MERTECT 340-F is stable during high temperature drying.

Can old corn (previous years crop) be treated with MERTECT 340-F? We have limited experience with treating large amounts of a previous year's crop with a fungicide to determine the efficacy of the fungicide on old crop. In using Mertect 340-F we are attempting to prevent germination and penetration of fungi into corn kernels. It has been our experience that after one year following harvest many kernels are infected with *Aspergillus*, or *Penicillium* or both. If the grain is already infected with these fungi it is doubtful that MERTECT 340-F would be of any benefit in preserving corn. We have, however, some information from laboratory studies that contradicts this assumption. We are also treating some old crop corn on farms to determine what efficacy may be obtained with this type of application. In general, however, we fully expect that the best results will be achieved by treating corn immediately after harvest.

Cost. The application of MERTECT 340-F at .03 fluid ounces of product per bushel will cost less than 3¢ for the fungicide. Any cost for treating equipment will need to be added onto the cost of the fungicide. This cost can be rapidly recovered from the avoidance of shrink and poor quality discounts.

Application of fungicide. The most likely source of error is to apply too little fungicide to grain and to have poor coverage of individual kernels. The entire kernel should be covered to protect all sites from fungus penetration. We have been extremely cautious in treatment methods to cover entire kernels. We probably have "over-engineered" our treating equipment for good coverage and are using water rates at higher than the minimum needed. A treater that we do know is effective is a proprionic acid treater. These treaters are short, 6-8 foot treaters that are basically a 6 inch auger for 3 feet that allows metering of grain so grain flow is established at one rate followed by an 8 inch auger in the same tube to allow for mixing. The 6 inch and 8 inch augers are both a solid tube with the auger screw on the inside against the tube wall. The treater we have used in the last two years of our experiments was developed by John Shriver of Merck and Company. This treater has a lower portion that regulates grain flow, with an 8 inch auger inside an 8-5/8 inch tube. The upper portion of the treater is a 12 inch auger in a 13 inch tube. The fungicide is applied as corn passes through the 12 inch portion of the auger and is sprayed onto the corn using hollow cone nozzles.

In the 12 inch section, the auger also contains, three sets of agitation bars which mix the grain after it passes each set of nozzles. These bars are rods welded between the flightings of the auger. A separate metering pump package that meters Mertect 340-F directly and mixes it with water just prior to being sprayed onto the grain has been developed. The treater auger and metering pump may be ordered through Paul's Machine and Welding, Villa Grove, Illinois.

1986-87 RESEARCH

On Farm Testing.

Merck and Co. conducted studies in numerous locations in Illinois and other states. Most of these studies involved a comparison of a bin treated with MERTECT 340-F and an untreated bin. For the purpose of this report four such locations were selected where treated and untreated bins could be compared (Table 1). All fungicide treatments of .03 fl oz MERTECT 340-F per bushel in 3 oz water carrier were made using the treater auger available at Paul's Machine and Welding in Villa Grove, IL. It is necessary to point out that data from unreplicated "on farm" bin experiments is difficult to interpret because moistures in bins are not always identical. Additionally, the corn used to fill one bin may be of a different hybrid than corn used to fill another bin. Data presented here represents an average of samples taken from four quadrants in the upper three to six feet of grain in the bin. The percent Penicillium spp and percent Aspergillus spp is based on isolations from 50 kernels per sample plated on malt salt agar. The percent damaged is based on results from federal grain inspection.

The data from Farm Study One are probably the most useful. At this farm the harvest moisture was 20-22% and one untreated bin could be compared to two different treated bins. In January the moisture was 20% or above and there was very little storage fungi activity. In March, the percent Penicillium spp increased in the untreated bin but was controlled by the MERTECT 340-F in both treated bins. The grain moisture in the untreated bin was reduced to 17%. In April, corn in the untreated bin continued to have Penicillium spp activity and corn in the two treated bins had little or no Penicillium spp activity even though grain moistures were at 20%. In May, corn in the untreated bin had started to go out of condition and the grain moisture was reduced to 13.3%. At this time, corn in the untreated bin had a 8.6% damage and corn in the two treated bins had less damage even though the moisture had been maintained at a higher level. Corn in the second treated bin, however, did have Penicillium spp activity. In August, corn in the two treated bins still had much less damage but did have some Aspergillus spp activity. Corn in the untreated bin, however, had 21% damaged kernels. In this experiment it was evident that corn treated with fungicide could be kept at a fairly high moisture with minimal damage.

The data from Farm Study Two represents a situation where no advantage was seen due to treatment with a fungicide. At this location the harvest moisture was 16-17% and corn was kept at 13-15% grain moisture. In both treated and untreated bins, the activity of storage molds was minimal and damage was below 1%. In Farm Study Three the harvest moisture was not known and only one sample was taken in May. It was known, however, that the two bins were filled at the same time with corn from similar fields. In this situation, corn in the untreated bin had Aspergillus spp and Penicillium spp activity and a percent damage of 26.2%. Corn in the treated bin, had much less storage fungi activity and much lower percent damage. In Farm Study Four the harvest moisture was 17-18% and was not dried below 15.2%. In this study it is unfortunate that the control bin was kept at a higher moisture than the treated bin. This may help to explain the bad condition of corn in the control bin at the final sampling in July.

Several conclusions can be made from the farm studies presented in this report and other farm studies done by Merck and Co. In all studies treated corn did have less fungal activity than untreated corn. However, in some bins where corn was held at a high moisture, storage molds were active and damage did occur even though grain was treated. It is necessary to continually emphasize that fungicides are part of integrated pest management system and are not a "cure-all" allowing for avoidance of other management techniques.

<u>University of Illinois Experiments</u>

Three separate experiments were done at the grain storage facilities at the University of Illinois. Experiment one was to determine the effects of high temperature drying on the efficacy of MERTECT 340-F. Experiment two was to determine the effect of various methods of application of MERTECT 340-F in conjunction with low temperature drying. Experiment three was to determine the effectiveness of Iprodione which is a compound from Rhone-Poulenc Corporation Inc. that was identified in laboratory testing during 1986 as a possible candidate for control of storage fungi in corn. Experiments were done in two modified 2700 bu grain bins located at the Agronomy-Plant Pathology South Farm, Urbana, Illinois. Each bin has 16 wedge-shaped compartments which contain various treatments. Each wedge has sample ports so samples can be taken various distances from the grain drying floor to the top of the bin. For the data reported here samples were taken from 1.2, 2.4, and 3.6 meters (bottom, middle and top respectively) from the drying floor. All experiments were in two replicates. Data on fungal isolations are based on the average of fifty kernels from each of two replicates and the three sampling levels. Percent damaged kernels is based on federal grain inspection of samples from three sampling levels and the two replicates.

<u>High temperature drying - Experiment one</u>. In the experiment with high temperature drying the treatments were untreated high temperature dried, treated with .03 fl oz MERTECT 340-F per bushel using 3 oz of water carrier after drying, treated with .03 fl oz MERTECT 340-F per bushel using .2 fluid oz of mineral oil as a carrier before drying, and treated with MERTECT 340-F per bushel using 3 oz of water carrier before drying. The main purpose of this experiment was to determine if high temperature drying caused any reduction in the efficacy of MERTECT 340-F due to chemical breakdown with heat.

Corn was harvested on September 23, 1986 at approximately 21% moisture and was dried to 17% moisture using an M & W Batch Dryer. The plenum temperature was kept at 200°F and grain was heated to 140°F to obtain the moisture of 17% (Fig. 1). Grain moistures were further reduced by ambient air drying with a flow rate of .5 CFM per bushel of air flow to an average of grain moisture of 15-16%. These moistures were then maintained for the duration of the experiment. As was expected, the amount of <u>Penicillium</u> <u>spp</u> occurring in the high temperature experiment was very low. (Fig. 2). In all cases, treatments controlled the Penicillium spp throughout the duration of the experiment. With respect to Aspergillus spp (Fig. 3) the MERTECT 340-F with mineral oil carrier before drying and the MERTECT 340-F with water carrier before drying provided the best controls. This result may have been due to the circulating activity of the batch dryer which may have resulted in better distribution of the fungicide on the kernels. The results of percent damaged kernels were similar to the results with Aspergillus spp in that damage was lower with the treatments applied before drying (Fig. 4).

Low Temperature Drying with Various Methods of Application of MERTECT 340-F - Experiment two - Three different methods of application of MERTECT 340-F were compared to an untreated control. One method of application was with a plexiglass hood which was built over part of the boot of the fill auger. This hood restricted grain flow and completed a spray chamber in which grain was exposed. With application at the boot, two different methods were used. One was to use 3 fl oz of water as a fungicide carrier and, the other was to use .2 fl oz of mineral oil as a fungicide carrier. The 4th treatment was the use of the treater auger which had been used in previous experiments. In this experiment grain was harvested at approximately 20% moisture treated with various fungicide treatments and placed into the bins for drying. Grain moisture levels at the bottom sample level were allowed to drop to approximately 15%. Grain at the middle sampling level was approximately 16.5% moisture and approximately 17.5% grain moisture at the top sampling level. These moistures were maintained through the first 31 weeks of the experiment after which the fans again were turned on, which further reduced grain moistures. (Fig. 5) All three methods of application were successful in reducing percent Penicillium spp. (Fig. 6) This was not the case with respect to Aspergillus spp in that the application with .2 fl oz of mineral oil was not successful. The treater auger however, was successful as was the application of MERTECT 340-F with water carrier applied at the boot. (Fig. 7). Percent damage had results similar to the total Aspergillus spp in that MERTECT 340-F with .2 fl oz of mineral oil as a carrier did not provide adequate control of storage molds and the damage with that treatment was as high as with the control (Fig. 8). The treater auger and the application of MERTECT 340-F at the boot with a water carrier did provide a significant decrease of percent damaged kernels. It appears in this experiment that the use of .2 fl oz of mineral oil is not advisable with low temperature drying. This is probable because the mineral oil in such low amounts does not provide enough carrier for the fungicide to give adequate coverage of individual kernels. It also seems that adequate coverage may not be as important with Penicillium spp as it is with the Aspergillus spp. This could be in part due to the fact that MERTECT 340-F is extremely effective against Penicillium spp but not as effective in the control of Aspergillus spp.

To Determine the Effectiveness of Iprodione - Experiment 3 - Iprodione was identified in laboratory studies in 1986 as being a potential candidate for control of fungi during low temperature drying and storage. The compound was evaluated in a low temperature drying study at the rates of 0, 5, 10, and 20 ppm fungicide per grain weight adjusted to 15% moisture. With this experiment grain was harvested at 21% moisture and treatments were applied using the treater auger. Grain was allowed to dry in a similar fashion to the MERTECT 340-F low drying temperature experiment (Fig. 9). Iprodione provided good control of Penicillium spp (Fig. 10) with all rates being effective in control of that fungus. With respect to Aspergillus spp, here again, the compound provided good control with higher rates being more effective. (Fig. 11) The differences in percent damage (Fig 12) was very striking with this compound in that increasing rates provided more effective control of damage to kernels. Iprodione is a very good candidate in grain storage and additional experiments have been started this year to evaluate it with even higher moistures at harvest and with high temperature drying.

CONCLUSIONS

The experiments done in 1986-87 support the contention that fungicides will fit into an integrated pest management system. They further point out that fungicides are not a "cure-all" for bad management and must be used in conjunction with other methods of control. It should be reiterated that fungicides will provide control and suppress storage molds particularly when compared to untreated grain, however, we do not want the effectiveness of these compounds to be overstated.

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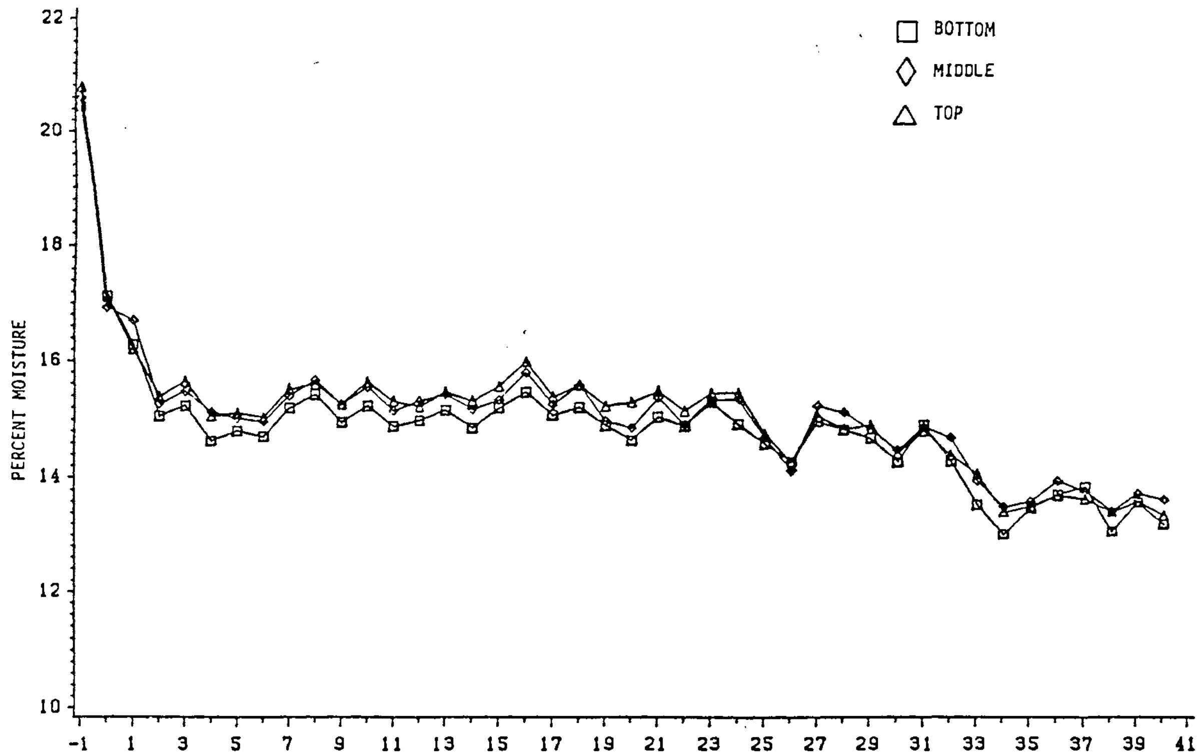

Figure 1. Grain moisture taken from three sampling levels in the bin averaged over two replicates in experiment 1. Week -1 is before drying.

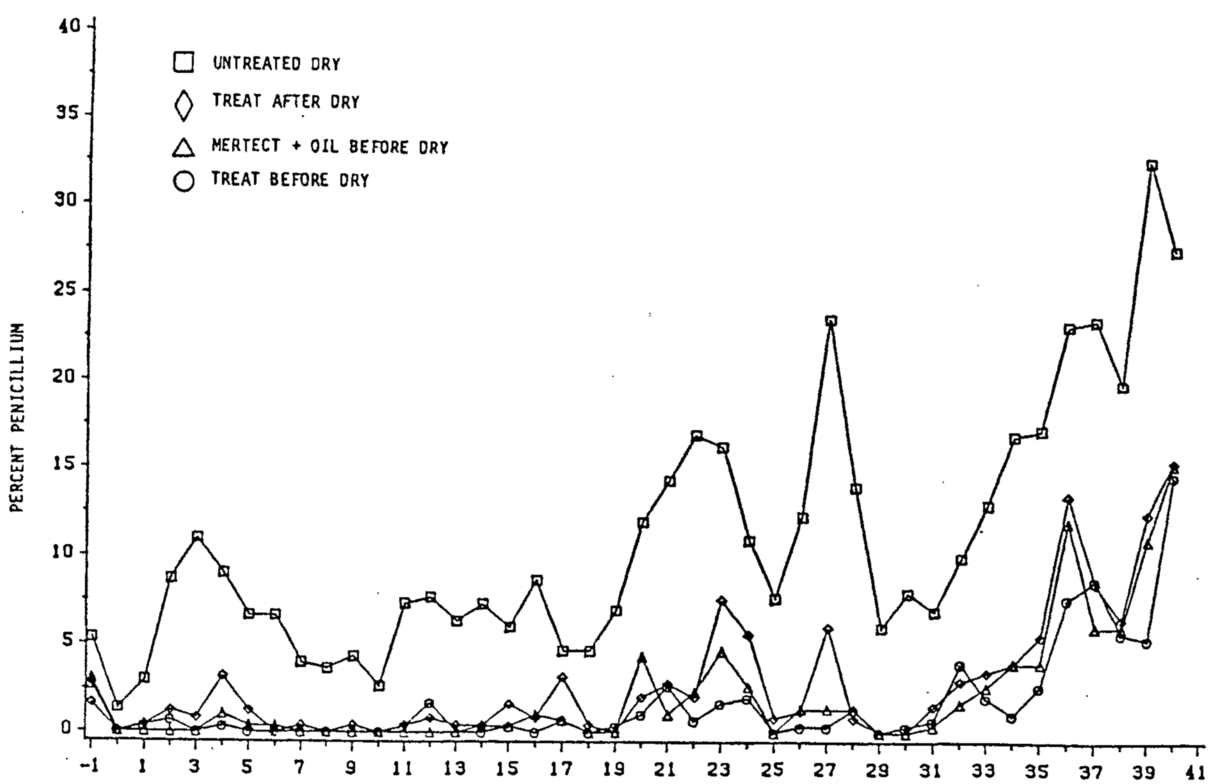

Figure 2. Percentage of kernels out of fifty infected with *Penicillium spp* averaged over three bin sampling levels and two replicates in experiment 1. Week -1 is pretreatment.

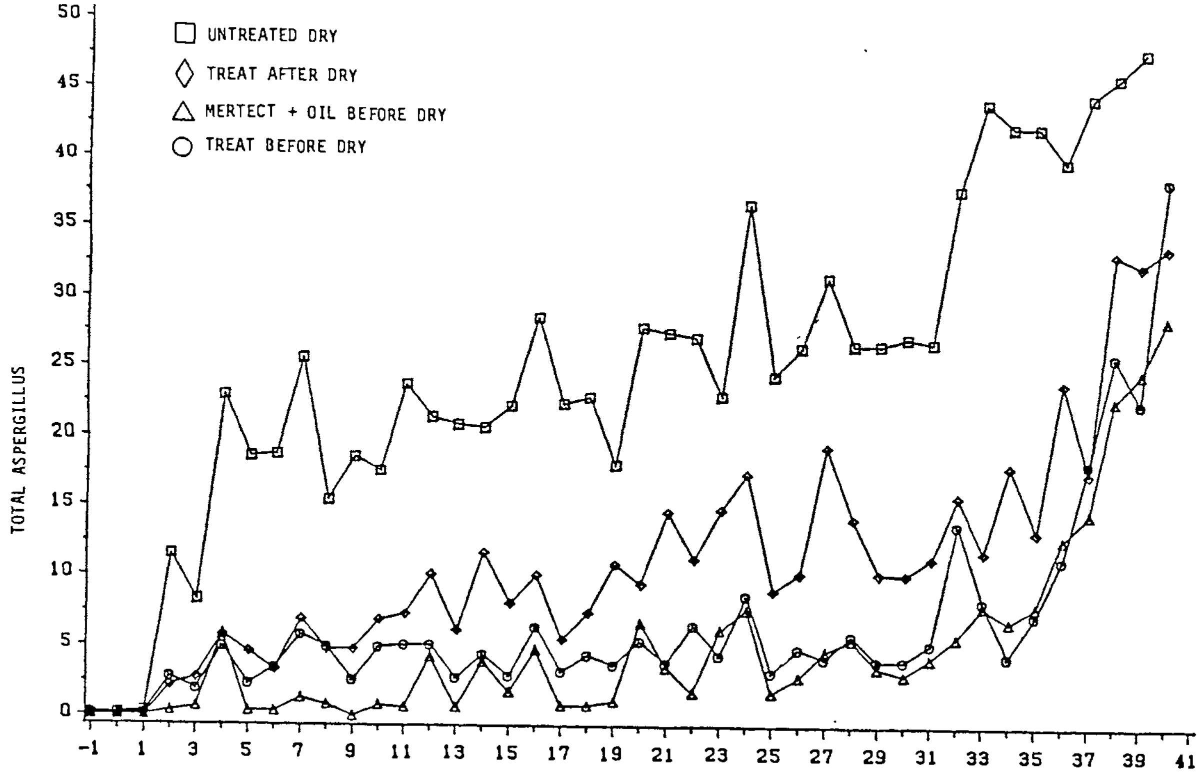

Figure 3. Total number of *Aspergillus spp* isolated from fifty kernels averaged over three bin sampling levels and two replicates in experiment 1. Week -1 is pretreatment.

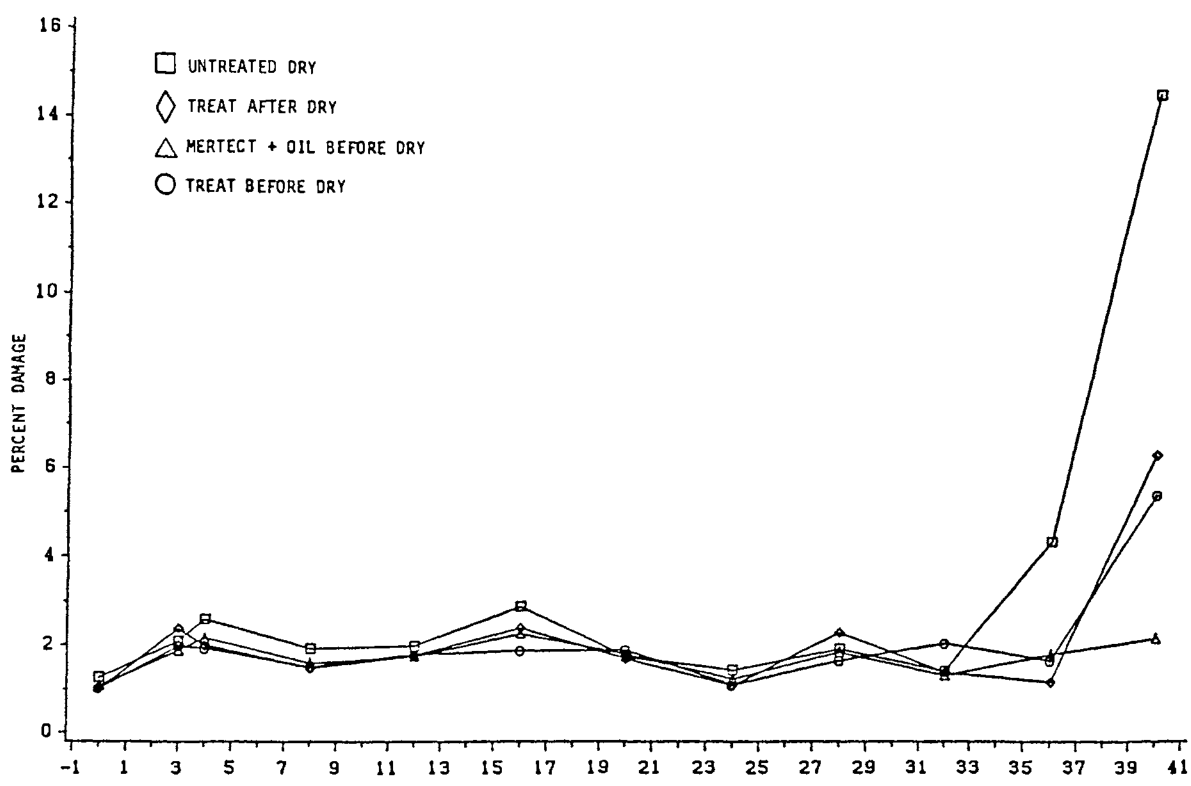

Figure 4. Percent damaged kernels as determined by federal grain inspection averaged over three bin sampling levels and two replicates in experiment 1.

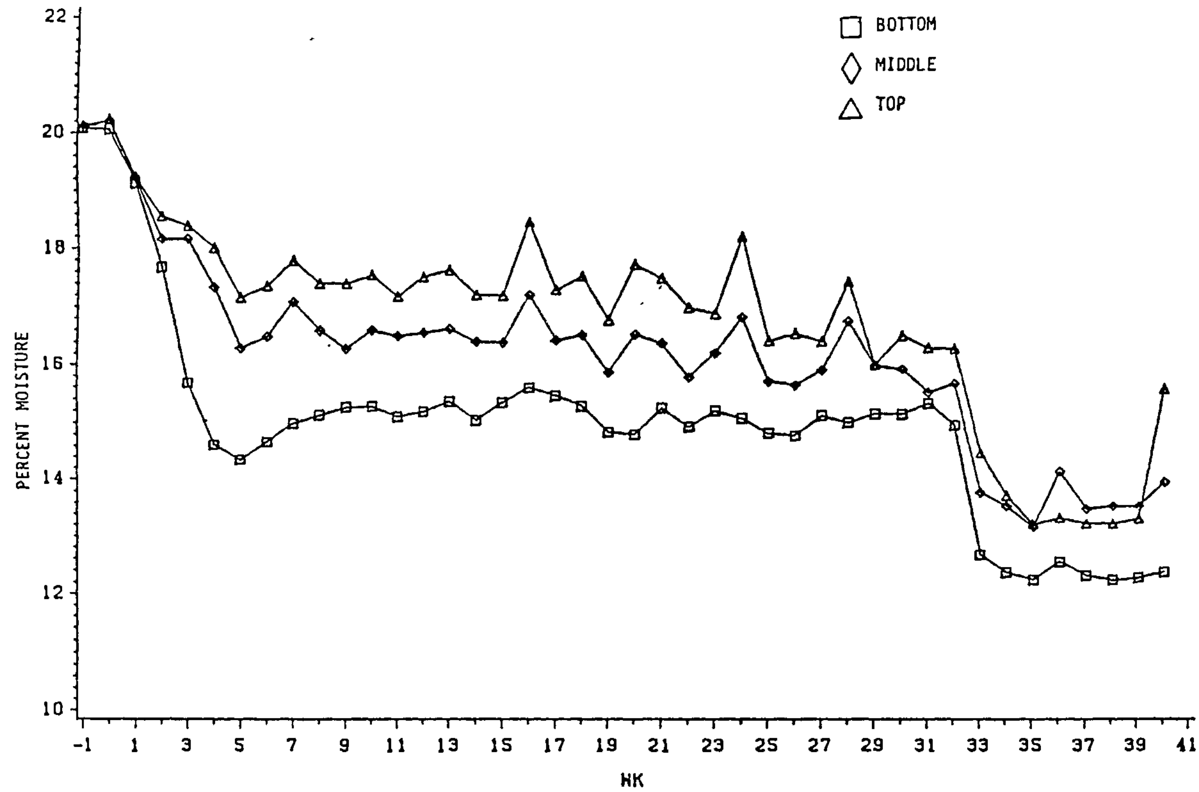

Figure 5. Grain moistures taken from three sampling levels in the bin averaged over two replicates in experiment 2. Week -1 is pretreatment.

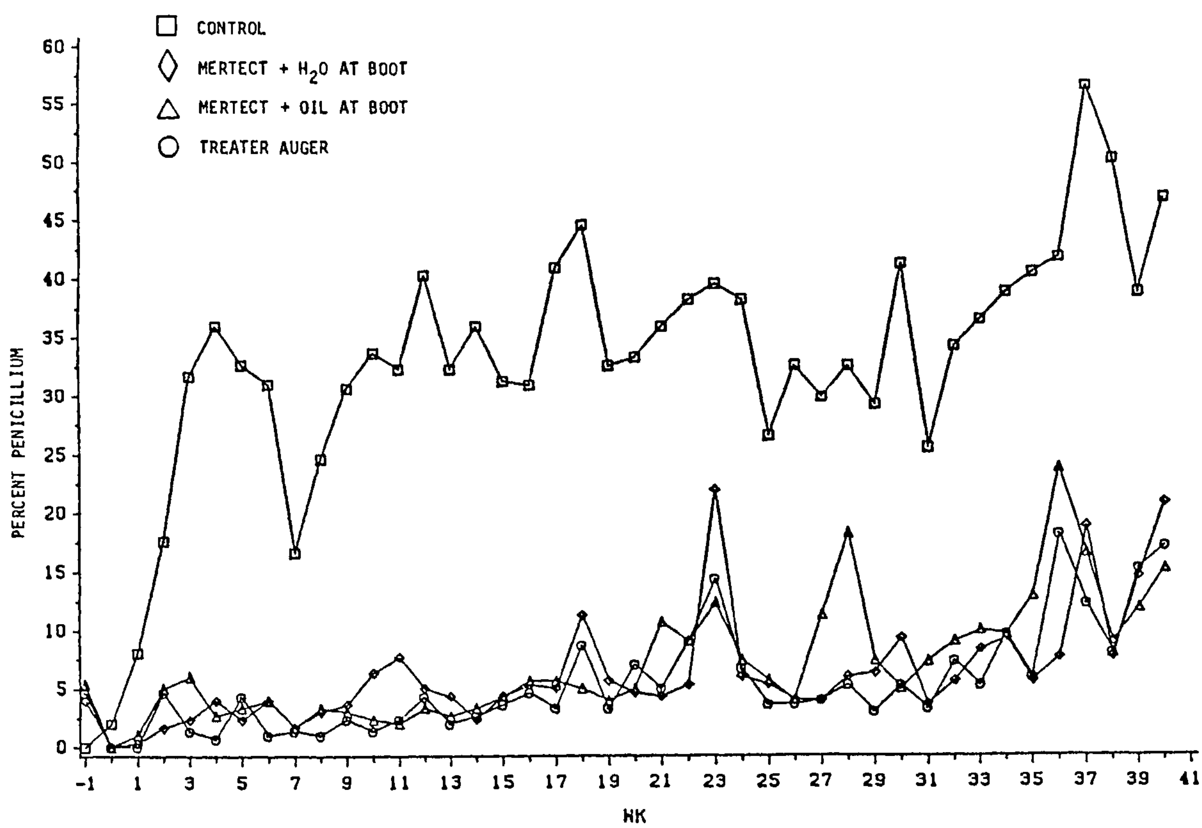

Figure 6. Percent of kernels out of fifty with <u>Penicillium spp</u> averaged over three bin sampling levels and two replicates in experiment 2. Week -1 is pretreatment.

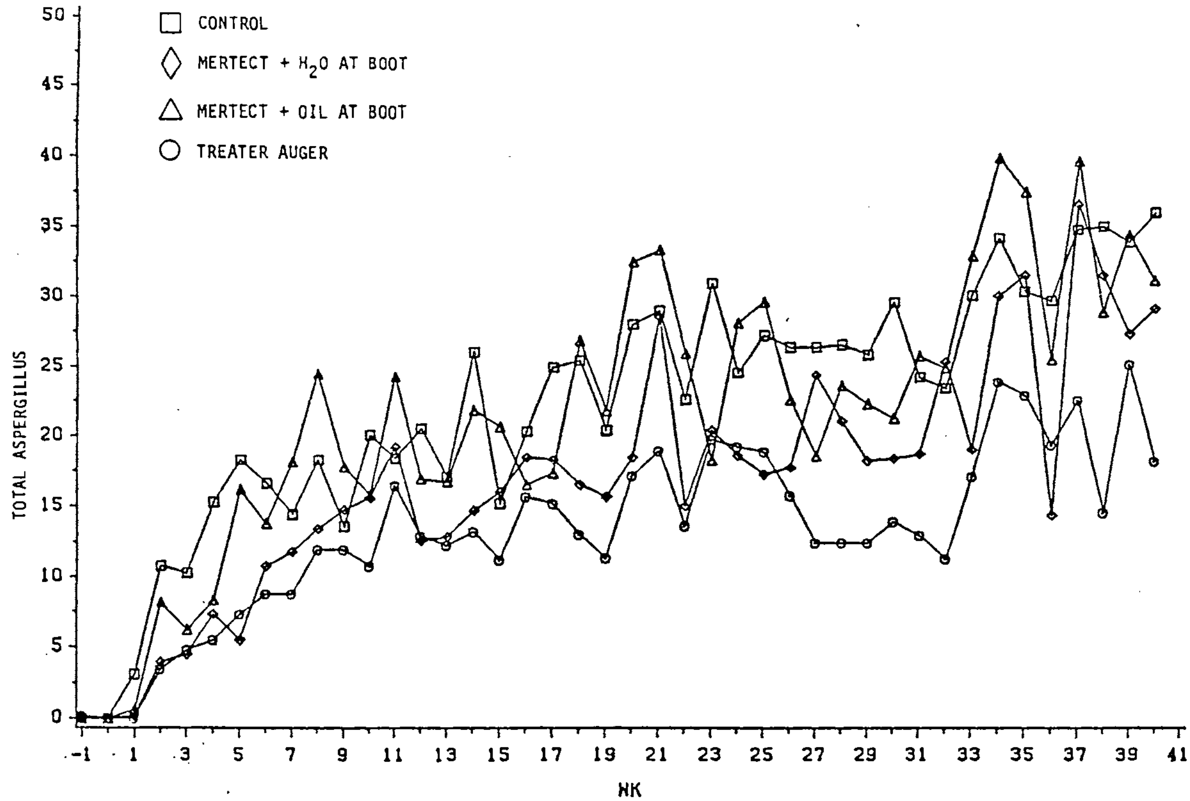

Figure 7. Total number of Aspergillus spp isolated from fifty kernels averaged over three bin sampling levels and two replicates in experiment 2. Week -1 is pretreatment.

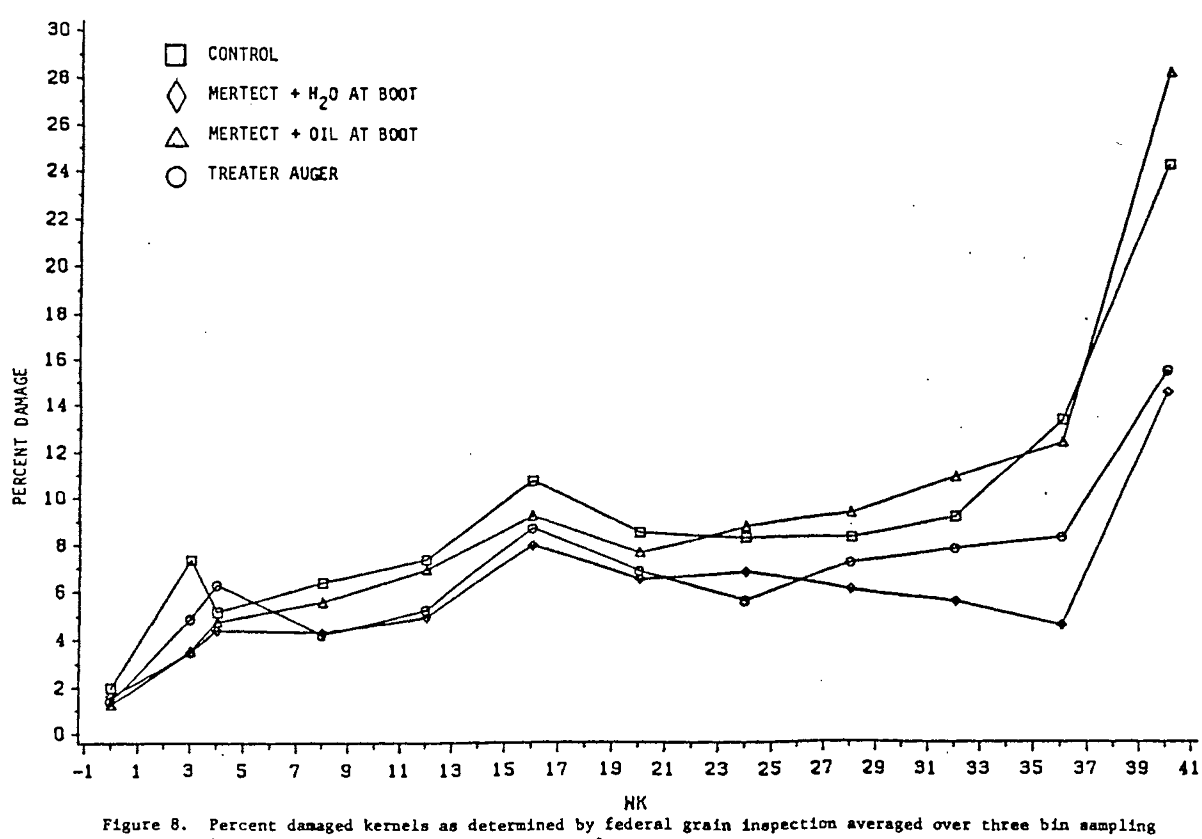

Figure 8. Percent damaged kernels as determined by federal grain inspection averaged over three bin sampling levels and two replicates in experiment 2.

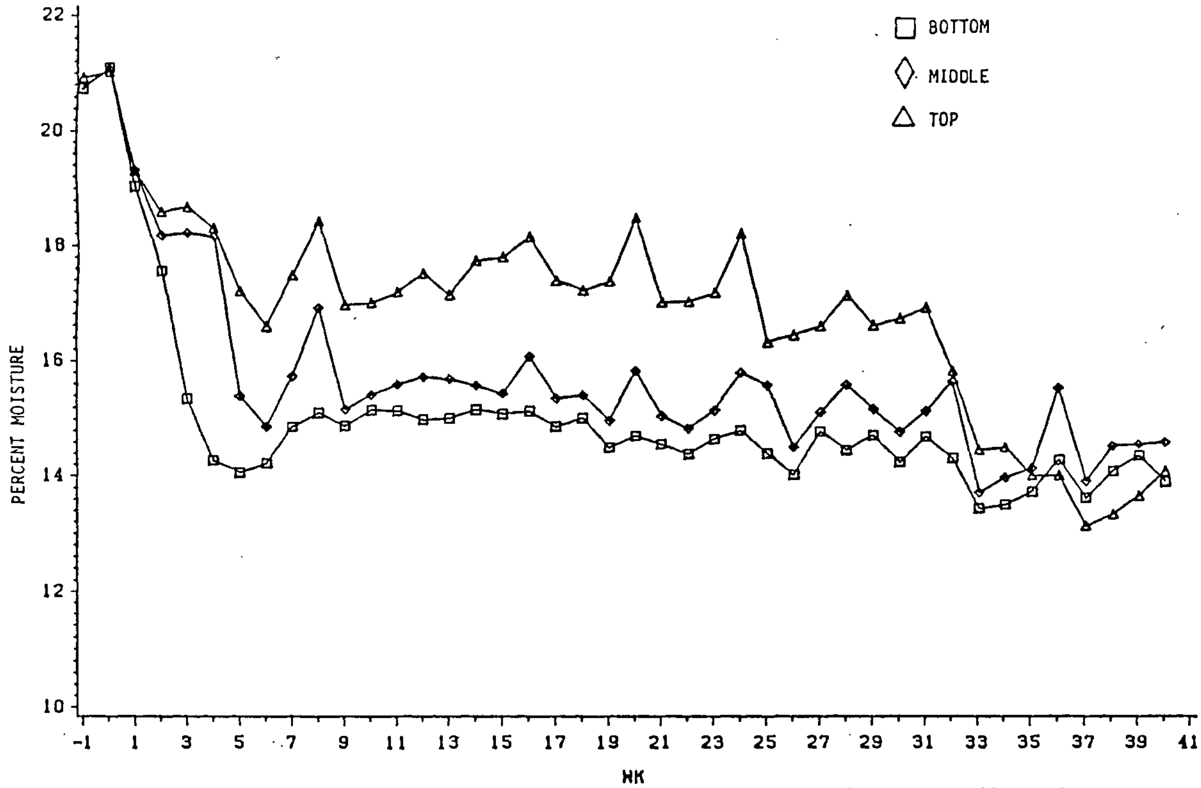

Figure 9. Grain moisture taken from three sampling levels in the bin averaged over two replicates in experiment 1. Week -1 is pretreatment.

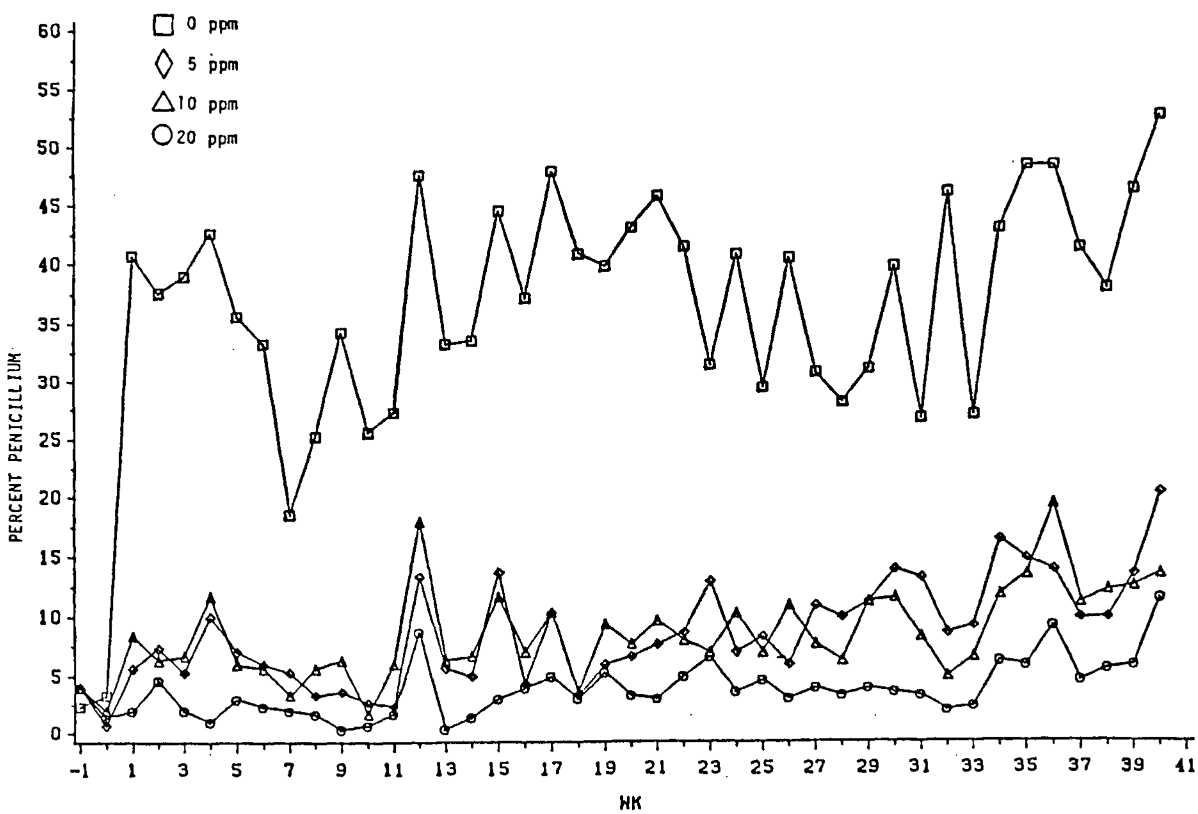

Figure 10. Percentage of kernels out of fifty infected with Penicillium spp averaged over three sampling levels and two replicates in experiment 3. Week -1 is pretreatment.

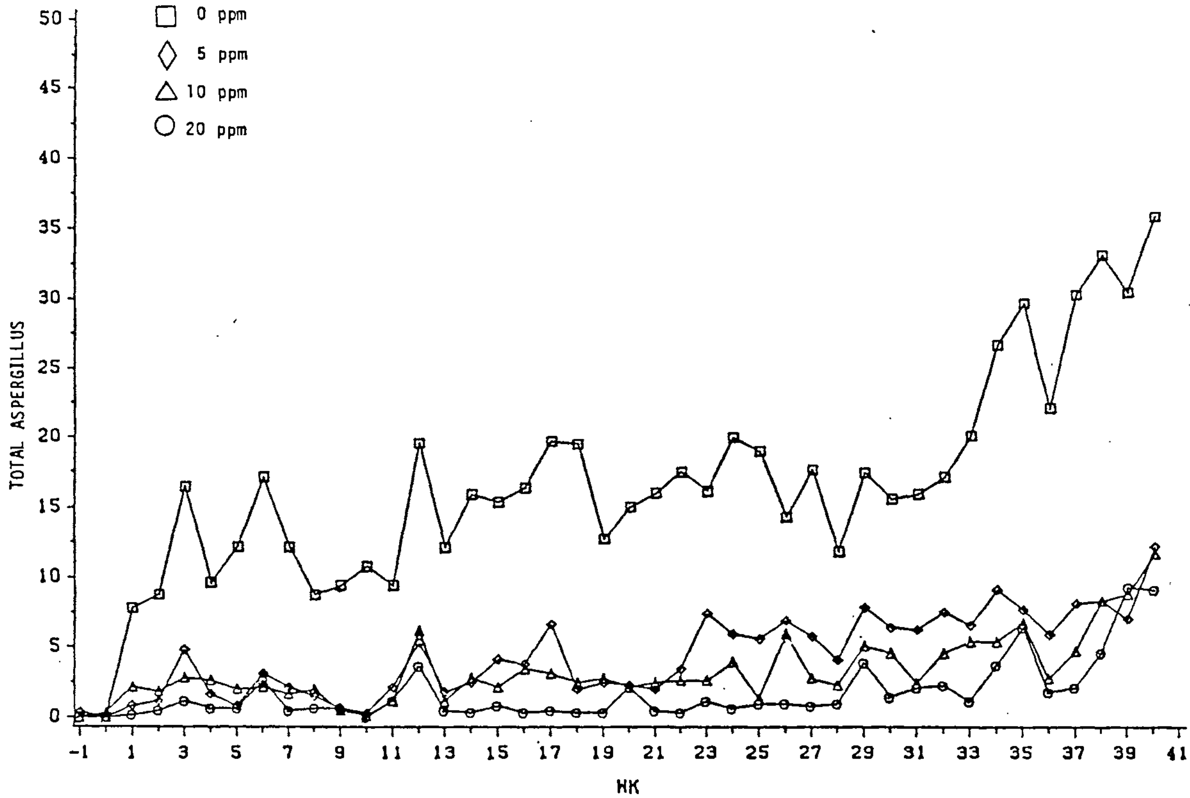

Figure 11. Total number of Aspergillus spp isolated from fifty kernels averaged over three bin sampling levels and two replicates in experiment 3. Week -1 is pretreatment.

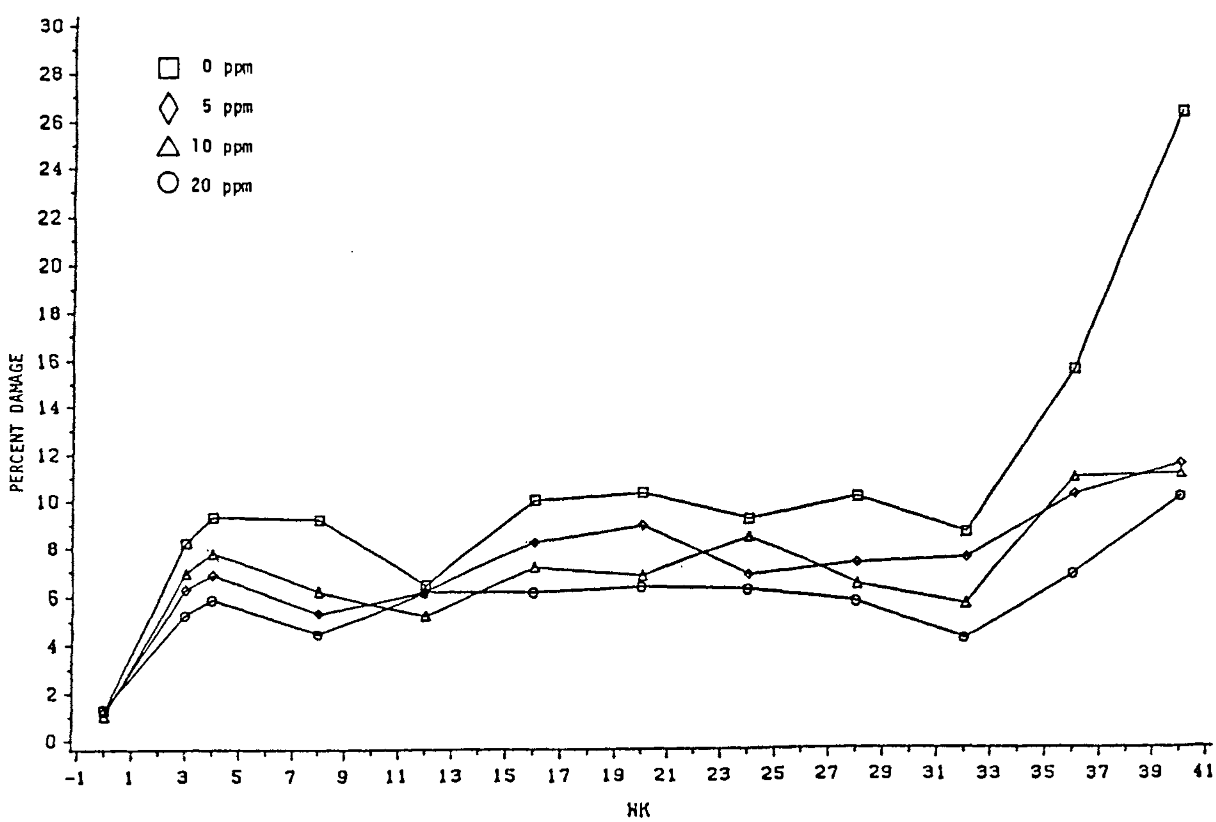

Figure 12. Percent damaged kernels as determined by federal grain inspection averaged over three bin sampling levels and two replicates in experiment 3.

Table 1. Moisture, Percent *Penicillium spp*, Percent *Aspergillus spp* and Percent Damage from farm bins treated or untreated with MERTECT 340-F

Treatment	Sample Date	Average moisture	Percent Penicillium spp	Percent Aspergillus	Percent Damage
Farm Study One - Harvest Moisture 20-22%					
Untreated	1-31-87	22.1	5.5	0.4	--
Treated 1		20.7	1.0	0	--
Treated 2		22.5	0.4	0	--
Untreated	3-11-87	17.2	39.5	0	--
Treated 1		19.2	0	0	--
Treated 2		20.5	0.4	0	--
Untreated	4-1-87	17.1	55.5	3	--
Treated 1		20.8	0	2	--
Treated 2		21.7	2.5	0	--
Untreated	5-28-87	13.3	29.0	10	8.6
Treated 1		15.3	3	2	2.5
Treated 2		14.7	17.0	2	7.5
Untreated	8-19-87	14.3	38	50	21.3
Treated 1		16.1	2	36	5.4
Treated 2		14.8	7	18	6.4
Farm Study 2 - Harvest Moisture 16.1 - 17.1%					
Untreated	5-28-87	13.9	2.5	0	0.5
Treated		15.4	0	2.5	0.4
Untreated	7-23-87	13.6	.5	9.5	0.6
Treated		14.6	0	.4	0.4
Farm Study 3 - Harvest Moisture Unknown					
Untreated	5-29-87	17.2	46	91	26.2
Treated		16.4	16	20.5	1.4
Farm Study 4 - Harvest Moisture 17-18%					
Untreated	4-4-87	18.2	2.5	0	2.3
Treated		15.9	2	0	2.6
Untreated	5-29-87	17.9	14.5	93.5	2.6
Treated		15.2	2	2.5	2.6
Untreated	7-17-87	15.4	28	92.0	92.8
Treated		15.5	0	4	3.1

ARE DISEASE PROBLEMS DEVELOPING IN SOYBEANS?

Ward C. Stienstra
Extension Plant Pathologist
Department of Plant Pathology
University of Minnesota

The title is in the form of a question only to get a response from you. The answer is clearly YES. There is no question that diseases of Minnesota soybeans, especially Soybean Cyst Nematode (SCN), Phytophthora Root Rot (PRR), and Brown Stem Rot (BSR), are increasing in acreage affected and are significant sources of yield loss. Soybean diseases in the last 5 years can be grouped into 5 categories: 1) Seed rot, seedling blights and seedling vigor. 2) Soybean Cyst Nematode. 3) Phytophthora Root Rot. 4) Brown Stem Rot. 5) Other foliar and stem disorders: Septoria, Phomopsis and Anthracnose.

First reflect on the seed related problems of the last few years. Soybean yields have been good and we may see new records in 1987, however yields would be greater if soybean diseases had not occurred. The development of seed and seedling disease, as is true for all diseases, is dependent on the air and soil environment, fertility, seed quality, crop rotation and variety planted. Seed rot and seedling blight, usually not a problem in Minnesota was very common in the 1985 crop and again in early varieties in 1986. The major cause of low germination scores was due to seed infection by Phomopsis species (Pod and Stem Blight). This disease can cause seed to be shriveled, misshaped or wrinkled. When infection is serious the seed may be white, chalky and off color, while seed can also be infected and appear normal-show no symptoms. These normal appearing seed may germinate but produce weakened plants and lack the vigor to establish quickly. This problem was minimized by seedsmen and producers who culled poor germinating seed lots and used fungicide seed treatment to protect seedling development when poor germination was due to fungal infection. Early season vigor of seedlings is very important in preventing or reducing seedling blights (Rhizoctonia) and herbicide injury. Poor seedling vigor, a result of marginal seed quality, combined with a dry seed bed, soil compaction and post application of herbicides contribute to increased herbicide injury reports and more diagnosis of Rhizoctonia seedling blight. Since weakened plants grow slower the fungus is able to cause more damage.

SOYBEAN CYST NEMATODE

The soybean cyst nematode (SCN) is known world wide and since 1978 in Minnesota. The disease first called "yellow dwarf" was described in 1915 and from 1954 when it was first reported in the US has spread into at least 22 states. The known distribution in Minnesota is increasing. Can, should more be done to restrict the movement? Presently little information is available to describe the local spread-in-field or in-farm and only large scale (township and county) measurements are available to describe its relentless progress in the Minnesota soybean growing area. The 3 years following its discovery in Minnesota resulted in 17 townships in 8 counties with known infestations. A second 3 year period added only 2 new counties and 7 townships. The last 3 year period has now increased the known distribution to 15 counties and 56 townships. SCN is spreading, not only in Minnesota but Iowa reports a total of 27 counties are infected (8 in 1986 and 4 in 87) and Wisconsin reports 2 counties just east of the Mississippi are confirmed locations (Buffalo and LaCrosse counties). Has the lack of dramatic increase of this disease acreage from 1981 to 84 caused us to become complacent? Does the expansion in area affected in 1985 to 87 cause us any concern? In Faribault county, where the disease was first found in 1978 it has spread from an original 6 townships to 12 more by 1985. In a period of 8 years all but 2 townships are infested in this county. While data on acres affected and at what level the land is infested are lacking, the picture is very clear. SCN is spreading and at a faster rate than most expect. All Minnesota soybean acreage may never be contaminated but more will become infested. Spread will continue and SCN, Heterodera glycines will not go away. Trends found in other states will not be different in Minnesota. More counties, more townships, more farms, more acres will be found as infested.

Management strategies of SCN differ and are important even if they ultimately fail ie, SCN continues to expand its acreage. The most overlooked tactic and it is a critically important one is early identification. The routine scouting and sampling of soybean roots where SCN has not been found is required to achieve the goal of early identification. It is not easy. Scouting requires selecting suspect areas in a field and the digging up of plant roots and then carefully removing soil from the roots to view the cysts. Soil conditions will at times prevent removing roots from soil that have intact cysts clearly visible. The sampling is best accomplished by use of a shovel to remove plant roots and soil and then careful removal of soil exposing the soybean root system. Soil that is to wet or sticky will prevent observation of the roots and cysts. Anyone, once having seen the cysts should be able to identify it in the field. Confirmation can be obtained, if needed from the Plant Disease Clinic or any other lab that handles nematode samples. Send or bring plants with suspect roots and soil for testing.

The next step in SCN management is rotation. Rotation to a non-host crop is estimated to reduce the nematode population by 75% and 2 years of a non-host crop can reduce the population by as much as 92%. In our climate 3 years of non-host rotation may be required to reduce SCN to the desired level. Non-host crops include corn, milo, wheat and alfalfa. Since weeds can also be a host for SCN, weed control in the non-host crop years is needed. The rotation effect or it's value varies between organisms and is dependent upon the ability of SCN to find alternate food sources and it's ability to survive without food. Rotation does not eliminate but is designed to reduce nematode numbers and allow maximum yield in the presence of the nematode. The rotation effect will be maximal when nematode numbers are low. Early identification of problem fields and rotation for 3 years to a nonhost will result in the least amount of SCN build up.

Resistant varieties, nearly non-existent in Minnesota is another management method. Resistant varieties should be used only in combination with rotation and only if they are resistant to the races of SCN in your field. Experience in other states show the value of resistant varieties can be lost if planted for more than 2 consecutive soybean crops. An ideal rotation/resistant crop use pattern in infested land is as follows. Year 1

SCN present on susceptible soybean. Year 2 Plant a non-host. Year 3 plant suitable resistant variety. Year 4 Plant non-host and test soil to insure the SCN population is at a level to again allow planting a susceptible crop the next year.

Nematicides such as Temik (aldicarb), Furadan (carbofuran) and Nemacur (fenamiphos) have been used on infested land. Temik has most consistently increased yields in SCN plots in other states (35.0 B vs 28.5 B in untreated susceptible check). Resistant varieties in similar studies yielded 31.8 B. Temik may be an alternate for some growers who can not rotate or obtain resistant varieties but the product use should be avoided where soils are sandy or water tables are high. Combination of nematicides and resistant varieties have resulted in a yield increase but it is reported to be usually not economical.

Are SCN disease problems developing in soybeans? Yes, even with the early identification and 3 year rotation to non-hosts, rotation/resistant variety pattern and the questionable nematicide use picture, the SCN problem continues. As more fields become infested with SCN and government programs direct growers to limit corn acreage the frequency of soybeans in the rotation, even continuous planting is likely to increase. The present availability of resistant lines is limited and most of the resistance is based on a rather narrow genetic base. Resistant lines are reported to quickly become no longer resistant to specific SCN populations, i.e. new races are being identified. And some report that even after 3 years of a non-host crop the severity and frequency of SCN damage is increasing. The outlook for SCN management is not bright.

PHYTOPHTHORA ROOT ROT

Phytophthora root rot (PRR) is another disease of soybeans that's increasing in Minnesota. The loss due to PRR in 1987, while less than the previous several years was significant. Average yields for a susceptible line with no race specific resistance and little tolerance, i.e. "field resistance" was 4 - 6 B/A less than a line with average tolerance and the addition of race specific resistance added little additional yield. As PRR became a major disease problem plant breeders developed new varieties with genes for resistance. The resistance pressure on the fungus also caused a selection pressure on the fungus for development of new races to overcome the genetic resistance. Next breeders and plant pathologists stacked genes for resistance, multi-race resistance soybeans and now even these "new" varieties appear to become "susceptible" to other races. The need for another resistance management strategy lead to "tolerant" soybeans. These varieties contain several genes which result in broad resistance to all races, but do not provide any protection against seedling infection. This resistance is not complete because under inoculated conditions of a greenhouse they are susceptible.

We also have chemical and cultural management methods. Cultural management strategies are based on a knowledge of the fungus and its preferred environment. Phytophthora is known as a "water mold" because it thrives in wet environments. The fungus releases swimming spores called zoospores that move toward plant roots by following a "chemical trail" of material released by the root. Under saturated soil conditions, zoospores can be released in a very short time period. However, if cultural practices such as tilling, ditching or ridge planting are used in wet fields, stresses on plant roots may be reduced and the favorable environment for the fungus is changed. The use of tillage operations to break hardpans or compacted areas is also helpful to increase water infiltration, which may help limit zoospore spread. Additional, PRR tends to be more severe when cool weather occurs at or shortly after planting. Soil temperatures of 55-60 F at planting although favorable for soybean germination, may also favor development of the root disease. Delaying planting until soils known to have a PRR problem are 60 F at the 4 inch depth may reduce the impact of this disease. Growers should be cautious when planting into no-till fields or where conservation tillage has left heavy residues. Research has shown that these fields tend to warm and dry out more slowly in the spring because of the insulating effects of the residues and can provide a favorable habitat for Phytophthora.

The last management method is the use of chemical treatments, applied to the seed or soil. The selective fungicide metalaxyl, sold as Apron seed treatment or as Ridomil soil fungicide has been shown to be an effective method of managing PRR losses. As a seed treatment, metalaxyl provide protection against early season stand losses. A crop insurance treatment against the need for replanting if conditions do not favor rapid germination and emergence. Apron is most effective when used with soybean lines that are not race specific resistant types but the tolerant varieties. Ridomil is usually applied for full season protection. It can be applied in-furrow, as a band or broadcast depending on the equipment available. In-furrow is the most economical.

The best management of PRR is an integrated approach to disease control. Combination of resistant varieties, cultural and chemical controls will provide growers with the best results. The importance of combinations must not be underestimated as dependence on a single method may leave the crop unprotected and has resulted in severe yield losses. The future for PRR management looks brighter than SCN, yet more and more growers must scout fields to determine if PRR is present. The disease is present and does damage crops in more locations yearly. The rapid utilization of multi-race specific resistance can "burn up" genetic material before it is really needed. The grower today must have a planned approach to PRR management and not grab at whatever is new.

BROWN STEM ROT

The 3rd soybean disease that's increasing in Minnesota is Brown Stem Rot (BSR). In 1986 the survey of 28 southern counties resulted in positive identification of BSR in 27 counties. The fungus that causes BSR was isolated from 71% of the sites. Frequency of BSR in 1987 was down, as only 9 counties of the 14 surveyed were positive for BSR. The disease severity was also down in 1987. An average severity score of 16% stem infection in a corn/soybean rotation was observed in the 14 counties. The BSR-Stem Color figures at R 6 indicate little to slight yield effect in 1987. Test plots in 6 southern Minnesota locations also had less disease present and the average yield advantage for the resistant line was very small. Hardin yielded better than BSR 101 by 3.8 B at 2 sites and BSR 101 yielded better than Hardin by 3.9 B at 2 sites.

In 1987 the adequate to short soil water supply early tended to develop good to excellent root systems and the adequate to surplus water supply mid to late season tended to reduce stress effects. The relatively high temperatures of 1987 would be expected to reduce the severity of BSR. The ability of this fungus (Phialophora gregata) to grow is restricted at 77 F and at temperatures of 85 F the fungus can not grow.

Previous crop history of soybeans in the rotation appears to still be the major factor in BSR severity. Of the fields surveyed in 1987 high scores were found in 2nd year soybeans and the highest score was a field where soybeans were grown for 3 years following a wheat/soybean rotation. The BSR yield effect in 1987 was not as large as the last 2 years, but the outlook for this disease is not changed. BSR is present in most soybean growing areas, confirmed in 36 counties and believed to be present in all 42 surveyed. This includes all of southern Minnesota from Big Stone county east to the Mississippi river. Disease identification in 1987 was done by splitting stems at the R 6 or R 7 stage. Stem samples with brown color were returned to the lab for isolation. Last year an 85% confidence score required finding 16 to 32 stems out of 100. This year the 80% confidence score occurred at 5 stems/100 sampled. This means that 80% of the time we will be able to isolate and confirm the causal fungus is present if you find as little as 5 stems with the brown color out of 100 sampled. Clearly the disease is present in Minnesota. Management is possible with rotations state wide and the use of resistant varieties in southern Minnesota.

DOES WHEAT SEED GERMINATION EQUAL STAND?

Howard L. Bissonnette
Extension Plant Pathologist
Department of Plant Pathology
University of Minnesota

Good crop yields are the result of sound planning, proper inputs, favorable weather and the luck of the Gods!

Quite often planning involves the selection of the field, and seed bed preparation. The proper inputs usually refer to the use of some amount of fertilizer, dependent upon price, and local inquiries about herbicide. Occasionally some growers will actually carry out a soil testing program so that they know how much fertilizer is required to produce their planned for crop. Likewise, some growers know their potential weed problems and have first hand knowledge on the proper herbicides to use and how to use them.

If a new wheat variety is on the market, growers will often purchase a small amount and use this production as a source of seed for future years. But more often, growers save seed from the previous year's crop for use in the current season. This seed may be tested for germination and if properly stored will have a good germination. Sometimes the seed may even be cleaned. Very seldom is it treated with fungicides that prevent seedling blights.

In spite of all of the above inputs the final good yield will depend upon having a stand of plants in the field to make use of the inputs.

WHAT MAKES A GOOD STAND?

A germination test will identify the viability of the seed being tested under very favorable conditions. When the seed is planted, research has shown that the actual emergence may be reduced by 10% because all of the seed is not well planted. Thus a seed lot that germinates at 95% in tests may only have an emergence of 85% at best. What if there is some type of biological stress? Say that 10% of the seeds are affected by the scab fungus, then the emergence might be 75% of original germination test. Is a 75% stand sufficient to produce your planned for crop? Are there biological stress (diseases) that may result in poor emergence of the wheat crop?

The 1986 wheat crop ended up the season with a substantial amount of the disease known as scab on the wheat plant heads. There was enough scabby wheat on the farms to give rise to a concern for the planting of the 1987 crop from this seed source. What might a grower expect for plant stand if he were to use such a crop for sowing?

To look at this problem, the Department of Plant Pathology announced to growers that we would test their seed during the winter of 1986-87, for potential emergence so that they would have some idea of what to expect if they used their own seed for sowing. One hundred and eighty one growers sent us samples for testing. Our testing started with a standard germination test which was followed with an emergence test where seed was planted in soil and allowed to emerge at 50^{o}F for 21 days. The emerged plants were counted and the roots examined. We also tested for the presence of fungi by cultural methods. The latter experiment did not provide us with usable information. However, the emergence tests were very enlightening (Table 1). Now keep in mind that when we planted the emergence test, that it was an exact planting. Each seed was hand planted and the soil was properly watered and maintained at 50°F.

The loss in emergence because of diseased seed in the 95-100% germination group could be from 6.4% to as much as 12.4%. If one now adds the 10% loss that occurs in the normal planting operation the resulting stand could be 16.4% to 22.4% less than the germination rate. In Table 2 there is a further break down of the data obtained, e.g. the 95 to 100% germination range had an average germination of 96.5, and the average emergence (potential stand) was 89.5% for an average loss of 9% or an overall loss of 17% stand from standard germination evaluation.

From Dr. Oelke's work, it is desirable to have at least 14 plants per row foot within 6 inch row spacing, as a sound production practice.

This work suggests that some adjustment must be made to attain the desired stands in the field. In the 90-94% germination group the average germination was 92.3% and the average emergence (potential stand) was 82.3% or a total loss of 20%.

One might agree that this is very interesting, however, it was done in the laboratory. To identify if what was found in the laboratory had any relationship to what might happen in the field, fifty-three of the tested seed lots were planted in the field by hand, using 3 replications, column 4 in Table 2 shows average emergence or stand achieved. The numbers are within a percent or 2 of the laboratory work. It appeared that most of our disease problem was related to the scab disease as the field planting conditions were warm and with no excessive moisture. In Table 3, by grouping the seed lots by variety, it appears that problem was most common on the varieties Wheaton and Len. So may be these varieties, Wheaton and Len are more susceptible to scab than the other varieties.

Were there any geographical differences as to the source of seed and the of the seed? The data in Table 4 suggests that the problem was not isolated to any one area of the state.

In these tests the seed was not cleaned or treated with fungicide. The benefits of seed treatment have been documented many times. However, less than 40% of the wheat seed planted is treated. Probably a similar amount is cleaned.

Seed quality appears to be an important part of seedling stand establishment. What might these field tests have been if the planting conditions had been cold and wet?

Making economically sound crop production decisions can be a challenge. The potential for obtaining high yield at economically acceptable inputs is known. In the past such decisions may not have included plant disease problems. This work identifies the importance of seedling disease and their impact on establishing and maintaining a good stand. For maximum response to crop inputs, use the best quality seed possible and know the quality, do not guess.

TABLE 1. The Average Germination and Potential Stand[1] of 181 Seed Lots Tested, 1987, grouped by germination range.

Germination Range as a %	**Average Potential Stand as a %**
95-100	87.6
90-94	84.7
85-89	80.2
80-84	77.0
Below 70	72.2

[1] Grown at 50°F for 21 days in greenhouse

TABLE 2. The Average Germination, Potential Stand and Field Stand of 53 Seed Lots, grouped by germination range, 1987.

Germination Range %	**Ave. Germination %**	**Ave. Potential Stand % Greenhouse**	**Ave. Field Stand %**
95-100	96.5	89.5	88.3
90-94	92.3	82.3	81.5
85-89	86.6	76.1	74.2
80-84	81.7	71.3	74.3
75-79	77.2	71.9	73.3
70-74	73.0	75	58.8
Below 70	58.3	60.3	50.7

TABLE 3. % Potential Stand of 1986 Spring Wheat Seed Planted and Grown at 50°F for 21 Days in Greenhouse; (181 seed lots).

Variety	% Potential Stand
Stoa	83.4
Wheaton	75.4
Marshall	84.5
Len	79.7
Pioneer 2369	83.7
Norseman	84.7
Unknown	84.4

TABLE 4. Potential Stand of 1986 Spring Wheat Seed Planted and Grown at 50°F for 21 Days in Greenhouse, by county.

County	% Potential Stand	No. of Samples*
Lac Qui Parle	81.0	8
Traverse	84.3	12
Big Stone	85.0	17
Stevens	81.1	33
Grant	86.0	17
Otter Tail	82.3	6
Marshall	82.2	13
Kittson	84.0	13
Roseau	82.2	6

* Counties with 5 or less samples not included.

NEBRASKA'S EXPERIENCE IN THE DEVELOPMENT OF WATER QUALITY LEGISLATION[1]

R. A. Wiese[2]

Water is societies most precious resource impacting on the quality of life for each and every individual. Water abundance and scarcity both exist and initiate challenges for management, for priority uses and for quality maintenance. Each region of the United States provides a different set of circumstances for water policy and within each state the water resources provide a different framework from which water policy decisions are made. Today, I'll give you a brief perception of the groundwater concerns in Nebraska, leading to an active 1986 year of water legislation, and project some impacts of that legislation on crop practices.

Nebraska's groundwater is characterized as very abundant. Yet one must also address scarcity where rural and urban communities must depend upon programs to obtain water for household use. The abundant water supply lies within the Ogallala acquifer system. The system contains water bearing material from several geological formations, only one of which is the Ogallala formation. The Ogallala is extensive, reaching into seven states, but has 70 percent of its water supply in the central Sandhills area of Nebraska. Parts of Wyoming, South Dakota, Colorado, Kansas, Oklahoma and western Texas obtain water from the Ogallala formation. A perception of the underground water supply of Nebraska can be given as follows: If the under groundwater were placed on the surface of the state, it would cover the state to an average depth of 34 feet.

The earliest record of irrigation is in the year 1926 in western Nebraska. In the next two decades irrigation developed along the major rivers on first or second terrace soils. By 1960 the state irrigated acres reached 2 million acres. Subsequently, a rapid growth period averaging 250,000 acres per year continued until today to reach at 8.4 million acres of irrigated land. Irrigation development and increased nitrogen fertilizer use were simultaneous. Availability of more local feed grains gave rise to cattle feeding enterprises. Today, Nebraska leads the nation with cattle on feed and exports red meat throughout the nation.

Interest in the nitrate content of groundwaters had its inception with a well-water survey (Hoover, 1962). Three percent of 1165 water samples had nitrate levels above 10 ppm (Table 1). One decade later (Muir et al., 1973), 547 of the original 1165 were sampled again (Table 2). These 547 water samples registered an average increase in nitrates of 29 percent. Most of the increase occurred in eight counties which registered a 50 to 170 percent increase. Granted, an increase from 2 ppm NO_3-N to 3 ppm represents a 50 percent increase. However, some wells registered changes of 10 ppm NO_3-N going from 20 to 30 ppm. In the decade between well water analysis, irrigation wells, corn acreage, nitrogen fertilizer use had increased. Nitrogen fertilizer use nearly

[1] Presentation, 1987 Minnesota, Soils, Fertilizer and Agricultural Pesticides Short Course. Dec. 15, 16.

[2] Extension Soil Fertility Specialist and Professor of Agronomy, Dept. of Agronomy, University of Nebraska, Lincoln, NE 68583 (402)472-1502.

Table 1. Nitrate-Nitrogen content of Nebraska groundwater.

Nitrogen	Number of Samples	Percent of Samples	N in an acre foot of water
ppm			lbs
0.9	440	38	0 - 2.4
1-9	695	59	2.7 - 24.5
10-19	24	2	27.2 - 51.7
19	6	1	51.7

Table 2. Ten-year change in NO_3-N

Number of wells	Year	Average NO_3^--N	% change in NO_3^--N
		ppm	
547	1962	2.52	
547	1972	3.24	+ 29%
Eight Counties			+ 50 to 170%

quadrupled, leading to renewed efforts to document the extent of NO_3^--N in groundwater from fertilizer. Research efforts further correlated residual soil NO_3^--N to crop nitrogen requirements. Nitrogen fertilizer suggestions subsequently were adjusted for residual nitrate in soil. Acceptance of sampling soils to depths of 2 to 4 feet has been slow. North Dakota, Nebraska, Kansas, and Oklahoma were the first states to implement soil tests for NO_3^--N, requiring deep soil samples. These were implemented in the early 1970's. More interest is shown for sampling to deeper soil depths. Soil sampling equipment costs, time, labor, and inconvenience are considerations for the slow acceptance. Each year, however, soil test laboratories are reporting increased requests for NO_3^--N from deep samples so gains in the practice are slow but steady.

The number of public drinking water supplies which contain NO_3^--N above the 10 ppm standard has been increasing. State Department of Health records of drinking water sources show 18 public water supplies above 10 ppm in 1979. By 1983 records show 66 public supplies above the 10 ppm level. One must grant, also, that some public wells are of poor construction, allowing for contamination from surface sources.

Any physical threat to human health rapidly becomes a society concern. Fears, emotion, skepticism become real particularly if the threat is unseen. Water contains unseen soluble substances. Any implication of these substances endangering health is as much of a psychological threat as a real threat. The principle threatful element is a continual suggestion of infant dealths due to methemoglobinemia from nitrates in water. Although most infant deaths are due to other causes, this threat is high in the minds of people even if occurances are rare and even more rarely due to water alone.

Widespread concerns are developed through communication (radio, T.V., newspapers, technical reports, research, etc.). When public fears develop and those concerns reach the elected legislative public servants, some response is inevitable. Nebraska's legislatures have been responding by developing laws. They were very active for three years and the outcome of legislative activity resulted in three statutes in 1986 related to groundwater. One statute addressed underground pipe and tank leaks and treated point source contamination.

In the 1986 banner year of legislation, two legislative acts directly affected agriculture practice. One is the chemigation bill. Its primary requirement is the installtion of safety devices on center pivot irrigation systems used to apply herbicides, and insecticides with injection systems. Under this bill some 30 percent of center pivot operators who inject chemicals will spend $400 to $700 for eight devices that can insure safe and reliable chemical application. The eight devices will eliminate any possible backflow of chemical into the well water source. The devices must be installed by the grower then inspected by the Natural Resource District (NRD) who has responsibility for soil and water resources. The devices include the following statewide requirements.

1. An interlock connecting the irrigation and the injection pump.
2. A low pressure drain.
3. A main pipeline check valve.
4. An inspection port.
5. A solanoid valve.
6. Chemical resistant hoses, clamps, fittings.
7. An injection line check valve.
8. Chemical suction line strainer.

In the same 1986 legislative year the Groundwater Contamination Act was passed. Its emphasis is on nitrate, however all contaminants of groundwater are addressed. The legislation provides for "Groundwater Protection Areas" to be designated by the State Department of Environmental Control (DEC), Nebraska's EPA. Once groundwater contaminant has been documented by the DEC, the DEC can designate a groundwater protection area for a given non-point contaminant. Subsequently, the Natural Resource District (NRD) must develop a plan to stabilize, reduce or provide corrective measures for the area. A sequence of public hearings on measures take place with final approval by the DEC and for final implementation with NRD authority. The sequence spreads responsibility to a wide group, heavily influenced by farmers, from which one can expect reasonable corrective measures. Thus far, one groundwater protection area has been designated along Platte river counties (See Figure 1). The Central Platte NRD has implemented rules for governing nitrogen fertilizer use in their area.

Rules governing nitrogen fertilizer use depend upon the average nitrate (NO_3^--N) content of irrigation and domestic wells in a given area. The higher nitrate (NO_3^--N) areas have more restrictive rules. Phase I rules apply to an average groundwater NO_3^--N from 0 to 12.5 ppm. Phase II rules apply to groundwater having 12.5 to 20 ppm average. Phase III rules apply to areas with greater than 20 ppm nitrate-nitrogen (NO_3^--N).

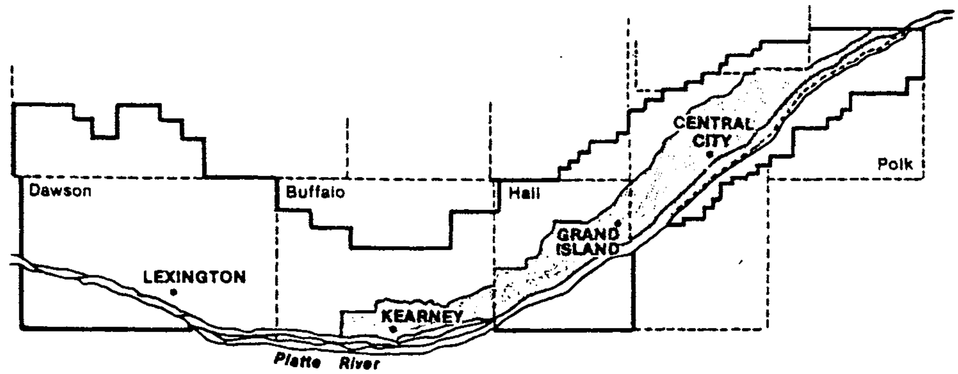

Figure 1. The Central Platte NRD area. Rules for Phase II practices apply only to the shaded portion of the area.

Rules for nitrogen fertilizer application for Phases I, II, and III are as follows:

Phase I (Groundwater; 0-12.5 ppm nitrate (NO_3^--N content).

- Bans fall and winter application of nitrogen fertilizer on sandy land. March 1st of the crop year is the earliest date for application. Sandy land is characterized as having a permeability of 2 inches per hour in the top 30 inches of soil.

- Irrigation water analysis for nitrate-nitrogen and deep soil samples analyzed for residual soil nitrate-nitrogen is recommended but not required.

Phase II (Groundwater; 12.5 to 20 ppm NO_3^--N content).

- Bans fall and winter nitrogen fertilizer application on sandy soils.

- Fall application of nitrogen fertilizer in fine-textured soils is allowed after November 1, with an approved nitrification inhibitor.

- Irrigation water nitrate-nitrogen is required for use as a credit toward the total nitrogen required of a subsequent crop.

- Soil analysis of 2 to 4-foot deep samples for residual nitrates are required.

- Fall application of phosphate, potash, zinc, sulfur or other nutrients cannot be accompanied by more than 15 pounds of nitrogen per acre.

- Fall applied nitrogen on crops other than corn cannot exceed 15 pounds of nitrogen per acre.

- Attendance at one educational meeting every 4 years is required.

- A report of crop yield and nitrogen fertilizer used for the crop is due December 1, to the NRD office.

Phase III (Groundwater; greater than 20 ppm NO_3^--N content).

- Rules not yet determined.

- Probably all rules of Phase II will be mandatory instead of voluntary.

Although the rules appear harsh, they become more of an inconvenience to growers who must presently volunteer to fulfill Phase I and Phase II. Additional planning and documentation is a must to use nitrogen fertilizer. "RESPONSIBLE NITROGEN USE," "NITROGEN USE EFFICIENCY," and "BEST MANAGEMENT PRACTICES" are key phrases which will become household words for crop growers. Conceivably additional costs to the grower will readily be offset by reduced or wise nitrogen fertilizer use without risk of yield reductions.

Inputs to the NRD rules came from a wide group of individuals. Fertilizer dealers, crop consultants, soil testing laboratories, farmers, farm managers, and nitrogen research scientists helped to formulate the rules. Undoubtedly, rules will change with experience and time. Since the Central Platte NRD must deal with the states first designated ground protection areas, logic, rational, and accepted change in nitrogen fertilizer practices can serve as a guide for future designated areas.

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THE STATUS OF NITROGEN MANAGEMENT RESEARCH ON MINNESOTA'S GROUNDWATER QUALITY

Gyles W. Randall
Soil Scientist
Southern Experiment Station
University of Minnesota

INTRODUCTION

Because of considerable concern throughout the agricultural section of the U.S. over nitrates (NO_3) in the groundwater, nitrogen (N) management research will be extremely vital to our understanding of economical crop production with minimal environmental impacts. First, we need to remember that N is an essential nutrient for plant growth. Without N plants die. On the other hand, non-leguminous plants respond dramatically to N additions. This response emphasizes the fact that the economical returns from N applications are highly profitable, especially when applied at proper rates to corn. Excess N is wasted, gives a poor economical return, and contaminates the environment. Second, N can be supplied to crops in a number of ways, i.e., various fertilizer materials, animal manure, legume-fixed N, sewage sludge, rainfall, and mineralized soil N. All sources in time can be converted to NO_3, the mobile form of N that can be leached to the groundwater. These two factors - essential role of N as a plant food and that various N sources are available for the crop - must be taken into account when assessing N management strategies and the effect of N on the environment.

Various N management factors have been outlined in abstracts from previous Soils, Fertilizer and Agricultural Pesticide Short Courses. Data from numerous studies around the State have been included to support these management arguments. This abstract will address the primary N management factors but will contain few data. In addition, it will summarize our current research activities in looking at the economical and environmental effects of N on Minnesota's groundwater.

NITROGEN MANAGEMENT FACTORS

Site Specific Nature

Management of N to improve crop yields while reducing environmental contamination is highly site or location dependent and will vary with the crop grown. In Minnesota, the primary crop of concern is corn because it receives the majority of fertilizer and manure N. The primary areas of immediate concern are in (1) southeastern Minnesota with its intense crop and livestock agriculture on permeable, somewhat shallow soil profiles over fractured bedrock and (2) in the irrigated, sandy areas where corn and vegetable production is dominant. Other areas of the state receiving large amounts of N inputs also need to be concerned with N management because of economical reasons, N contamination of surface waters due to tile drainage and sub-surface flow, and potential long-term effects on the groundwater.

Source of Nitrogen

All sources of N can be converted to NO_3, and thus, can contribute to groundwater contamination. This means that under most conditions that no one source of N is better than another if applied properly. Some sources, such as UAN, however, require additional restrictions such as only spring or sidedress applications and precautions such as incorporation/injection when applied to high pH and residue covered soils. Manure contains substantial amounts of nutrients that must be considered in the growers nutrient budget. To do this requires that he know what is in the manure (chemical analyses) and the application rate to his fields. This assumes uniform application. Unless these management factors are used, manure can lead to substantial contamination of the groundwater.

Rate of Application

USING THE PROPER APPLICATION RATE OF N CAN HAVE A GREATER EFFECT ON CROP YIELD, N EFFICIENCY, ECONOMICAL RETURN, AND THE ENVIRONMENT THAN ANY OTHER MANAGEMENT TOOL. Application rates that are either too high or too low result in less profit to the farmer. To arrive at the optimum rate of N application the grower must consider the crop being fertilized and productive capacity of the soil when setting a realistic yield goal. In addition, credits for N, which may be present due to previous legume crop, manure, residual NO_3 carried over from past fertilization, or N in the irrigation water, must be considered. In southern Minnesota N rates for corn following either soybeans or good alfalfa should be reduced by 40 and 100 lb N/A, respectively, compared to continuous corn . Nitrogen applied in excess to crop requirements contaminates the environment and is costly to the grower. In addition, excessive N rates at this time may lead to a great regulatory impact on the fertilizer industry, namely the dealer.

Time of Application

Time of N application is important in increasing N efficiency and reducing potential N loss. A shorter time interval between fertilizer application and maximum crop uptake reduces the probability of loss due to either leaching or denitrification. For this reason, many corn growers throughout the Corn Belt are returning to spring and early summer applications.

Time of application between the fall and spring becomes less important as rainfall decreases. The drier conditions usually found in western Minnesota are more acceptable for fall applications of N than the more humid conditions of eastern Minnesota. Data from a 24-year study with continuous corn at Lamberton showed only a 5.1 bu/A average gain with spring-applied urea compared to fall-applied and plowed down (Table 1). However, yields were increased by over 11 bu/A with spring applications in 8 of the 24 years (Table 2).

Table 1. Corn yield as influenced by fall and spring applications of urea at Lamberton.

Time/Method of Urea Applc'n[1/]	24-Year Avg. Yield
	bu/A
Fall, plowed down	97.0
Spring, top dressed, preplant	102.1

1/ 80 lb N/A — Malzer and Nelson

Table 2. Frequency and size of yield difference between fall and spring applied urea at Lamberton.

Yield advantage for[1/] spring application	Number of years
bu/A	
-5	1
-1 to -5	4
0 to 5	9
6 to 10	2
11 to 15	5
16 to 20	2
21 to 25	1

1/ Ranges from -6 to +22 bu/A

Studies conducted at the Southern Experiment Station at Waseca using ammonium sulfate clearly show both a yield and environmental advantage for the spring preplant application compared to the late-fall, plowed down application. Corn yields over the five-year period were increased by 15 and 5% with spring application at the 120-lb and 180-lb rates, respectively. Spring application of N also reduced NO_3 losses to the tile lines by about 30%. (See Proceedings from 1986 Soils, Fertilizer & Ag Chemical Short Course).

Split applications of N are currently receiving notable interest among growers because of application flexibility and the potential for increased N efficiency and crop yields. This potential is greatest on the sandy coarse-textured soils and has been documented frequently by research. Research on the medium and fine-textured soils of southern Minnesota has not shown a consistent advantage for split applications of N. Yield responses have ranged from negative to positive and have often been related to specific climatic conditions (rainfall) or application technique. Results from a recent 3-year study with continuous corn at Waseca show a slight (2 to 5 bu/A) yield advantage with a split application of UAN (preplant) and anhydrous ammonia (sidedress) compared to a single preplant anhydrous ammonia (AA) application

(Table 3). Split applications of UAN with either rainfall or shallow cultivation to incorporate the 8-leaf application resulted in 15 to 24 bu/A yield reductions compared to the single preplant application of AA.

Table 3. Corn yield as influenced by split applications of N at Waseca (1985-87 average).

Time/Method[1/]	N Rate (lb/A)		
	60	120	180
	--3-yr avg. yield (bu/A)-		
All preplant (PP) as AA	109	138	149
1/3 PP (UAN) + 2/3 SD (AA)	114	143	151
1/3 PP (UAN) + 2/3 SD (UAN)	94	114	132

1/ 0 lb N/A = 68 bu/A
Preplant applications of UAN were broadcast and incorporated immediately with a field cultivator. Sidedress application of UAN was incorporated either by rainfall or shallow cultivation.

Results from other split application studies have shown greater amounts of residual NO_3 left in the soil profile after harvest when the N has been sidedress or split-applied. This residual NO_3 is highly susceptible to overwinter and early spring losses and may result in greater contamination of the groundwater. Thus we need additional information on split applications of N; should the rate of application be adjusted, if so, how much and how are these delayed applications affected by soil and climatic conditions.

Placement of N

Compared to anhydrous and aqua ammonia, dry and solution forms of N have had the flexibility of either being surface-applied or injected. Recent evidence, however, does point toward greater efficiency with the injection or deeper incorporation of these materials, especially when conditions are dry. The data shown in Table 3 testify to this fact under moldboard plow tillage. Under ridge tillage data obtained from 1981-1983 showed 12 and 7 bu/A advantages for AA compared to urea and UAN, respectively, when applied at the 8-leaf stage (see Proceedings from the 1986 Soils, Fertilizer and Ag. Chemical Short Course). Both the urea and the UAN were applied to the soil surface and cultivated in to a 1 to 3" depth. The reason for this yield difference was thought to be positional unavailability due to limited rainfall in the 4-week period following the sidedress application. Apparently, this amount of rain was not sufficient to nitrify the urea and UAN and move it down into the active rooting zone.

Nitrification inhibitors

Nitrification inhibitors add an extra dimension to a N management plan. By slowing the conversion of NH_4 to NO_3, the materials often result in greater amounts of fertilizer N being kept in the upper root zone and available for plant growth. This has been especially true on coarse-textured soils where leaching can be significant. As a result, yields and N uptake have often been increased on these soils by nitrification inhibitors. Consequently, the potential for contamination of the groundwater by the fertilizer is reduced.

PRESENT NITROGEN/GROUNDWATER QUALITY RESEARCH

Beginning in 1986 a "Center for Agricultural Impacts on Water Quality" was established in the College of Agriculture, University of Minnesota. One of the major objectives of this Center is to facilitate inter-disciplinary research and education on the management of N and its impact on the environment. As an outgrowth of that objective, detailed and intensive studies were started in 1986 and 1987 in both the coarse textured, irrigated sands of central Minnesota and in southeastern Minnesota. A brief description of the sites, treatments, measurements, etc. follows.

Locations:
- Rosholt Farm, Pope Co.
- Lawler Farm, Olmsted Co.

Treatment Comparisons:
- N Rates
- N Sources (Fertilizer & Manure)
- Time of N Application
- Nitrification Inhibitors
- Crop Sequence
- Tillage Systems

Measurements:
- Crop Yield and N Uptake
- NO_3 Distribution in soil profile to a depth of 10' in fall and spring
- NO_3 in groundwater taken from lysimeters at 4' and 7½' depths
- Additional soil physical and chemical measurements plus hourly weather data.

These studies will be conducted over a 5-year period. In addition, corollary studies were established in Goodhue and Winona Counties to further examine spring, split, and sidedress applications of N to continuous corn with chisel plow and no tillage systems.

Studies will be continued at the branch stations at Lamberton and Waseca to monitor the effects of corn, soybean, and fallow cropping systems, fall, spring and sidedress N applications, nitrification inhibitors, and tillage on the loss of N from tile systems. In addition, studies to examine the effects of alfalfa and manure on N management will be continued by extension specialists in a number of southeastern Minnesota counties.

FERTILIZING SOYBEANS: THE FORGOTTEN CROP

Dr. John A. Lamb
Northwest Experiment Station
University of Minnesota
Crookston, MN

Soybeans have become a well-established crop in the farming rotations in the Midwest. Since 1960 the soybean acreage has increased to the point where the soybean has become a significant factor in the farm economy. The amount of soil fertility research on soybean has not paralleled this. Most research in the Midwest is now centered on efficient use and environmental implications of nitrogen. The soybean plant under most conditions does not require N fertilization so has not been researched as vigorously as corn.

NITROGEN (N):

As mentioned earlier, soybean plants under normal conditions (long history of soybean-corn rotation) do not require fertilizer N. This does not mean the soybean plant does not require N. Because the soybean is a legume, its N requirement is met by N produced through N_2 fixation by a bacteria called rhizobium. The rhizobium form nodules on the soybean root. The plant provides materials for the bacteria to live on and the bacteria fixes N from the soil air and provides it to the plant. This symbiotic relationship between the plant and bacteria is beneficial.

To ensure a satisfactory rhizobia population it has been recommended that soybean seed be inoculated with rhizobium at seeding. Again, in most normal situations with a history of soybean production, the native population in the soil is large enough that inoculation is not needed.

What happens in areas where soybean production is relatively new like Northwest Minnesota? Information gathered in Northwest Minnesota suggests that when soil NO_3^--N test 0-2 ft is less than 70 lb/A a grain yield response can occur (Figure 1). In 4 of 6 locations, a significant yield response to N fertilization occurred. The response in terms of percent increase was largest at the lower soil nitrate-N contents and decrease in magnitude as the soil nitrate-N content increased. At 70 lb/A and greater, the yield response was not significant. Also involved in these studies was the use of inoculum. Because most of these locations had no history of soybean production, the effects of inoculating soybean seed could be evaluated. At soil nitrate-N values greater than 70 lb/A, no grain yield response from inoculation was observed. At 5 of 6 locations with soil NO_3^--N level less than 70 lb/A a positive grain yield response occurred. In the case of 2 of the yield responding locations, the increase was greater at the smaller N applications (0 and 30 lb N/A) than at the greater application (120 lb N/A). At the other three locations, the yield responses were additive.

Why do we see different N responses in Northwest Minnesota compared to Southern Minnesota? Three explanations come to mind:

1. Little or no history of soybean production. This means a limited amount of rhizobium in the soil.

2. Different cropping rotations. Southern Minnesota normally has soybean in rotation with corn. In Northwest Minnesota the soybean is in rotation with small grain. Corn utilizes more NO_3^--N from the soil compared to small grain. This leaves a higher NO_3^--N concentration in the soil and reduces the ability of rhizobium to fix N_2.

3. Different maturity groups - Group 1 vs 00. The shorter the maturity, the less capable the soybean nodule is to provide all the N needs of the plant.

More work is needed to understand the relationship of fertilizer N and fixed N in the soybean.

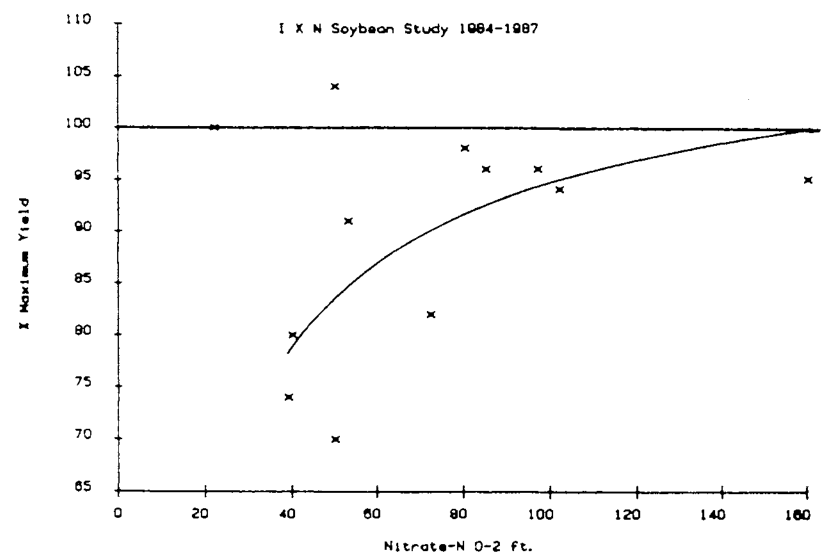

Figure 1. The effect of soil nitrate-N on soybean grain yield in Northwest Minnesota 1984-1987.

PHOSPHORUS (P):

The soybean is one of the least P-responsive crops commonly grown in the Upper Midwest. Even in this light, grain yield responses on a soil with a lower soil P test, less than 20 lb/A, have been documented in Minnesota. Since P is an immobile nutrient, placement has been a very important factor for efficient use in many other crops. Research on soybean in Minnesota has produced mixed results. Ham and Caldwell in 1978 investigated five different P placements: broadcast and incorporated, surface broadcast, surface banded 1.5 in. from the row, band 1.5 in. from row and 3 in. deep, and banded 9 in. from row and 3 in. deep at the Rosemount Experiment Station. They reported a P grain yield response to P fertilizer, but no method of application differences.

In 1986, a study with the objective of determining the efficiency of P placement methods (starter 2 x 2, knife midrow, and broadcast) was started at Waseca, Lamberton, and Crookston, MN. In 1986 and 1987 there was no grain yield response to P at the Crookston location. In both years, Waseca and Lamberton trials had significant grain yield responses.

At Waseca there were no method of application effects on grain yield in either year (Figure 2). The grain yields at Lamberton were in both years affected by method of placement. In 1986, the broadcast application produced the best grain yields (Figure 3). The 2 x 2 starter placement performed intermediate and the knife method performing the poorest. In 1987, again broadcast application on the average, performed superior to the other placement methods (Figure 4). The knife and starter placements changed positions with knife performing better than the starter placement.

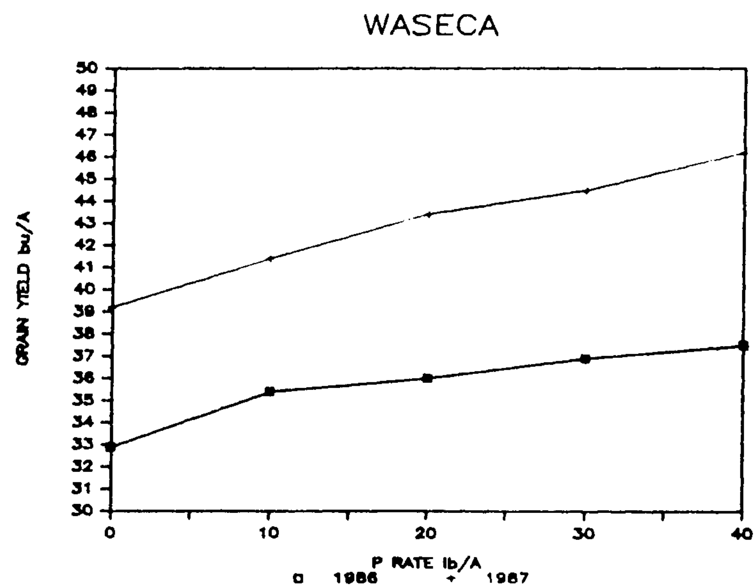

Figure 2. The effect of phosphorus on soybean grain yield at Waseca, 1986 and 1987.

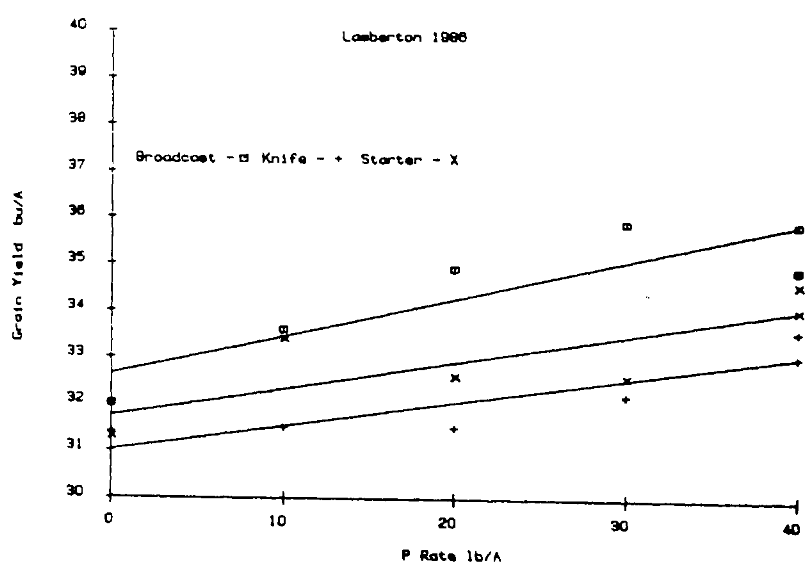

Figure 3. The effect of phosphorus placement on soybean grain yield at Lamberton, 1986.

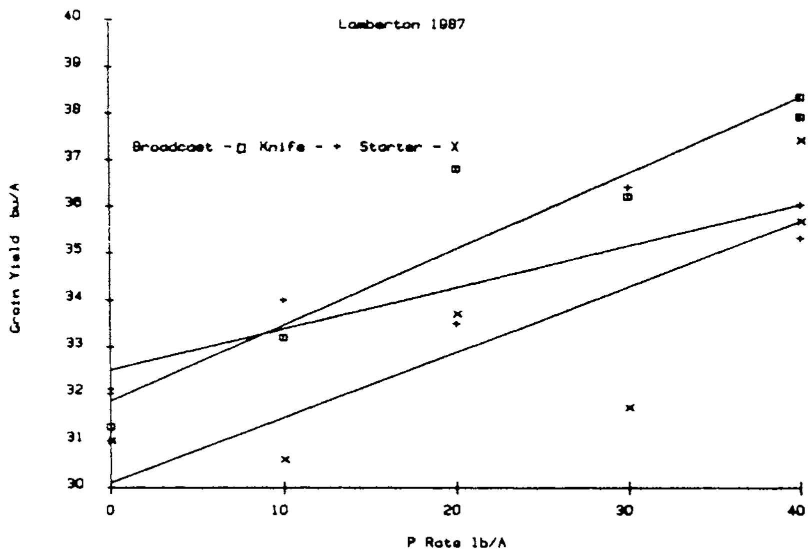

Figure 4. The effect of phosphorus placement on soybean grain yield at Lamberton, 1987.

Normally it was thought that a starter 2 x 2 placement should perform better than broadcast. In soybeans this does not seem the case. Another instance was reported in Nebraska (Rehm and Wiese in 1979 and 1980) that a broadcast application performed better than a starter 2 x 2 method (Table 1).

Table 1. The effect of P fertilizer placement on soybean grain yield in Nebraska, Rehm and Wiese, 1979 and 1980.

P Rate	Grain Yield bu/A			
	1979		1980	
lb/A	Starter 2 x 2	Broadcast	Starter 2 x 2	Broadcast
0	32.6	34.7	34.2	35.1
10	32.7	41.9	35.4	38.6
20	35.2	42.5	34.9	41.1
30	36.6	45.9	36.6	41.5
40	36.7	43.0	35.9	43.5
Avg.	35.3	43.3	35.7	41.2

One explanation for this difference in application method response in soybeans when compared to corn or small grain could be the difference in root systems. The soybean was a tap root where corn and small grains has a fiberous root system. This difference in root system evidently effects the way soil is explored for nutrients. Under circumstances where soybean grain yield responses are predicted by soil test, a broadcast application is the most efficient method of P application. Stated another way, use of starter fertilizer in particularly low soil tests is not the most advantageous method of application as it is for corn and small grain production.

POTASSIUM (K):

There is not any recent data on K placement on soybean. Since K is a relatively immobile nutrient like phosphorus, it can be assumed that what happens with phosphorus also occurs for K fertilization.

IRON CHLOROSIS:

When discussing fertilization of soybean, iron chlorosis is a matter which warrants some discussion. Iron chlorosis is not a deficiency of iron in the soil. There is plenty of iron in Minnesota soils. The problem is that it is not in a form used by the plant. Normally, the iron is in an oxidized state, one which the plant uses. In cases of wet soil conditions iron is changed to a reduced or unusable form. What can a producer do to correct this problem:

1. The producer can spray chelated iron on the crop to supply iron through the foliage. This has met with limited success. Research conducted in the 1970's concluded a yield increase from application of foliar iron was unpredictable.

2. Cultivate deep to dry and warm the soil. This procedure is more effective than the first and probably cheaper. The drying of the soil causes the iron to revert back to the oxided or usable form.

SUMMARY:

Fertilizing soybeans correctly, although not as complex as corn, is important and can be the key to profitable soybean production. The following are some factors that should be considered when fertilizing soybean:

1. Get a soil test from a reputable soil testing lab. If you doubt the recommendation, compare it to the land grant University's recommendations.

2. Soybeans get most of their N from N_2 fixation by rhizobium.

3. In Northwestern Minnesota, N fertilization may be needed.

4. Inoculation of seed with rhizobium is needed in areas with no previous history of soybean production.

5. Broadcast application of P and K is normally superior to band application methods.

6. Iron chlorosis can be treated with iron chelate with limited success. Cultivation is probably a better alternative for greening up a chlorotic crop.

SOIL TESTING: LOOKING THROUGH THE SMOKE WITH CONFIDENCE

Jerome N. Lensing
Agronomist
Pioneer Hi-Bred Int'l., Inc.

With the emphasis today on keeping production cost down without reducing yields, implementation of a sound fertility program is a major step towards increasing a farmer's profitability. In developing a profitable fertility program the following steps need to implemented:

1. Establish yield and fertility objectives.
2. Implement a good soil testing program.
3. Apply fertilizer in the most efficient way.
4. Monitor and evaluate your fertility program.

Today my emphasis will be on the first two steps - establishing objectives, and soil testing.

OBJECTIVES

The objective of a profitable fertility program ultimately is to make fertilizer applications that will result in the most economical as well as the most profitable return on the fertilizer dollar. When evaluating the various philosophies on fertilizer recommendations, two interpretations stand out. They are:

1. "Fertilize the soil" philosophy
2. "Fertilize the crop" philosophy

FERTILIZE THE SOIL

The "fertilize the soil" philosophy has two objectives, which are:

1. To BUILD UP the nutrient status to a desired level
2. To MAINTAIN the nutrient status at these optimum levels

Using this philosophy, fertilizer is added at "buildup" levels until the soil reaches an "optimum" level. A problem occurs when there is no universal agreement as to what is considered "optimum" for a nutrient. To some of us a P test of 35 may be considered high, while others may consider it only medium or even low. This lack of agreement results in large differences in the fertilizer recommendation.

This philosophy involves a yield response curve (Fig. 1) where yields are directly related to soil test values. This approach assumes that as long as soil test levels are increasing, yields will also increase - up to the optimum level for that nutrient. The "fertilize the soil" philosophy also assumes that maximum yields are not reached until the optimum soil test value is reached. A combination of buildup and maintenance is used for fields where soil test values are less than high.

At the optimum level for a given nutrient, the maintenance or crop removal concept applies. This implies that once the optimum soil test level is reached, the nutrients that are removed by harvest need to be replaced to maintain the soil test level. We have an excellent handle on what the removal amounts are for most crops and nutrients, however, long term data indicates that application of crop removal amounts will actually build soil test levels, and that some rate less that crop removal can maintain soil test levels. Fixen summarized data from the North Central region that indicates that the maintenance requirement is not constant, varying from 0 to 100% of crop removal. (Fig. 2) The data indicates that on an acid or near neutral soil of medium or fine texture with a Bray-1 of 40 lbs/A or less, P rates less than removal are required for maintenance. Application of rates equal to removal should build up, not maintain soil test P.

This philosophy does not take into consideration that nutrients such as P and K are fixed or "tied up" in some soils. This is especially true of phosphorus in the western part of the corn belt where high levels of free calcium carbonates react with applied phosphorus to form insoluble phosphates. This may not be measured by the phosphorus test, and subsequently more phosphate will be applied even though the soil will not reach the "optimum" level and needless fertilizer dollars are spent on a soil that cannot be "built up", except at substantial expense.

There are two soil tests that should be used in determining extractable phosphorus, the Bray-1 method and the Olsen method, with the Olsen method being used on highly calcareous soils and the Bray on neutral and acid soils. These are the only two P tests that have been correlated to phosphorus response in Minnesota and the use of other P tests and ratios only adds confusion and frustration to the interpretation of soil testing.

Many soils in the corn belt, because of the type of clays involved, have the ability to "fix" K. The "fixed" K in these soils will not be measured by routine soil testing procedures to measure the K status. Use of the "fertilize the soil" philosophy with these soils will require high fertilizer K additions to raise the K test to optimum levels. This will lead to substantial expense to growers.

The use of a "cation ratio", or saturation concept, is generally incorporated into the "fertilize the soil" philosophy. This suggests that there is a fixed percentage of exchange sites that should be occupied by K, Ca, and Mg in an "ideal" soil. With this concept comes a cumbersome set of ratios of these nutrients without any regard for soil test levels. This concept originated in the eastern United States with early limited data. More recent information from the Upper Midwest clearly shows that there are no ideal ratios and that excellent yields are realized over wide ranges in these ratios.

Alfalfa data from Wisconsin shows that alfalfa yields were not affected by a wide range of Ca/Mg ratios. This was the case for both a silt loam, as well as a loamy sand soil. (Table 1) A Nebraska three-year study evaluated the rates of K_2O. If the cation ratio or saturation concept worked, the added K_2O should have decreased yield. (Table 2) This is a sampling of the data that clearly indicates that this concept does not need to be used to make recommendations in the corn belt.

Table 1. Effect of various Ca/Mg ratios on alfalfa yield in Wisconsin

Theresa silt loam		Plainfield loamy sand	
Ca/Mg Ratio*	Yield	Ca/Mg Ratio	Yield
	ton/acre		ton/acre
2.3	3.3	2.6	4.1
3.6	3.1	3.3	4.1
4.1	3.6	4.0	4.4
5.3	3.5	4.8	4.1
8.4	3.2	7.6	4.3
		8.1	4.4
	NS		NS

* A variation in ratios achieved by using gypsum ($CaSO_4$) and epsom salts ($MG\ SO_4\ H_2O$)

Simpson, et al 1979

Table 2. Effect of rate of applied K_2O on corn yield 1979-1981

K_2O Applied	Yield
lb/acre	bu/acre
0	164
67	163
134	163
210	162
268	160
	NS

Initial soil K test = 160 lb/a
CEC = 2.64 m.e/100 gm

Rehm and Sorenson, 1985

Use of this concept can lead to excessive applications of K, Mg, Ca without yield increases but with substantial cost. In many cases, the elimination of this concept from the interpretation of test values would reduce much of the variation in recommendations.

FERTILIZING THE CROP

The other philosophy, "fertilizing the crop", is used by most land grant universities and some private labs. This philosophy is also called the sufficiency approach, where nutrients are applied only when a high probability of a yield response is indicated. As the probability of a response decreases, the rate of applied fertilizer also decreases. The same response curve is used as in the "fertilize the soil" approach, however relative yield is correlated not only with the soil test level, but also with the degree and likelihood of a response IN A GIVEN YEAR. (Fig. 1) The maximum economic yield may be reached at a particular level for one crop, but a different crop will respond to applied fertilizer at that soil test level.

This philosophy does not assume that soil levels must be in the high range before maximum yields are achieved. Also, a maintenance rate of fertilizer is generally not recommended when this philosophy is used. This approach relies on intensive field, greenhouse and laboratory research to identify what the fertilizer needs are for a particular crop at various nutrient levels in the soil. Correlation research is ongoing with changes in farming systems, application methods, and yield levels.

Recommendations are based on results of long term studies where amounts of a nutrient needed to provide for optimum yield at any soil test level has been identified. If long term data indicates that at a low soil test level an application of 100 lb. P_2O_5/A is needed for optimum yields, then this is what the recommendation will be. Since this philosophy does not use excessively high rates to rapidly build soil test levels, recommendations of the "fertilize the crop" approach usually result in lower fertilizer costs for the grower.

WHAT'S THE DIFFERENCE?

Use of both philosophies will eventually bring about optimum yields. Either philosophy should give us the confidence that only through soil testing can we have some means of giving the grower a fertilizer recommendation. It is also quite apparent that the two approaches can result in wide differences in recommendations. The purpose of a soil testing laboratory should be to evaluate the nutrient-supplying status of a soil and then, if asked, to provide fertilizer recommendations that will be profitable as well as economical.

Through the years the question has been asked, "Which approach is correct for soils in the Northern Corn Belt?". To answer this question, a number of trials have been conducted to evaluate the recommendations from various soil testing laboratories over a period of years.

In a seven year study with corn and wheat at Morris, MN, the combined average return per acre ranged from $50 to $90 over the unfertilized checks. Fertilizer cost ranged from a low of $153 (U of M) to $325 on wheat. The range on corn was $292 (U of M) to $483. (Table 3)

Table 3. Influence of laboratory fertility programs on total crop value, total fertilizer cost and economics on corn and wheat at Morris, MN, from 1980-1986

Lab	Wheat[1] 7-yr Total			Corn[2]			
	Crop Value	Fert. Cost	Return[3]	Crop Value	Fert. Cost	Return[3]	Comb. Ave. Return/yr
	$/A						
Agvise	1569	184	334	2065	352	206	87
A & L	1632	299	292	2038	419	112	58
Harris	1603	325	237	2101	483	111	50
Eco-Agri[4]	1529	218	270	2040	431	102	53
U of M	1608	153	414	2013	292	214	90
Check	1041	---	---	1507	---	---	--

[1] Wheat valued at $4/bu, 1980-84, $3.50/bu, 1985, and $2.50/bu in 1986.
[2] Corn valued at $3.00, $2.40 $2.00, $3.00, $2.80, $2.07 and $2.00/bu.
[3] Return = crop value - (value of check treatment + fertilizer cost).
[4] Tested by Willmar, MN, 1980-83.
Evans & Regimbal, 1987

Similar results were found on a medium high testing site in Waseca, MN. The range in total return per acre was from $121 to $326 (U of M) with $12 difference in total crop value with the various fertilizer recommendations varying by a difference of $211 in fertilizer cost. (Table 4)

Table 4: Effect of fertilizer recommendations on total crop value, total fertilizer cost and resulting economics on the medium-high testing site at Waseca from 1980-86

Lab	Crop Value[1]	7-Yr Total Fertilizer Cost	Return[2]
		$/A	
A & L	2409	389	+199
Harris	2421	474	+121
MVTL	2412	287	+299
Cropmate	2411	449	+136
U of M	2415	203	+326
Check	1826	---	---

[1] $3.00, $2.40, $3.00 and $2.07/bu used for corn in 1980, 1987, 1983 and 1985, respectively, and $5.50, $6.00 and $4.57/bu used for soybeans in 1982, 1984 and 1986, respectively for a seven-year total crop value.
[2] Return over 7-year period = crop value - (fertilizer cost & value of check treatment).
Randall & Kelly, 1987

In a South Dakota Study, SDSU and the U of M recommendations returned over $70 while the other two labs returned only $4-$25 over a period of three years. (Table 5)

Table 5. Influence of laboratory fertility programs on total crop value, total fertilizer cost and total return for corn at Brookings, SD, 1984-86.

Lab	Crop Value[1]	3-Yr Total Fertilizer Cost	Return[2]
		$/A	
SDSU	844	34	76
Harris	862	103	25
A & L	858	120	4
U of M	849	44	71
Check	734	---	--

[1] Value of corn $2.50/bu, 1984, 1985 and $1.50/bu in 1986.
[2] Total return = crop value - (fertilizer cost + value of check treatment).
Gelderman and Gerwing, 1986

On a very high testing site at Waseca, Mn, the economic returns to recommended fertilizer range from sizeable losses to modest gains. (Table 6)

Table 6. Influence of laboratory fertility programs on total crop value, total fertilizer cost and resulting economics on a very high testing site at Waseca from 1980-85

Lab	Crop Value[1]	6-Yr Total Fertilizer Cost	Return[2]
	-----------------	$/A	-----------------
A & L	1926	337	-101
Harris	1946	352	- 96
MVTL	2009	248	+ 71
Cropmate	1999	407	- 98
U of M	1962	206	+ 66
Check	1690	---	---

[1] \$3.00, \$2.40, \$3.00 and \$2.07/bu used for corn in 1980, 1981, 1983 and 1985, respectively, and \$5.50 and \$6.00/bu used for soybeans, respectively, for crop value.
[2] Return = crop value - (fertilizer cost + value of check treatment).
Randall and Kelly, 1986

Soil samples taken after six years of fertilizer applications showed that the soil test P and K levels were maintained in the high to very high range with all fertilizer applications. The applications of fertilizer increased the soil test levels in magnitudes equal to amounts applied. (Table 7)

Table 7. Soil test results after six years of fertilizer with the five laboratories' recommendations - Waseca, 1980-85.

Lab	Soil pH	Bray Ext. P	Exch. K	Ext. SO_4-S	Zn
		------lb/A	------	--------ppm	------
			Very high testing site[1]		
A & L	5.7	59	384	10	3.0
Harris	5.6	71	400	10	2.0
MVTL	5.9	59	320	5	2.1
Cropmate	5.8	76	356	6	1.8
U of M	5.9	50	340	7	1.1
Check	6.3	32	275	6	1.2
			Medium high testing site[2]		
A & L	6.5	39	334	7	3.1
Harris	6.6	44	342	7	2.3
MVTL	6.5	39	308	5	1.5
Cropmate	6.6	44	332	3	2.0
U of M	6.8	35	290	4	1.3
Check	6.9	15	282	6	1.4

[1] Initial tests in 1980 were pH = 5.4, P = 56, K = 318
[2] Initial tests in 1980 were pH = 6.4, P = 18, K = 294
Randall and Kelly, 1986

On medium testing sites at both Waseca and Morris, soil tests after six years of fertilizer applications showed increasing soil test levels. It should be noted that the University, as well as some of the other labs, whose recommendations were similar to the University, slowly built soil test levels, but at lower cost per acre without any yield loss. (Tables 7, 8)

Table 8. Total N, P, K and Zn applications and final soil test results Morris, 1980-86

Block 1

Lab	Total 7-year Fert. Appl. N	P_2O_5	K_2O	Zn	Soil Test Results pH	Bray P	Olsen P	Ex.K	Zinc	Org. Matter
	lb/acre	lb/acre	lb/acre	lb/acre		lb/acre	lb/acre	lb/acre	ppm	%
Agvise	659	457	325	0	8.0	38	27	204	1.3	4.3
A & L	737	405	670	6.0	7.9	37	27	249	1.8	4.5
Harris	858	452	938	7.5	7.9	39	29	249	1.8	4.5
Eco-Agri[1]	774	401	584	8.0	8.0	37	26	276	2.3	4.2
U of M	580	365	200	0	8.0	30	21	198	1.2	4.0
Check	---	---	---	---	8.0	20	16	226	1.5	4.3

Block 2

Lab	Total 7-year Fert. Appl. N	P_2O_5	K_2O	Zn	Soil Test Results pH	Bray P	Olsen P	Ex.K	Zinc	Org. Matter
	lb/acre	lb/acre	lb/acre	lb/acre		lb/acre	lb/acre	lb/acre	ppm	%
Agvise	607	506	375	0	8.1	5	24	216	1.0	3.3
A & L	860	485	665	8.5	8.1	26	21	219	1.6	3.9
Harris	815	566	1238	6.0	8.2	14	23	283	1.3	3.4
Eco-Agri[1]	489	407	645	14.0	8.1	23	18	232	2.1	3.9
U of M	545	425	318	0	8.1	23	19	190	1.1	3.9
Check	---	---	---	---	8.2	2	10	186	1.0	3.5

[1] Willmar recommendations followed from 1980-83.
Evans and Regimbal, 1987

The conclusions from these studies have been consistent. The "fertilize the crop" philosophy has produced the least cost fertilizer program as well as maintaining optimum yields. In other words, maximum economic yield.

SOIL TESTING

The purpose of soil testing is to determine the ability of a soil to supply nutrients to a crop. To insure accurate and reliable test results, a set of standardized procedures has been established that is recommended for testing soils in the Upper Midwest. In general, analytical results for the measurement of pH, organic matter, P, and K should be reasonably close. However, with some of the other nutrients, various procedures may be used, causing differences in the results. When comparing soil test results, it is important that similar procedures were used, and that the numbers are reported in similar units or converted to same.

SAMPLING METHODS

When evaluating soil test results, some causes for differences in the year to year results include:

1. Depth of sampling
2. Time of sampling
3. Non-representative samples

Depth of sampling many times is the main culprit, because a different person is sampling or a different probe is causing a change in depth of sample. Sampling one year at a four-inch depth and the next time to a eight-inch depth will give a totally different set of numbers. This is becoming especially important now that more acres are in reduced tillage, where the soil is not mixed as much as when moldboard plowed. Maintaining the same depth when sampling greatly increased the accuracy of the soil test.

Time of sampling can also have an effect on soil test results. The type of crop, environmental factors and soil types all have an influence on the concentrations of nutrients, causing variations throughout the year. Fall or early summer generally give the best results when sampling after the same crop, or while the same crop is growing.

Non-representative samples also cause a major share of the variations in soil test results. Across an individual field there may be numerous soil types, each varying in its nutrient supplying power as well as yield potential. Over the years these differences may have increased due to cropping history, fertilizer and manure applications and erosion. Wide variations in soil organic matter, pH, and major nutrients can be found. Taking an "average" soil sample can give a very misleading picture of what the nutrient needs are for a large soil area. To get detailed knowledge of the variations found in an individual field, intensive soil sampling by grids or soil types needs to be considered.

The adage that the soil test results are only as good as the sample procedure should be a constant reminder to us to maintain consistency and accuracy. Sampling to the same depth, after the same crop, and at the same time of the year will go a long way to to improve the accuracy of soil test results. Taking samples that are representative of a specific soil area, plus incorporating the yield potential of that area, will result in a fertility program more precisely matched to the individual nutrient needs of each soil area. This will increase fertilizer efficiency as well as net profits.

CONCLUSION

Combining proper sampling techniques with the use of sound recommendations will go a long way to a profitable fertility management program. Recommendations should be based on correlation/calibration data from your local university. Studies have clearly indicated that the "fertilize the crop" recommendations are the most economical as well as most profitable. Careful soil sampling along with sound fertility recommendations does not cost - it pays dividends in the form of increased yields and profits.

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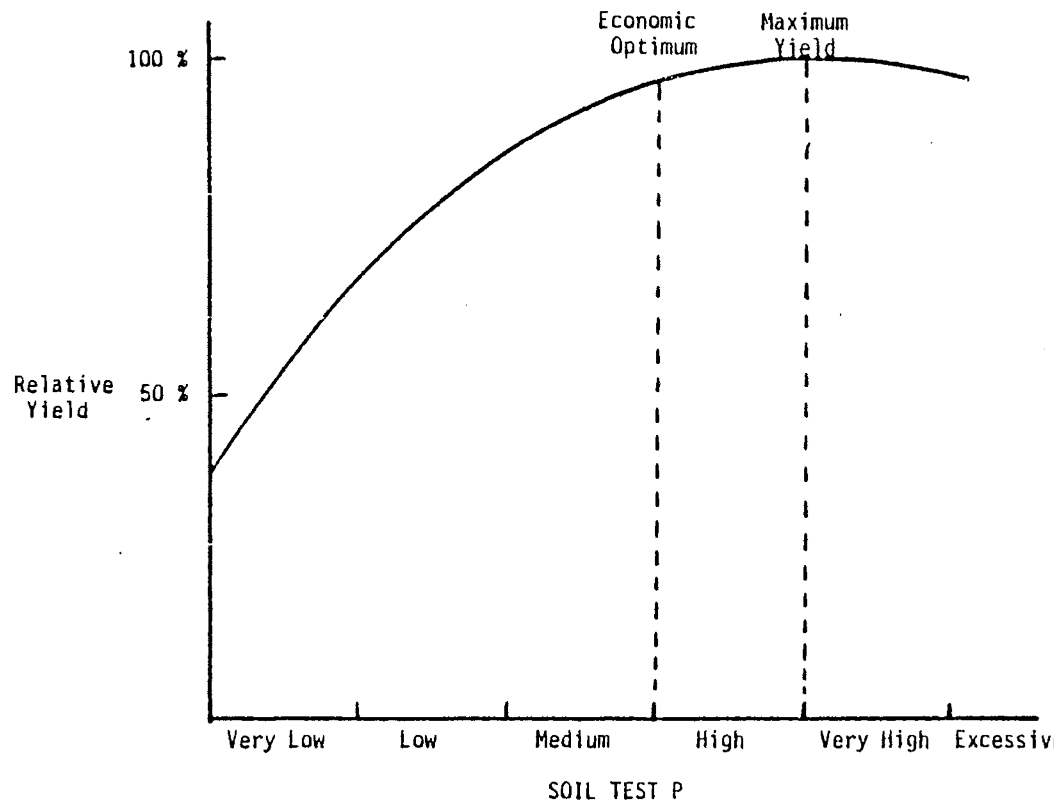

Fig. 1. General relationship of relative crop yield to soil test level for P.

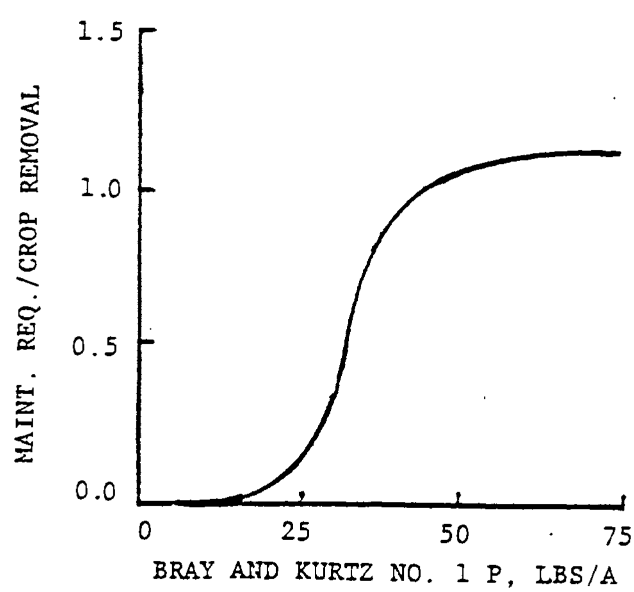

FIG. 2. Influence of soil test P level on maintenance requirements for acid and neutral soils.

NEW CONCEPTS IN P/K PLACEMENT

by

Steve Sodeman
United Ag Tech
Trimont, Minnesota

Interest in fertilizer placement began about five years ago. Parties that have highlighted this interest have been: Barber and Mengel of Purdue, Herman Warsaw of Saybrook, Illinois, Dan Stadtmueller of Monticello, Iowa, the Iowa State University group working with the spoke injector, Tilney Farms of Lewisville, Minnesota, the University of Minnesota, and various others.

The driving forces behind this activity are: environmental concerns, increased cost consciousness, yield benefits, and new equipment technology. The advent and propagation of ridge-till farming has brought about a need and desire to change old fertilizer application practices. Many of these "unconventional" farmers are early adopters and innovators with excellent mechanical skills and inventive minds. I have the privilege of being located in a hotbed of this activity in Martin County and surrounding counties. The principal source of much of this activity centers on the Harvey and Brady Jass farm of Odin, Minnesota.

Many of the new fertilizer application concepts are tailor-made for ridge-tillage because of (1) the permanency of the seedbed, (2) the erosion control benefits, and (3) the control of compaction. However, the no-till philosophy behind ridge-till may have necessitated a change in old fertilizer application practices particularly on sloping land. If you combine this with the economic, yield, and equipment forces, you could have a real advantage in tomorrow's farming practices.

People have wondered why we do not do this as we plant. The answer is MUD. Ridges are firm and moist in the spring. We do not wish to destroy the "perfect seedbed" plus we want to maximize our planting efficiency. We encourage fall first, sidedress second, and preplant-off to the side third. The advantages of these systems are:

1) To maximize fertilizer efficiency.

2) There is an apparent yield advantage over broadcast.

3) It is environmentally sound i.e., low rates, reduced loss.

4) Fall fertilization and "self-service" fertilizer.

5) It represents a return to shotgun methods rather than prescription blending but it should tend to make the poorest fertility soils better and enhance field uniformity.

6) It is a major improvement on the advantages of ridge tillage.

7) No starter fertilizer at planting is required.

8) Nitrogen fertilizer may be added.

9) Sidedressing of N-P-K is possible.

Some disadvantages are:

1) It requires additional capital investment.

2) It requires more labor and time.

3) It is slower than broadcast (15, 20, or 30 feet @ 4-6 mph) (approx. 11 acres/hour).

4) Thus far it is a separate operation.

5) The uncertainty of the farm program.

6) No soil test-rate research available.

7) The long-term effects of this concept are unknown.

We have attempted to test these ideas in an on-going, expanding fertilizer plot on the Harvey and Brady Jass farm. The purpose is to:

1) Determine the best rate.

2) Determine the effect of time on the rates.

3) Determine if soil testing and plant analysis are appropriate tools.

4) Determine the effect of rate on the yield of corn and soybeans as it relates to profit. (See Tables 1, 2, 3)

Thus far we are well satisfied with the results; however, we also would like to answer the questions:

1) What are the long-term effects of this system?

2) What rates for high and low fertility soils?

3) What rates for coarse and fine-textured soils?

4) How do rates relate to soil test levels, plant analysis, and crop removal?

5) What is the best position to place the fertilizer in the soil in relation to the seed?

TABLE 1

Economics of P/K Placement in the Ridge for Corn

Treatment	Fert. Cost	Yield(86)	Yield Inc. Over check	Profit Over Check
	$/A	bu./A	bu./A	$/A*
Check	-	170	-	-
11-30-30 Fall(85)	9.36	175	5	-.81
19-50-50 Spring SD(86)	15.60	182	12	4.92
19-50-50 Fall(85)	15.60	183	13	6.63
28-75-75 Fall(85)	23.40	186	16	3.96
56-150-150 Fall(85)	39.00	190	20	-4.80

* Corn = $1.71; LSD = 9.2

TABLE 2

Economics of Residual P/K Placement in the Ridge for Soybeans

Treatment	Yield(87)	Yield Inc. Over Check	Profit Over Check
	bu./A	bu./A	$/A*
Check	43.6	-	-
11-30-30 Fall(85)	45.1	1.5	6.69
19-50-50 Spring SD(86)	47.7	4.1	18.29
19-50-50 Fall(85)	46.8	3.2	14.27
28-75-75 Fall(85)	47.2	3.6	16.06
56-150-150 Fall(85)	48.6	5.0	22.30

* Soybeans = $4.46/bu; LSD = 1.0

TABLE 3

Economics For Corn - Soybean Rotation

Treatment	Total Fert. Cost	Profit Over Check
	$/A	$/A
11-30-30 Fall(85)	9.36	6.69
19-50-50 Spring SD(86)	15.60	18.29
19-50-50 Fall(85)	15.60	14.27
28-75-75 Fall(85)	23.40	16.06
56-150-150 Fall(85)	39.00	22.30

DO WE NEED DIFFERENT RATES OF FERTILIZER N FOR CORN HYBRIDS IN MINNESOTA?

Michael A. Schmitt
Extension Agronomist-Corn
University of Minnesota

In recent years there has been much discussion and experimentation evaluating whether various corn hybrids respond differently to different nitrogen (N) management schemes. Along with all this publicity comes some confusion as to the practical implications this may have for Minnesota corn producers. The objective of this paper is to provide some insight as to what the goals of this type of research are and how much should one extrapolate the results of theoretical research to an applied agricultural situation.

Notice what the title of this paper does say and what it does not. It does not ask: 1) If different N management schemes are needed for corn hybrids in Minnesota, 2) If different hybrids take up N differently throughout the growing season in Minnesota, 3) If hybrids yield differently at constant N rates, or 4) How much control does a producer have on the ultimate amount of N available to corn throughout the season. While each of these questions will be discussed, the focus will be on different N rates for corn hybrids in Minnesota.

Since the goal of the research presented is to study an interaction effect of N and hybrids, it is important to qualify what constitutes an interaction. Many producers confuse an interaction effect with the individual effects of N or hybrid. A hybrid by N interaction occurs when different hybrids have different responses to a uniform change in N treatment. It is common that a significant interaction effect will also have significant individual effects. Most often though, individual effects occur without major interaction effects, such as when hybrids' yields vary in a variety plot or when hybrids' yields increase with increasing N rates. Figure 1 graphically shows these situations.

In studying this interaction, it is impossible to exclude studying the individual effects, in this case, those of N management and hybrids. Therefore, discussion in this paper will focus on the individual effects as well as the interaction effect.

HYBRIDS

Documented data suggests that all hybrids do not utilize N in the same manner. However, a problem in interpreting this data is that the environment (location, year, and/or location by year effects) does play a major role in the expression of this N utilization difference. Nitrogen utilization differences are important to crop producers only if these affect the hybrid's yield.

From the aspect of yields, each year conclusive data shows that all hybrids do not yield the same, regardless of N factors. The majority of the hybrid corn sold in Minnesota comes from a relatively small number of elite inbred lines. Even with the small genetic diversity, there are significant differences in some of the corn hybrids, as one observes each year in county corn growers' hybrid trials, experiment stations' elite hybrid trials, or seed industrys' hybrid test plots. Genetic superiority one year may not always continue each year due to environmental conditions favoring some particular genetics in some years.

Since some hybrids are genetically superior to others in yield, determining hybrid's response to N is difficult because N fertilizer rates should be based on yield goals. This is an inherent confounding factor in hybrid by N studies. In many instances, producers and researchers select N rates by stating an expected yield goal and assuming this yield goal is genetically feasible by all hybrids in a study.

A situation that occurs when studying hybrid responses, especially interactions, is that interpretation of the data is not always clear. Hybrid corn is sold as a company's number or designation that tells nothing of the inbred parents used to make the hybrid. If several companies market hybrids with the same inbred parents, unless the company discloses the inbreds used, it will take too long to screen all the hybrids. In contrast, when a researcher expresses data using the inbred lines, its practical usefulness is limited until everyone knows if the hybrid was from those particular inbreds.

NITROGEN

In the process of studying the hybrid by N interaction, much attention has been solely directed at N management. Whereas hybrid selection may not change the input costs to a producer, N management, especially with regard to rate, does vary input costs.

In refining N management, several key points have been made. Many cases can be cited where too much N is being applied to fields without an economic basis for return and also creating an environmental concern. In N response studies throughout the state, top economic yields are sometimes being reached with up to 50% less N than what some producers are applying. Why? A combination of factors contribute to this. First, the amount of N mineralized from organic N fractions in the soil is often underestimated or not accounted for. Years in which there are good environmental conditions for corn yields are generally good years for N mineralization. Second, many times the N rate recommended and applied was overestimated due to too high yield goals. There is also the problem of producers not accounting for the N credits that should be subtracted for rotations or from manure applications. All of these factors tell us that N rates need constant refinement.

While N rates may be too high or not as profitable for some, the increased awareness and applications of complete N management has made significant strides forward. Some of the N management practices that have gained in popularity, partially due to the hybrid by N debate, are the use of split applications, refined timing of application, nitrogen stabilizers, crop and hybrid rotations, and tissue testing. All of these practices can be used with a refined N rate to provide the most efficient use of the N.

HYBRID BY NITROGEN

This interaction is of top importance because it can answer the question of whether hybrids respond differently to various N rates (or management schemes). The interaction effects that most producers are curious about are whether some hybrids will perform well with low N rates (or poor N management) or if some hybrids perform exceptionally well with high N rates and sound N management.

Relatively little data in Minnesota is available that can statistically look at this interaction. The relatively few studies which did have both N rate and hybrid variables provide inconsistent interaction results which leads to belief in the strong influence of the yearly environment. Several project sites were started in 1987 for the sole purpose of studying this interaction. The generalized results of these experiments for this year were that hybrid selection was very important, N rate was of lesser importance since there was not a great response to N rates, and the hybrid by N interaction was mainly insignificant.

Thus far, the strong hybrid by N interaction has been difficult to document in the northern corn belt. This lack of consistent response may be partially explained in that the yearly environmental conditions play such a major role in the N response and the smaller genetic base of the hybrids adapted in the north will mask any possible real interaction that may be there.

PRACTICAL APPLICATIONS

Table 1 was developed to help producers evaluate the relative importance of the interaction in making management decisions based on this concept. Three N management schemes were selected and characterized (from an unlimited number of potential schemes), and three theoretical hybrid classes were designated. The yield response curves for these theoretical hybrid classes are represented in Figure 2. The bulk of the Table 1 was then an interpretation of the economic response of the inputs compared to the yield returns.

In using Table 1, one should select an N system and look at its economic possibilities for all theoretical classes of hybrids, because N systems are something that a producer can control and assumed hybrid responsiveness is not known for sure. For a low effective N rate, the only way to get a good economic return is if there is a significant hybrid by N interaction and one could identify this assumed nonresponsive hybrid.

Any other hybrid category will suffer more in yield than the savings in N can offset. When a high effective N rate is used, the high rate of N can be justified only when a hybrid that responds to high N rates is (identified and) grown. Otherwise the economic response is not there.

Very good economic returns are calculated when the medium effective N rate is used, regardless of the theoretical hybrid class. This is because it is a cost efficient program maximizing N efficiency and allowing response potential to all hybrid types. It is unlikely that hybrids will soon be categorized according to their N responsiveness, which should put more emphasis on the long-term N response returns listed in Table 1. For the majority of hybrids in Minnesota, the economic response is best at the medium effective N rates which can be equated to the carefully adjusted recommended rates using sound N management practices.

SUMMARY

Currently, there is not enough conclusive data to state that there is a consistent hybrid by N interaction affecting yield in Minnesota. What has been learned is that hybrids do vary greatly in their yields and in some of their N uptake patterns. Corn producers should continue to select their hybrids based on yield, maturity, standability, pest resistance, etc.

Insights into the N management schemes have generally showed that by using an integrated N management system and by properly calculating N rates, N application rates can be lower than those currently used. Failing to account for mineralizable N in a good year, lower yields in a bad year, and N credits from legumes and manure have kept N rates higher than they need to be. By improving N management factors with the use of rotations, split applications, stabilizers, and tissue tests, the N applied will be most efficiently used.

Consequently, we do not need different rates of fertilizer N for corn hybrids in Minnesota--at least at this point. What we do need is a better defined rate of N to use and more prudent selection of corn hybrids based on conventional performance characteristics to maximize our return per acre.

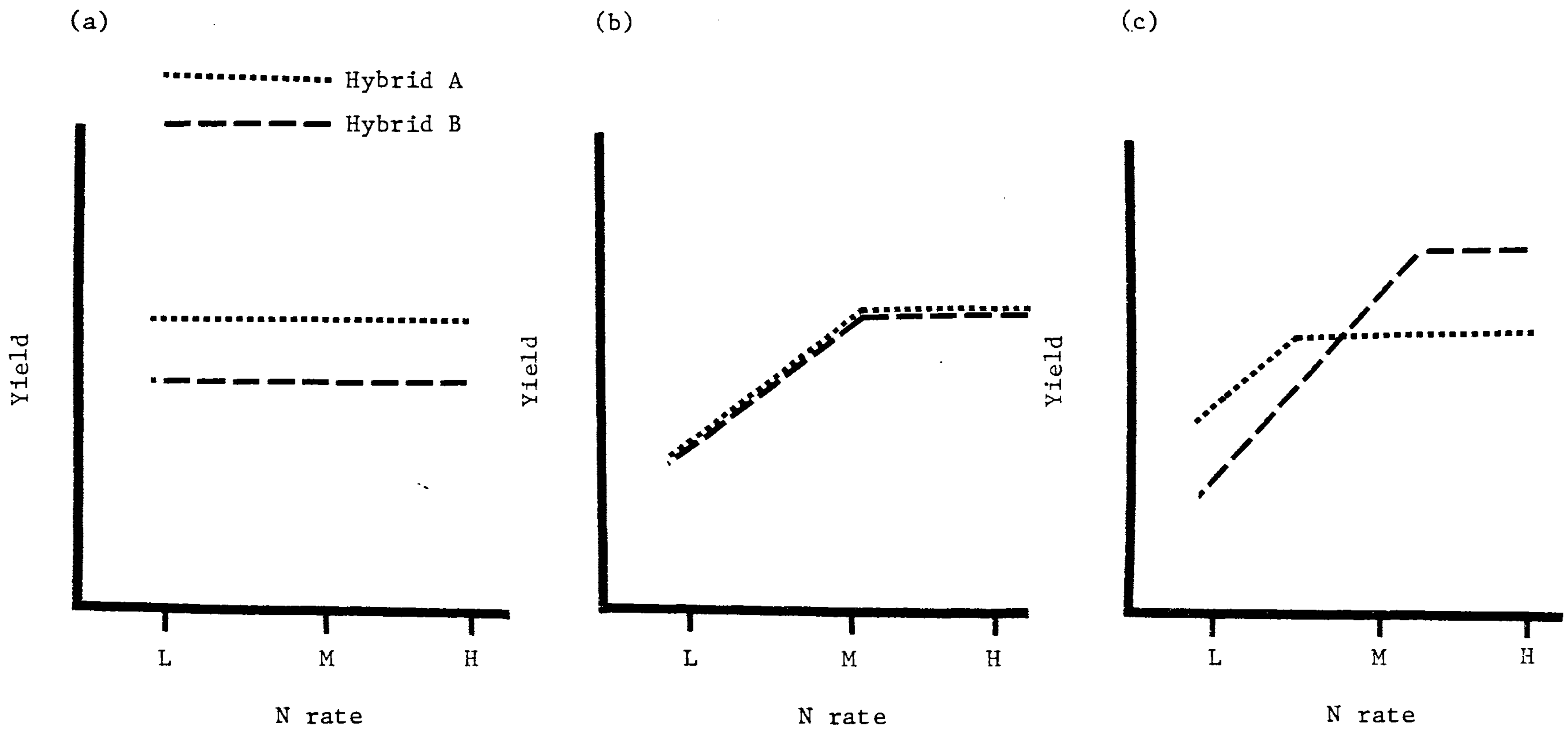

Figure 1. Graphical representation of significant hybrid effect and nonsignificant N rate and interaction effects (a), significant N rate effect and nonsignificant hybrid and interaction effects (b), and a significant hybrid by N rate interaction effect (c).

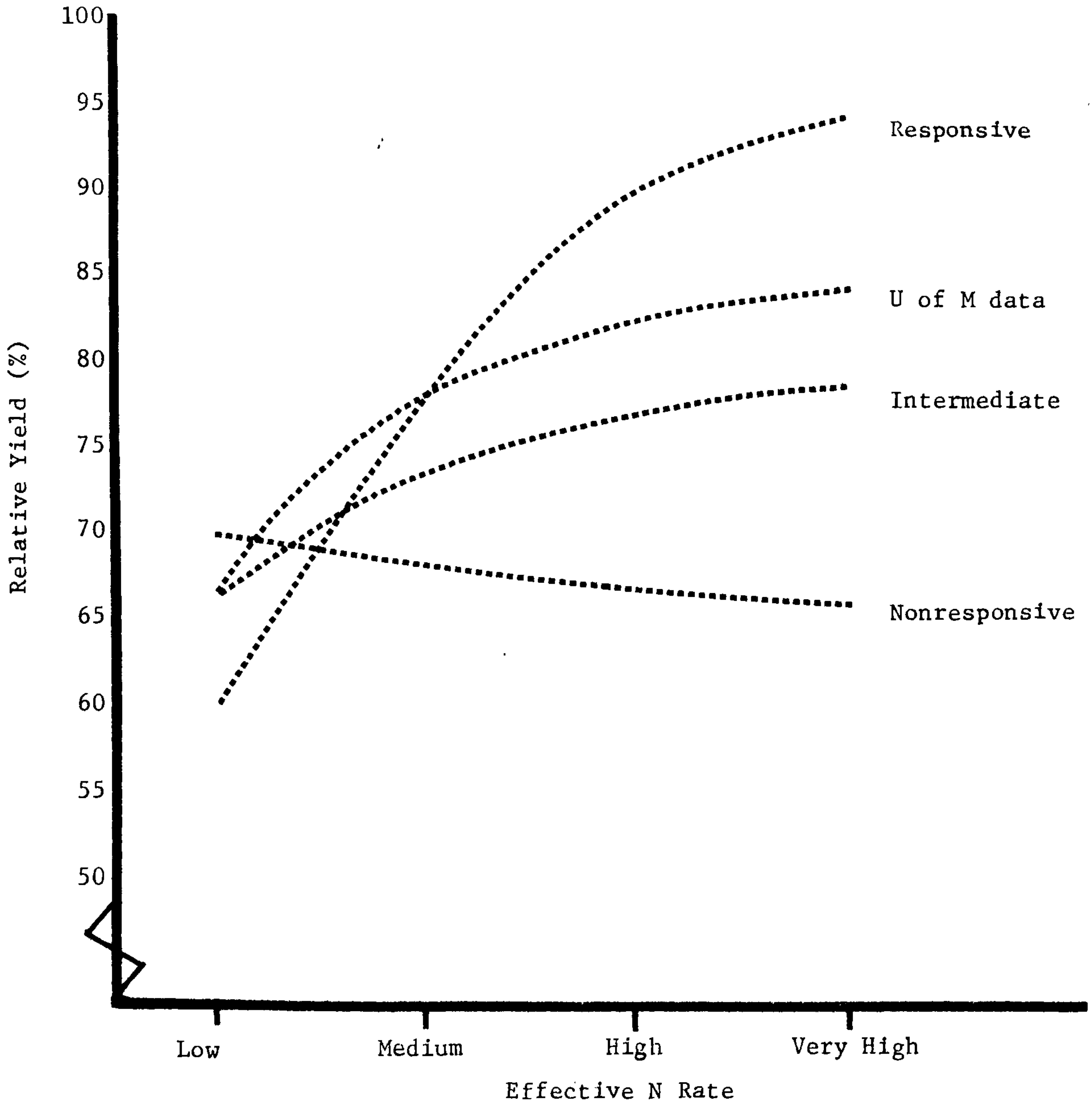

Figure 2. Theoretical N response curves for 3 hybrid classes as well as long-term N response curve from University of Minnesota research.

Table 1. Relative economic returns ($$$$-very good, $-poor) based on three selected N management schemes and hypothetical as well as actual hybrid responses.

Effective N Rate	Characteristic N Program	Long-term data Univ. of Minnesota Yield[1]	Long-term data Univ. of Minnesota Relative Return[2]	Assumed theoretical classifications: Nonresponsive Yield[1]	Nonresponsive Relative Return[2]	Intermediate Yield[1]	Intermediate Relative Return[2]	Responsive Yield[1]	Responsive Relative Return[2]
Low	Cont. corn 10# N/A starter 90# N/A U.A.N. -weed and feed	66	$$	71	$$$	66	$$	59	$$
Medium	Corn-Soybean 80# N/A Stab. ammonia -preplant 40# N/A injected U.A.N. -sidedressed	78	$$$$	68	$$$	74	$$$$	78	$$$$
Very High	Corn-Soybean 125# N/A urea -preplant 125# N/A stab. ammonia -sidedressed	84	$$$	66	$$	78	$$$	94	$$$$

1 Relative yields are from Figure 2.
2 Returns are calculated using current market prices for fertilizers and corn.

CURRENT RESEARCH: FACTORS INFLUENCING PESTICIDE MOVEMENT INTO GROUNDWATER

Donald L. Wyse
Weed Scientist
Center for Agricultural Impacts
on Water Quality
University of Minnesota

Modern agriculture relies heavily on the use of herbicides for the control of weeds. Over one-half of the cropland (more than 100 million ha) in the United States is treated annually with herbicides. Widespread herbicide use creates a potential non-point source for herbicide contamination of groundwater. The presence of herbicides in groundwater has been determined in a number of different studies.

For instance, in Minnesota, the Department of Agriculture has conducted a survey to determine the extent of the groundwater contamination by agricultural chemicals. As of September 1986, preliminary results showed that of 504 wells tested, 193 (38%) were contaminated with at least one pesticide. It has been suggested that the contamination is due to non-point sources. The pesticides were detected prior to spring application, suggesting that they persist throughout the year and may be leaching into the groundwater during late winter or early spring recharge events. Results of a study conducted in the Platte River Valley of Nebraska support direct downward leaching as a non-point source of low-level atrazine contamination in groundwater. Research must be conducted to determine pathways of pesticide movement to groundwater so that herbicide usage and cultural practices may be modified to reduce the risk of groundwater contamination. Modifying herbicide management to prevent groundwater contamination will be easier, safer and less expensive than removing the contaminants once present in the water.

THE CENTER FOR AGRICULTURAL IMPACTS ON WATER QUALITY

With the diversity of research and educational groups involved with water, none were closely focused on research concerning water quality relating to agricultural management practices in the College of Agriculture. The College of Agriculture, charged with research and educational programs related to agriculture, established the Center for Agricultural Impacts on Water Quality to focus on this important issue. The Departments of Agronomy and Plant Genetics, Plant Pathology, Entomology, Agricultural Engineering, Soil Science, and the Branch Station all have relevant expertise through their missions of fertilizer and pesticide usage and natural resource management. Research at the Center focuses on the basic behavior of chemicals and nutrients in the environment, the practices for responsible management of chemicals, and modeling of chemical behavior in the environment. Its objectives include minimizing groundwater contamination by agricultural chemicals, developing and improving managerial procedures that reduce agricultural chemical use, and increasing our understanding of the behavior and longevity of agricultural chemicals in soil and groundwater systems, and assessing the social and economic impacts of management practices.

PESTICIDE MOVEMENT TO GROUNDWATER

There are many factors that interact in a complicated system to influence the movement of pesticides to groundwater: 1) properties of individual pesticides; 2) rate of pesticide application; 3) soil properties; and 4) environmental conditions.

I. Properties of individual pesticides
   A. water solubility
   B. soil binding ability (adsorption)
   C. persistence
      1. adsorption
      2. volatilization
      3. microbiological decomposition
      4. plant decomposition
      5. chemical decomposition
      6. photodecomposition
      7. surface run-off

II. Rate of application
   A. increased rate
      1. increases amount available for transport to groundwater
      2. increases time that pesticide is available for transport

III. Soil properties
   A. clay or sand content
   B. organic matter content
   C. pH
   D. type of subsoil
      1. coarse sand to shallow groundwater
      2. thin A horizon with underlying rock or gravel
      3. Karst-topography in carbonate aquifers

IV. Environmental conditions
   A. rainfall/irrigation
      1. increases the potential for movement of mobile pesticides to groundwater
   B. temperature (air, soil)
   C. sunlight

In most of the major crop production areas of Minnesota, soil type and underlying geological structure are not ideal for pesticide movement to groundwater. Much of the soil in Minnestoa is high in clay content and organic matter with deep underlying water tables. However, there are two areas in Minnesota that may be susceptible to groundwater contamination with pesticides. Central Minnesota is one area which has sandy textured soils and shallow water tables, and in some areas rainfall is supplemented with irrigation. These conditions provide an ideal situation for the movement of persistent and mobile pesticides to groundwater. Since the soil in this area has little adsorption capacity and the water table is shallow, surface water reaches the water table each year and could carry mobile pesticides with it. The second area in Minnesota that may be susceptible to pesticide movement to groundwater is the southeastern area. Two geological situations exist in this area of Minnesota that are of concern. In some areas "Karst-topography" exists in the carbonate aquifers. Groundwater has made caverns in the limestone which allow for direct surface water movement through vertical fractures and sink holes. In other parts of southeastern Minnesota coarse gravel underlies the thin surface soil which could allow for rapid pesticide movement to groundwater once the pesticide has entered the coarse material.

CORN TOLERANCE TO ACETANILIDE HERBICIDES

Charlotte V. Eberlein, Weed Scientist
Paul R. Viger, Graduate Student
Dept. of Agronomy and Plant Genetics
University of Minnesota

INTRODUCTION

The acetanilide herbicide family contains several compounds used for weed control in corn, including alachlor (Lasso), metolachlor (Dual), propachlor (Ramrod), and an experimental herbicide, acetochlor (Harness). Corn seeded early into cold, wet soils may be injured by acetanilide herbicides, but no information is available on the relationship between early season corn injury and yield. Therefore, field studies were conducted to compare the tolerance of early seeded corn to acetochlor, alachlor, metolachlor, and propachlor.

METHODS

Experiments were conducted at the University of Minnesota Agricultural Experiment Stations at Rosemount, Waseca, and Morris, MN in 1985 and 1986. The soil type at Rosemount was a Waukegan silt loam; the soil type at Waseca was a Webster clay loam in 1985 and a Nicollet clay loam in 1986; and the soil type at Morris was a McIntosh silt loam. Two corn hybrids commonly grown in Minnesota, 'Pioneer 3906' and 'Pioneer 3732', were seeded as early as possible each year at each location. Acetochlor, alachlor, and metolachlor at 2.5, 5.0, 7.5, and 10 lb/A, and propachlor at 5, 10, 15, and 20 lb/A were applied preemergence. The experimental design was a split plot arrangement of a randomized complete block with four replications. Main plots were hybrids and subplots were herbicides and rates. Plots were maintained weed free with a preemergence application of atrazine at 2.0 lb/A and hand weeding as needed.

RESULTS

Corn injury from acetanilide herbicides varied depending on environmental conditions at or near the time of herbicide application. At Rosemount and Waseca in 1985, temperatures were 21% and 16% above normal for two weeks after herbicide application, and rainfall was 41 and 22% below average, respectively. Under these relatively warm, dry conditions, very little corn injury from alachlor, metolachlor, or propachlor was observed and yields were not reduced by these herbicides at any of the rates tested. Only acetochlor at high rates (7.5 and 10 lb/A) caused significant injury (9 to 18%). Acetochlor at 10 lb/A reduced corn yields 7% at Waseca. Hybrids did not vary in their response to the acetanilides.

In 1986, temperatures were near normal for two weeks after herbicide application and rainfall was about two times greater than average at all three locations. Much more injury was observed under these cool, wet conditions than was observed in 1985. Over the range of rates tested, early season corn injury ranged from 0 to 40% for acetochlor, 0 to 15% for alachlor and metolachlor, and 0 to 10% for propachlor. There were no differences in hybrid response to the acetanilides at any location. Although acetochlor at 7.5 and 10 lb/A reduced yields from 7 to 20%, yields were not reduced by any rate of alachlor, metolachlor, or propachlor tested. Corn showed good ability to recover from early season injury from alachlor, metolachlor, or propachlor.

Across the range of environmental conditions encountered in 1985 and 1986, corn showed the greatest tolerance to propachlor and the least tolerance to acetochlor. The potential for corn injury from acetanilides was greater under cool, wet conditions than under warm, dry conditions. However, injury from typical use rates of the acetanilides did not reduce corn yields.

CORN AND SOYBEAN WEED CONTROL UPDATE

Jeffrey L. Gunsolus
Extension Weed Control Specialist
Department of Agronomy and Plant Genetics
University of Minnesota

Postemergence soybean herbicides are the only area of the corn and soybean herbicide market that have any new chemistry to discuss since the update last year. Since last year, lactofen (Cobra) and fenoxaprop (Option/Whip) have been introduced into the market place. Cobra is a postemergence annual broadleaf herbicide from PPG, that has proven to be very effective on common cocklebur and redroot pigweed with fair to good activity on velvetleaf. Cobra is not effective on common lambsquarters or the smartweeds. Be careful with the use of additives with Cobra because even without an additive this herbicide can cause significant leaf burn. The Cobra label states to use a nonionic surfactant at 1 to 1.5 pts/100 gal of water carrier or 0.25 to 1 pt/A of crop oil concentrate.

Fenoxaprop appears to be a new postemergence annual grass herbicide with two names. Fenoxaprop will be marketed in most of Minnesota as Option by the FMC Corporation. However, Hoechst will be marketing this herbicide as Whip in northwestern Minnesota. Option/Whip is labeled for use at 0.8 to 1.2 pts/A. Option/Whip is not effective on perennial grasses or volunteer rye or barley and cannot be tank mixed with postemergence broadleaf herbicides.

Additives for postemergence soybean herbicides are also a hot topic in 1987-1988. Dash an "oil like" additive is being marketed by BASF to increase the weed control potential of Poast. Dash is to be used as a substitute for oil concentrate and may increase the ability of Poast to control volunteer corn and may help to reduce the antagonism in Poast plus Basagran tank mixtures. University of Minnesota research indicates that a mixture of Dash at 1 qt/A plus 28% nitrogen at 2 to 4 qt/A, in place of oil concentrate, does reduce but does not completely eliminate antagonism in Poast plus Basagran tank mixtures. See the Dash label for more details on the use of Dash.

Several package mixtures were added to the soil applied soybean herbicide market last spring. These package mixtures were Commence and Salute. Commence is a mixture of trifluralin (Treflan) and clomazone (Command). Salute is a mixture of Treflan and Sencor. Both of these package mixtures must be preplant incorporated.

This last year we experienced very little problem with the volatilization and off-target movement of Command. The reason for this is simple, in 1987 all products that contained Command herbicide had to be incorporated. The only areas that experienced problems with Command movement this last year were areas where the herbicide was not incorporated. FMC has expanded Command tank mix options this year to include Lasso, Sonalan, Dual, Prowl, Treflan, and Sencor/Lexone.

There is no new chemistry for 1988 in the corn herbicide market. However, there are several new package mixtures and one major label expansion. For 1988, DuPont will introduce Extrazine, a mixture of Bladex and Atrazine. Extrazine is very similar to Conquest, the only difference being that Extrazine contains more Atrazine and less Bladex than the Conquest package mixture. **Both Extrazine and Conquest are restricted use herbicides.**

Prozine, a package mixture from American Cyanamid, contains Prowl and Atrazine. Prozine can be applied preemergence or postemergence to corn but it should not be incorporated. Lariat, a package mixure from Monsanto, is a new formulation of Lasso plus Atrazine that should be more compatible with liquid nitrogen solutions. Last year tridiphane (Tandem) was introduced by Dow into some corn growers postemergence weed control programs. Tandem may enhance the activity of Atrazine and Bladex and must be tank mixed with either of these products in order to be effective. This year the Tandem label has been expanded to include the use of Tandem plus Atrazine and/or Bladex on wild oats, woolly cupgrass, and wild proso millet, as well as 4 to 6 leaf foxtails in a salvage (rescue) treatment. Please see the label for the details pertaining to each specific weed problem.

SMALL GRAIN WEED
CONTROL UPDATE - 1988

Beverly R. Durgan
Extension Agronomist - Weed Control
University of Minnesota

There have not been a lot of changes in the small grain area since I gave this presentation here last year. As of this date, only one new herbicide has received EPA clearance for use in small grains. However, I do anticipate the clearance of at least two more herbicides before the 1987 growing season.

Curtail received EPA clearance in April 1987. Curtail (clopyralid + 2,4-D amine) is a new package mixture that is being marketed by Dow for broadleaf weed control in spring wheat and barley. Curtail is a mixture of clopyralid and 2,4-D amine. Curtail was marketed in North and South Dakota last year, but was not sold in Minnesota. Curtail will give good control of most annual broadleaf weeds. In addition, research has shown that Curtail will provide excellent shoot suppression of Canada thistle. However, repeated applications over several years will be needed for complete Canada thistle control. I feel that Curtail will be a useful product in fields that have a Canada thistle problem. The use rate for Curtail is 2 pts/A (0.09 lb/A cloryralid + 0.50 lb/A 2,4-D amine). Curtail should be applied from tillering until prior to the boot stage of spring wheat and barley. Curtail can be tank mixed with Avenge for wild oats control. Curtail does have some soil residual, therefore, only wheat, barley, oats or grass can be planted the year following a Curtail application.

The two products that I anticipate to receive clearance before the 1988 growing season are Assert and Harmony.

Assert is a wild oats herbicide being developed by Cyanamid. Research at the University of Minnesota and at North Dakota State University has shown that Assert gives excellent control of wild oats and wild mustard. Assert will also give suppression of wild buckwheat, field pennycress and kochia. The use rate will probably range from 0.38 to 0.50 lbs active ingredient per acre (1.2 to 1.6 pts./A). Table 1 summarizes University of Minnesota data on wild oats control with Assert over the last five years.

Table 1. Wild oats control with Assert averaged from 1982 to 1986.

Herbicide	Rate	Wild Oats Control	
		2 to 3 leaf	4 to 5 leaf
	(pts./A)	(%)	(%)
Assert	0.75	85 (5)[a]	--
Assert	1.2	92 (7)	71 (5)
Assert	1.4	95 (7)	77 (4)
Assert	2.4	--	87 (4)

[a]Number of trials included in the mean.

From this data, you can see that Assert will give better control of 2 to 3 leaf wild oats than 4 to 5 leaf. Check the label for tank mixes; however, research has shown that Assert can be tank mixed with 2,4-D ester and MCPA ester without reduced wild oats control. Assert has soil activity and carryover potential; therefore sugarbeets, lentils, rape or mustard cannot be planted for 15 months following an Assert application.

Harmony (DPX-M6316) is a broadleaf weed control herbicide being developed by DuPont. Research at the University of Minnesota has shown that Harmony will control many annual broadleaf weeds, including wild buckwheat, and smartweeds, in spring wheat, barley and oats. Harmony will be formulated as a 75% active ingredient dry flowable, and the use rate in small grains will probably range from 4 to 10 grams active ingredient per acre (0.008 to 0.023 lbs active ingredient/A). Harmony must always be applied with a nonionic surfactant. Harmony can be applied from the 2-leaf to boot stage of wheat, barley and oats. However, Harmony needs to be applied to weeds 4 inches tall or less for best control. There will probably be no recropping restriction with Harmony.

Package mixtures are starting to play a larger role in the small grain herbicide market. As you are probably aware, package mixtures are combinations of two or more herbicides in one container. Table 2 summarizes the package mixtures available for use in small grains.

Table 2. Package mixtures available for weed control in small grains.

Trade Name	Common Name	Act. Ingred. (lb/gal)	Clearance (crop)[a]
3 + 3 Brominal	(bromoxynil + MCPA ester)	3 + 3	all
Bronate	(bromoxynil + MCPA ester)	2 + 2	all
Buckle	(triallate + trifluralin)	10% + 3%	durum, barley
Curtail	(cloryralid + 2,4-D amine)	.38 + 2	spring wheat, barley
One Shot	(diclofop + bromoxynil + MCPA ester)	3 + 2.5 + .45	spring wheat, barley
Stampede CM	(propanil + MCPA ester)	3 + .85	spring wheat, barley

[a]Not all package mixture can be used on all small grains; check the label.

Package mixtures can be convenient to use because they decrease the amount of mixing needed, however it is sometimes difficult to determine what herbicides are in a package mixture, and at what rate. Read the label carefully and determine if the herbicides in the package mixture are in the right combination and ratio for your soil type and weed problem.

PROTECTING STORED GRAIN WITH RESIDUAL INSECTICIDES

Phillip K. Harein
Department of Entomology
University of Minnesota
St. Paul, MN 55108

INTRODUCTION

To help protect people, pets, livestock, wildlife, and the environment from harm, the use of pesticides is regulated under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) [as amended by the Federal Environmental Pest Control Act (FEPCA) of 1972] and the Federal Food, Drug, and Cosmetic Act (FD&C Act) of 1983, as amended. The rate and method of application and any resulting residues must comply with the requirements of these Acts. The following instructions given here, for the chemical control of stored-grain insects, are intended to assist the user in complying with these regulations.

TREATMENT BEFORE STORAGE

Any grain that is to be stored for more than six months can become seriously infested. The key to good storage is anticipating and preventing problems through good bin management.

New grain should never be placed on old grain unless the old grain is largely free from insect infestation. Market grain should be stored away from the farmstead if at all possible. If stored on the farm, it should be stored as far away as possible from feed rooms and feed bins because they are likely sources of new infestations.

Before treating with protectants, make sure that the storage structure itself is virtually free of insect-infested grain. Leftover grain should be removed from the bins. The floor and walls should be swept and vacuumed. This cleanup is most effective if done in early spring or immediately after the bin has been emptied.

All grain-handling equipment, including augers, combines, trucks, and wagons, should also be cleaned and grain residues removed before harvest. Places where seeds, livestock feed, and pet foods are stored can be serious sources of infestations. Grain and feed accumulations that are frequently overlooked include empty feed sacks, dusts created by the feed grinders, seed litter from the haymowers, feed left in animal self-feeders, and grain-based rodenticides.

Bin wall, ceiling, and floor treatments. As soon as the bin is cleaned, it can be treated with protective insecticides. However, it is better to treat during the warmer months when insects are active. If treatments were applied more than three months earlier, an additional treatment should be applied two to three weeks before new grain is placed in the bin. The treatment will kill insects emerging from their hiding places (cracks, crevices, under floors, and in aeration systems). Also, insects crawling or flying in from the outside will be killed.

Malathion (premium grade) used for this purpose in metal bins will remain effective for four to eight weeks when the grain is 80°F. In wooden bins, malathion may remain effective for up to six months. Chlorpyrifos-methyl (Reldan®) is registered for bin treatments in those situations where the bins will be used to store barley, oats, rice, sorghum, wheat, and any other grains on which chlorpyrifos-methyl has been approved for use. To date, pirimiphos-methyl (Actellic®) is not registered for use as a prestorage bin treatment.

Apply the spray to as many surfaces as possible, especially joints, seams, cracks, ledges, and corners. Spray the ceilings, walls and floors to the point of runoff. Use a coarse spray at a pressure of over 30 pounds per square inch (psi) and aim for the cracks and crevices.

Spray the area beneath the bin and spray the bin supports; apply spray to a six-foot border around the outside foundation. Treat the outside surface, especially cracks and ledges near the door and fans. In addition, treat pertinent areas in your cleaned harvesting equipment, elevators, augers, trucks, or wagons.

Insecticides, formulations, concentrations, and rates of application approved for this and other uses are subject to change. You should always follow the label directions for current recommendations.

Empty metal grain bins. The increased use of metal bins with perforated floors for grain drying and aeration has helped produce a serious insect problem in farm-stored grain. Grain dockage (broken kernels, grain dust, and chaff) sifts through the floor perforations and collects in the subfloor plenum creating a favorable environment for insect development. If possible, remove the perforated floors to clean the plenum area and spray it with an insecticide. When the floor or the screen over aeration ducts cannot be removed, the area may be treated with a fumigant (Harein, 1982).

TREATMENT DURING STORAGE

Insect infestation is prevented or reduced by treating the product as it is moved into storage with one of three approved insecticides (see labels for application rates, permitted target commodities, and other essential information):

1) Chlorpyrifos-methyl (EC or dust) wheat, oats, and barley (not registered for application to corn). Reldan works relatively well even on high-moisture grains and is effective against insects resistant to malathion.

2) Malathion (EC or dust) is labelled for use on corn and other small grains. Water is required as a diluent for malathion EC. Water added to the grain at the maximum recommended rate of 5 gallons per 1000 bushels will increase the moisture content of the grain by less than 0.1%.

3) Pirimiphos-methyl (EC) is registered for application to corn and sorghum.

Effectiveness.

The effectiveness of treating bulk grain depends on at least five factors.

1) Proper mixing. Application so thorough and complete that the protectant reaches nearly every kernel is not necessary. This became apparent when the "drip-on" application procedure for liquid protectants was found to be adequate on the basis of both insect kill and residue analysis. One disadvantage of emulsifiable formulations is that most of them must be agitated to avoid settling. Consequently, gravity-flow or "drip-on" applicators and pressure-type sprayers must be shaken periodically to ensure that the formulation is mixed evenly. Power sprayers do not have this problem because the formulation is agitated continuously.

2) A fresh spray mixture. Mix only enough insecticide for one day's

use. Do not use excess insecticide mixture for the next day's treatment. The concentrated insecticide, mixed spray, or insecticide dust should be kept cool and not stored in direct sunlight. Use fresh dust formulations and avoid carry-over from one year to the next.

3) Point of application. Protectants should be applied to the grain just before it reaches final storage. Protectants can be applied into the hopper of the elevating equipment. However, grain which is treated and then transferred long distances through numerous grain handling systems (such as pneumatic systems, belt augers, conveyors, spouts, legs, etc.) before storage will have less insecticide residue when the grain is finally dropped into the bin. Any insecticide left in the handling systems will help reduce insects in these areas.

4) Application pressure. If you use other than a gravity-flow system, the spray pressure should be as low as possible, preferably 10 to 20 psi. With low spray pressures, larger spray droplets are produced. The larger droplets fall on the grain and are less likely to drift off into the air.

5) Moisture and temperature of the grain. Most failures with protectants occur because of excessive grain moisture content (mc) and/or temperatures. Grain should not be treated if it is above 13% (16% for corn) and its temperature is above 90^{o}F. If warm grain is treated, it should be cooled by aeration as soon as possible after treatment. The operation of an aeration system will not remove the protectant from the grain. A 10 ppm treatment with malathion on grain at 10% mc and 60^{o}F degrades to 6.3 ppm in one year. The same treatment on 14% mc grain at 80^{o}F degrades to 0.2 ppm in one year. As a general rule, the higher the

moisture content and the higher the temperature, the faster the rate of malathion degradation. A 3 ppm residue will prevent the development of most stored-grain insects (except the Indianmeal moth, Plodia interpunctella), but grain treated at 14 and 16% mc will be protected for only short periods depending on the temperature.

Application.

Liquid formulations. Any low-pressure sprayer that can be calibrated to deliver a known volume of liquid is suitable for application of protectants. This includes compression-type sprayers and gasoline-engine-driven power sprayers. The garden-type compression sprayer may be used for treating small lots of grain. The power sprayers and the metering-type sprayers are generally used when large lots of grain are to be treated.

It is important to have the correct orifice size in the sprayer nozzle because orifice size and pressure are used to regulate the rate of insecticide flow. Every manufacturer of spray nozzles has nozzle charts giving the capacity in gallons per minute and the spray angle for each size of orifice. Nozzle selection can also determine the spray particle size.

A simple gravity or "drip on" applicator that does not use any moving parts may be purchased or constructed. An application system may be built by fitting two brass valves and polyethylene tubing in sequence to an opening in the bottom of a plastic jug. These fittings are readily obtainable at a plumbing supply store. The upper shut-off cock on the jug serves as the on-off valve while the lower needle valve regulates the amount of insecticide flowing through the plastic tubing. The needle valve is first calibrated to the desired flow for the rate of grain delivery into storage. It then can be kept at the same setting, without the need for fine adjustment each time flow is turned on.

The gravity-feed applicator is used to treat grain as it is unloaded from a truck by means of an auger. The tubing is taped horizontally along the auger tube at the pick-up end, with the end of tubing extending 1/4" beyond the end of the auger tube so that insecticide flows directly into the grain. The plastic container can be suspended from the top of the grain bin or auger and must be agitated periodically to keep the formulation mixed (Raney, 1987).

Installation. Sometimes it is necessary to use two or more nozzles to obtain the proper application rate or to get adequate coverage on a wide belt. When spraying grain on a moving belt, the nozzle should be 6 to 8" above the belt, and the spray should be angled against the flow of grain. The nozzle should be set in such a manner that the spray pattern covers the entire width of the stream of grain but does not touch the belt. It is extremely important to reduce and direct air movement above the belt around the spray nozzle to keep the spray from drifting off into the air. This can be done by placing a baffle across the belt several inches above the grain to deflect the air allowing the spray to fall directly on the grain.

Calibration. After the turning rate of the grain passing on the belt, auger, or conveyor is known (i.e., the amount of grain passing a point in a given time), choose from the manufacturer's chart a nozzle that will deliver the gallons per hour needed in the range of 10 to 20 psi. For example, if the turning rate of the grain is 5,000 bushels per hour, and the amount of insecticide to be applied is 2 gallons per 1,000 bushels, then a nozzle with a capacity of 10 gallons per hour at 15 psi is required.

From the manufacturer's chart, choose a nozzle that will deliver 10 gallons per hour at a pressure of about 15 psi. Install this nozzle on the sprayer and, using plain water, operate the sprayer at the pressure required. Catch all the water delivered in 10 minutes. Weigh or measure the amount collected, and multiply this by six to determine the amount delivered per hour. The output of the nozzle will vary slightly from the rated output. If the amount collected was more than a gallon, decrease the pressure slightly and rerun the test. If the amount collected was less than a gallon, increase the pressure slightly and rerun the test. Do this until the sprayer is delivering the correct amount. Calibration of the pressurized garden-type sprayer may be done as above, or calibration can be done by weighing the entire unit on a platform or hanging scale to determine the amount delivered. One gallon of water weighs about 8.3 pounds.

Dust formulations. For small lots of grains, a special dust applicator may be used. Several different models, available from various manufacturing companies, utilize the 1 or 2% formulations of malathion (consult the label for specific application rates). These dust formulations are sometimes applied by spreading them evenly over the grain surface while the grain is in a truck prior to binning. It is then mixed in with a shovel and is mixed further as it falls into the auger hopper. A large dust applicator using the 6% formulation is more suitable for treating large quantities of grain as in a grain elevator.

Safety. Insecticides are poisonous. They should be used only when needed, and should be handled with extreme care. Always refer to current pesticide labels before selecting or using pesticides. Follow the directions and precautions carefully.

When handling or mixing any insecticide concentrate, avoid spilling it on the skin and keep it out of the eyes, nose, and mouth. If any is spilled, wash it off the skin and change clothing immediately. If it goes in the eyes, flush them with plenty of water for 15 minutes and get medical attention.

The insecticides mentioned have not been designated as "restricted" to date under FIFRA. Malathion, chlorpyrifos-methyl, pirimiphos-methyl can be applied safely without special protective clothing or devices when they are diluted and used as directed on their respective labels. However, appropriate breathing protection is recommended when these insecticides are applied in the enclosed head spaces of grain storage bins. Grain bins are dangerous places in which to work (Raney, 1987).

SURFACE TREATMENT

Immediately after the bin is filled and the grain leveled, apply a surface treatment ("top dressing") of malathion as a grain protectant. A surface treatment may also be applied when the grain is going to be stored through a warm season or after a general fumigation to help prevent insect reinfestation. The surface treatment will help control insects that enter the grain through roof openings.

Surface treatments alone generally will not keep the grain insect-free but they can reduce insect populations during the storage period. Surface treatments are effective if the following limitations are understood.

1) Surface treatment will not control insects already in the storage bin; thus the grain must not be infested prior to surface treatment.

2) The surface treatment should not be disturbed since it provides

the protective barrier against insect infestations.

Keep in mind that the malathion surface treatment will probably not control or prevent an infestation of the Indianmeal moth because these insects are resistant to malathion. Chlorpyrifos-methyl and pirimiphos-methyl are effective against insects resistant to malathion but neither have label approval at this writing by EPA for surface treatments. To get the best results from a top dressing of malathion, fumigate the stored grain first. Then mix up the required amount of diluted insecticide (based on the surface area to be protected and the application rates given on the label) and divide this quantity into two equal portions. Apply one portion to the grain surface and rake it in to a depth of 4". Now apply the second portion to the grain surface and take special care thereafter to make sure that the surface remains undisturbed.

The same equipment used to spray the bin wall can be used to apply the surface spray. Surface treatments should be applied no more than one time during a storage year.

INDIANMEAL MOTH CONTROL

Indianmeal moths infest areas of grain and grain residues that are exposed to exterior areas of the grain mass such as the grain surface, aeration ducts, and materials beneath false floors. The worst infestations are found on the grain surface, but anywhere the moth larvae are found, they will leave a mass of webbing which constricts air flow and makes fumigation or surface treatments less effective. Damage by these insects to farm-stored grain is relatively low compared to that caused by beetles or weevils. Compared to other grain pests, Indianmeal moths usually cause serious economic damage only when they infest seed grains.

Suspend a dichlorvos (DDVP) resin strip above the grain surface to aid in control of the adult moths that emerge or invade the overspace. These strips slowly release vapor that kills the adult moths. They are most effective when used at the rate of one strip for every 1,000 ft^3 of air space in those situations where the space in which the strips are hung has minimal or no air exchange or movement.

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CORN ROOTWORMS, INSECTICIDES, AND CROP ROTATION

Kenneth R. Ostlie
Extension Entomologist
Department of Entomology
University of Minnesota

INTRODUCTION

How should I manage corn rootworms (CRW)? This simple question is frequently asked by farmers and agricultural professionals concerned about extended diapause, enhanced biodegradation, contamination of ground and surface water by pesticides, and profitability. My current answer is limited to only two viable, economic options; crop rotation and insecticides. We are standing, however, on the brink of tremendous changes in how we manage corn rootworms. A flush of new insecticides promises to reshape the soil insecticide marketplace and our range of insecticide options. The potential for adult control programs, based on attractant/insecticide baits or on biological insecticides derived by biotechnology, and the potential for biological control of larvae promises to reduce our dependence on soil insecticides. Increasing public concern about pesticides in the environment promises to foster legislative and regulatory limitations on insecticide use, especially soil applied insecticides. The farm program with its unpredictable shifts in crop acreages creates new uncertainty by disrupting normal crop rotation strategies. Finally, the appearance of corn rootworm problems in corn/soybean and corn/small grains rotations raises questions about our major control strategy, crop rotation.

Regardless of future alternatives, today's question remains how to effectively manage CRW populations using our two current options: soil insecticides and crop rotation. Concern about personal safety, environmental contamination, and farm profitability are causing farmers to question the routine use of soil insecticides in CRW management. At the same time, the extended diapause problem with northern corn rootworms threatens to increase the use of soil insecticides. How can a farmer decide if a soil insecticide is really needed? In the next few pages I'll summarize the University of Minnesota's research on CRW management that will help determine if a soil insecticide is really needed.

CORN ROOTWORM STATUS IN 1987

A warm, early spring on the heels of a mild winter signaled the potential for early and severe CRW damage. Throughout the late spring and early summer I received reports of unexpectedly severe CRW damage from SE Minnesota. This marks the third straight year of mild winters and excellent CRW survival. Benefiting from these mild winters, adult populations have increased from statewide averages of 1.92/plant in 1984 to 2.85/plant in 1986. A survey of adult CRW populations by the Minnesota Department of Agriculture - Plant Industry Division (Table 1) confirms that survival must have been excellent during 1986-1987 in eastern (EC,SE) and central (C,SC) Minnesota. The percentage change in adult levels from 1986 averaged 35%. In contrast, populations declined an average of 36% from 1986 levels in western (WC,SW)

Minnesota, indicating either winter egg mortality or reduced larval survival. Adult CRW populations statewide were approximately the same this year as compared to last year, 2.83/plant vs 2.85/plant, respectively. Despite the heavy pressure in central and esatern Minnesota, early damage, excellent brace root formation and a lack of heavy thunderstorms tended to minimize the lodging and yield responses to CRW injury.

Table 1. Survey of corn rootworm adult populations in continuous corn in Minnesota (July 20-31). Data supplied by Dharma Sreenivasam, Minnesota Department of Agriculture - Plant Industry Division.

District	No. Fields	CRW adults/plant 1986	1987	% Change	Ratio NCR:WCR	% Lodging
WC	38	4.57	2.15	-53	94: 6	1.8
C	40	1.43	1.70	+19	94: 6	0.1
EC	9	0.85	1.18	+39	77:23	0.1
SW	27	4.17	3.36	-19	93: 7	1.5
SC	33	2.86	3.97	+39	94: 6	0.3
SE	27	3.22	4.63	+44	68:32	0.2
State Average		2.85	2.83	- 1	87:13	0.7

CORN ROOTWORM MANAGEMENT IN CONTINUOUS CORN

Early entomologists recognized the value of cropping history in predicting CRW damage. Damage often occurred when corn followed corn. Our current management practices revolve around this correlation. Entomoligsts urge crop rotation to avoid damage or the use of a soil insecticide when corn follows corn. However, this relationship is not perfect and many continuous corn fields escape economic damage. How can we predict the potential for economic damage and the need for CRW management?

Economic Threshold Study - 1987

The potential for economic damage by a corn rootworm population can be estimated using existing sampling techniques for larval, egg, and adult stages. As you might expect, sampling the soil-dwelling larval and egg stages is much more difficult but provides more reliable damage predictions. Considering the sampling effort and cost required for larval and egg samples, adult sampling offers the only economically feasible means of estimating damage potential for the coming season. Adult counts are not without their problems since they provide only an index of the eggs laid in a field and do not account for variable egg or larval mortality.

A recent study by Foster et al. (1986) explored the "value" of adult population estimates in predicting the need for soil insecticides. They concluded that given current thresholds, adult counts accurately classified root damage in 83% of the fields but accurately classified yield loss in only 49% of the fields. The most common error, when using a threshold of 1 beetle per plant, occurred when a soil insecticide was recommended but untreated yield loss did not justify the insecticide expenditure. Based on their results, they conclude that adult counts do not justify the sampling effort.

In 1986 with the help of Minnesota crop consultants, I initiated a parallel study in Minnesota. The purposes of this study were (1) to assess the value of adult counts in predicting root damage, lodging, and yield loss and (2) to determine what threshold should be used for northern and western corn rootworms under Minnesota conditions. Preliminary results based on the study of 27 fields from 1986-1987 indicate that adult counts do provide an adequate estimate of CRW damage. Damage in 1987 was significantly correlated ($r=0.699$) to peak adult counts taken in 1986. CRW damage and peak adult counts were linearly related by the equation: root damage (1-6 scale) = 2.25 + 0.54*(peak adult count), $p<0.0001$, $R^2=0.489$. Based on this linear model, ca. 1.39 beetles per plant in 1986 were required to produce root damage equivalent to a 3.0 on the Iowa 1-6 rating scale. Recall that lodging and yield losses begin to occur at damage levels of 3.0. If this threshold were used in 1986, the following results would have occurred:

		Insecticide Used	
		Yes	No
Damage rating > 3.0	Yes	11	3
	No	4	9

An incorrect decision would have been made on 7 (26%) of the 27 fields. Of these errors, four involved using an insecticide when it wasn't required while three involved the potentially more costly error of not using an insecticide when one was required. A correct decision was reached on 75% of the fields in this study. Considering that 13 (48%) of the 27 fields would have received an unnecessary insecticide treatment based on crop history, using adult counts would have prevented unnecessary insecticide expenditures on 6 (22%) of the fields. Thus, preliminary data indicate that adult counts have value in predicting CRW damage. The threshold of 1.4 beetles per plant is not considered reliable at this time since it was derived from a small sample set that reflects only 1 year of environmental conditions. Further analysis of the 1987 data will focus on yield loss predictions. The study will be continuing in 1988.

Soil Insecticide Performance

The performance of soil insecticides was evaluated at 4 locations in Minnesota: Rosemount, Waseca, Lamberton, and Morris. Corn rootworm pressure was generally less severe than in previous years with damage exceeding a 3.0 (Iowa 1-6 scale) only at Rosemount. Mean root ratings for each inscticide treatment are presented in Table 2. At Rosemount, all insecticides reduced root damage ratings below a 3.0 with the exception of Furadan 15G. The poor performance of Furadan 15G suggests that this site has a soil aggressive towards Furadan. Soil samples have been taken to confirm this hypothesis.

Promising unlabelled insecticides include the following:

Insecticide	Class	Company
Brace 10G	organophosphate	Ciba-Geigy
Force 1.5G	pyrethroid	ICI Americas
Fortress 10G	organophosphate	Dupont

Further development of Lance 15G by BASF has ceased at this time. The potential increase in product selection and diversity is encouraging but the market is highly competitive. Whether or not these insecticides will be labelled for corn and their relative role in the soil insecticide market remains to be seen.

Table 2. Effectiveness of soil applied insecticides against northern and western corn rootworms at Rosemount, Minnesota - 1987.

Insecticide[a]	Rate (lb ai/A)	Placement[b]	Root Rating[c] (1-6 scale)
?Lance 15G	1.00	A	2.38 f
?Fortress 10G	0.50	IF	2.40 f
?Fortress 10G	0.65	A	2.45 ef
*Counter 15G	1.00	IF	2.48 def
*Counter 15G	1.00	A	2.53 def
*Thimet 20G	1.00	A	2.55 cdef
?Fortress 10G	0.35	A	2.58 cdef
?Fortress 15G	0.50	A	2.60 cdef
?Brace 10G	0.50	A	2.68 cdef
Broot 15GX	1.00	A	2.68 cdef
?Force 1.5G	0.10	A	2.73 bcdef
*Mocap 15G	1.00	B	2.80 bcdef
Lorsban 15G	1.00	A	2.85 bcde
?Fortress 10G	0.50	A	2.88 bcde
?Force 1.5G	0.125	A	2.90 bcd
*Dyfonate 20GM	1.00	A	2.98 bc
*Furadan 15G	1.00	A	3.10ab
Untreated check	----	-	3.55a

[a]Insecticides coded as follows: * denotes a restricted use insecticide, ? denotes an insecticide not currently labelled on corn in Minnesota.
[b]Placement is coded as follows: A = ahead of presswheel, B = behind presswheel, and IF = infurrow.
[c]Means followed by the same letter do not differ significantly ($p < 0.05$, DMRT).

Consistency of Corn Rootworm Insecticide Performance

Corn rootworm insecticides vary in their performance from year to year and location to location depending on CRW population pressure, weather, crop development, soil characteristics, tillage and weed populations. The ability of a soil insecticide to consistently maintain root damage below the economic threshold (3.0) is an extremely important attribute. Consistency should be considered along with price and pest spectrum when selecting a soil insecticide. Consistency of soil insecticide performance during recent years is presented in Table 3.

Table 3. Consistency of corn rootworm insecticide performance in Minnesota, 1977-1987, as measured by the proportion of trials where the insecticide maintained root ratings below a 3.0 (Iowa 1-6 rating scale).

	Consistency (%)	
Insecticide	All Trials	Trials with Check > 3.0
Counter 15G	97	94
Thimet 20G	97	94
Broot 15GX	96	93
Dyfonate 20G	82	69
Furadan 15G	79[a]	69[a]
Mocap 15G	75	56
Lorsban 15G	72	53
Untreated Check	38	--

[a]Consistency values for Furadan 15G include results from sites which were confirmed to aggressively degrade Furadan.

Damage Potential for 1988

Surveys of adult CRW populations levels (Table 1) indicate extremely high population levels in SE, SC, SW, and WC Minnesota. Farmers who have not scouted their fields and who will be planting corn following corn should use a soil insecticide. Populations levels in the SE are sufficiently high that insecticides will face severe pressure in 1988 unless overwintering mortality is high. Hope for a cold, open winter!

EXTENDED DIAPAUSE AND CORN ROOTWORM MANAGEMENT IN FIRST-YEAR CORN

Since 1985, northern corn rootworm (NCR) damage in corn following soybean and corn following small grains has now been documented in Minnesota, Iowa, South Dakota, Nebraska, and possibly, in Illinois (Fig. 1). Originally attributed to northern corn rootworm egg laying in weedy soybean fields or harvested small grain fields, the damage now appears to result from "extended diapause". Extended diapause is the ability of northern corn rootworm eggs to successfully overwinter more than a single winter. This trait has no benefit in continuous corn but is especially suited to crop rotation. In a corn/non-corn rotation, all larvae that hatch after the first winter face starvation in the non-corn crop because they only can survive on the roots of corn and a few grasses.

Larvae that hatch after the second winter when corn is again planted survive. Because extended diapause larvae survive in a crop rotation while their regular diapausing counterparts suffer extreme mortality from starvation, the proportion of the NCR population with the extended diapause trait would be expected to increase over time.

Preliminary evidence indicates a shift has taken place in NCR populations in Minnesota. Chiang (1965) originally reported less than 0.3% of the eggs possessed the extended diapause trait. A more recent study by Krysan et al. (1985) reported 40-50% of the eggs from adults collected in corn/soybean rotations possessed this trait compared to only 9% from a continuous corn area. Clearly, these data suggest NCR populations are adapting to a corn/soybean rotation.

Confirmation that damage results from extended diapause comes from examinations of field histories. The USDA diversion/PIK program of 1983 disrupted normal crop rotations for many farmers. Unwittingly, these altered rotations provided the ideal situation to evaluate alternative hypotheses about NCR damage in first-year corn. Twenty corn fields in Minnesota and Iowa that were damaged by northern corn rootworms in 1985 had split crop histories in 1983, corn and set aside. Without exception, damage and lodging were only observed where corn was grown in 1983, regardless of the intervening crop in 1984. Fig. 2 summarizes the pattern for one of these fields.

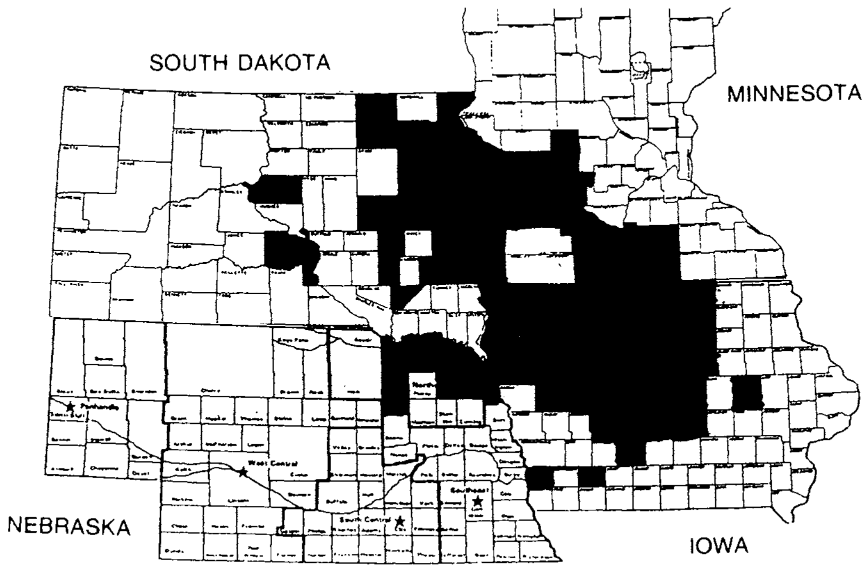

Fig. 1. Distribution of counties with confirmed northern corn rootworm damage in first-year corn, 1985-1987.

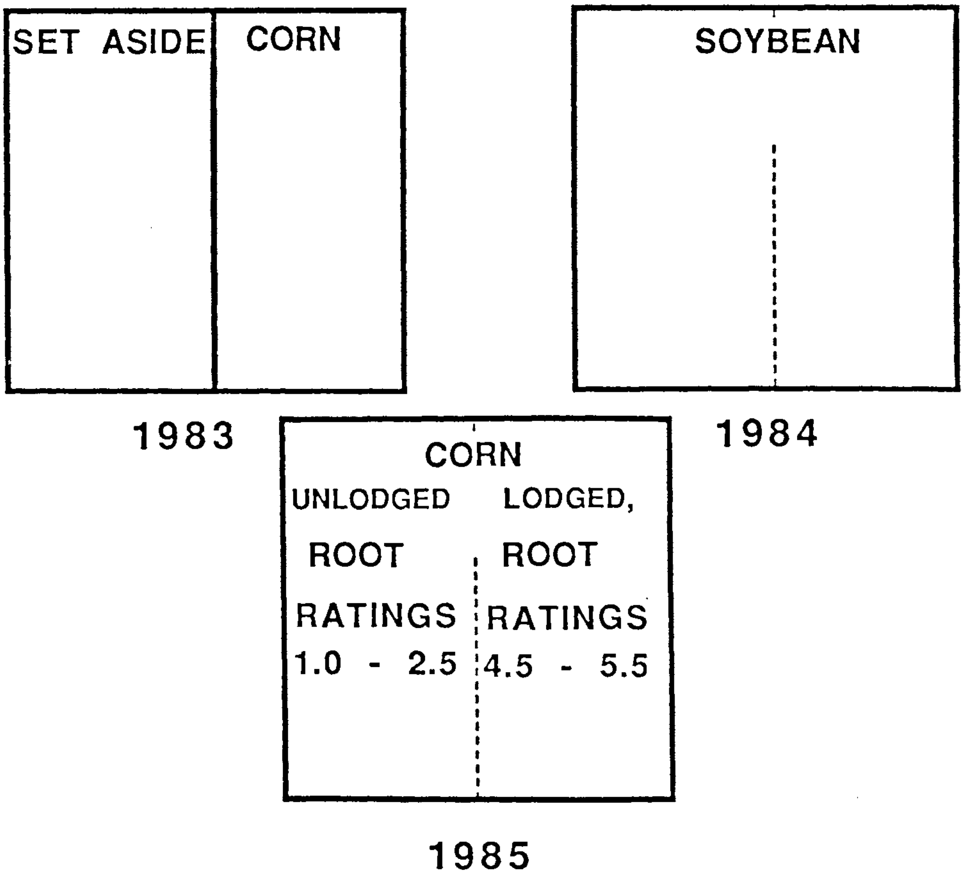

Fig. 2. Typical evidence from cropping history that supports the extended diapause hypothesis of northern corn rootworm damage in corn/soybean rotations.

The extent of this adaptation and its resulting damage in a corn/soybean rotation were intensively studied from 1985 to 1987 at several locations in SC Minnesota. On one site with a history of the problem, crop rotations were manipulated to provide corn following corn, corn following soybean, and corn following 2 years of soybean. Adult emergence and root injury in 1987 were greatest in the normal rotation for the field, corn/soybean (Table 3). This finding illustrates the extent of this adaptation and may explain why damage tends to recur in fields with a previous history of the problem.

Table 3. Adult emergence and root injury (Iowa 1-6 scale) from various crop rotations in a field with a history of corn/soybean rotation and extended diapause of northern corn rootworms. Faribault Co., MN.

Crop History			Adult Emergence	Root Injury
1985	1986	1987	(no./3 row ft)	(1-6 scale)
S	C	C	10.0	2.35
C	S	C	37.1	3.78
S	S	C	14.4	2.78

Status of First-Year Corn Problems in 1987 and the Potential for 1988

Although isolated occurrences of the extended diapause problem have been observed for the last 15-20 years, the problem became widespread in 1985. Since then, the problem has generally diminished in Minnesota. The areas of worst damage have tended to shift through the years from Blue Earth Co. in the early 1980s to Waseca and Yellow Medicine Co. in 1985 to Freeborn and Faribault Co. in 1987. In contrast, Iowa reports continuing and severe problems over the last 3 years with damage repeating in many areas.

Surveys of adult CRW populations in first-year corn fields in indicate a marked decline in population levels in WC, SW, and SC Minnesota (Table 4). These areas, especially SC Minnesota, had the most first-year CRW problems in previous years. The decline indicated in this survey parallels the general decline in reported incidence of this problem in 1987. At this time not enough is known about the problem and the variables influencing its occurrence to predict its status in 1988. The geographical variation of the problem in Minnesota and its persistence in Iowa suggest an environmental influence either on survival of the diapausing eggs or on the length of diapause.

Soil Insecticides on First-Year Problem Fields

Research was initiated in 1985 to determine if the extended diapause problem recurred in the same fields and if soil insecticide use provided an economical solution to the problem. A total of 12 fields, 3 in 1985, 5 in 1986, and 4 in 1987, with a previous history of the problem were selected. In each field untreated and insecticide-treated strips were alternated across the field by filling half of each planter's insecticide boxes with Counter 15G. Root ratings, lodging, and yield were measured on selected strips. A summary of mean values for each treatment is presented by site in Table 5.

Table 4. Survey of 1987 CRW adult populations in first-year corn fields in Minnesota, July 20-31. Data supplied by Dharma Sreenivasam, Plant Industry Division - Minnesota Department of Agriculture.

District	No. Fields	CRW beetles/plant 1986	CRW beetles/plant 1987	CRW beetles/plant % Change	Ratio NCR:WCR
WC	24	1.44	0.48	-67	98: 2
C	25	0.38	0.80	+111	95: 5
EC	6	0.63	1.15	+83	76:24
SW	18	1.87	1.13	-40	100: 0
SC	22	2.49	1.48	-41	95: 5
SE	18	1.09	1.15	+6	61:39
State Average		1.32	1.03	-22	88:12

Table 5. Root damage (Iowa 1-6 scale), yield and lodging in first-year corn fields with strips treated using Counter 15G.

Year	Site	Root Rating		Yield		% Lodging	
		Counter	Check	Counter	Check	Counter	Check
1985	Mn. Lk. 1	2.45	3.13	151.3	153.4	48.2	62.5
	Mapleton	2.16	2.42	170.8	167.4	0.0	0.0
	Janesville1	2.56	2.86	180.6	175.3	27.6	48.7
	Average	2.39a	2.80b	167.6a	165.4a	25.3a	37.0a
1986	Mn. Lk. 1	2.15	2.86	159.2	155.0	1.3	29.3
	St. Clair	2.17	3.19	144.2	143.0	0.6	2.7
	Waldorf	2.33	2.96	164.6	162.8	1.5	22.5
	Mn. Lk. 2	2.94	3.51	148.0	145.7	1.5	14.5
	Janesville2	2.58	3.00	174.0	156.5	---	----
	Average	2.43a	3.15b	158.0a	152.6a	1.2a	17.3a
1987	Mn. Lk. 1	2.80	3.66	153.4	154.2	26.5	70.0
	Janesville 1	2.85	2.78	146.0	131.0	5.0	55.0
	St. Clair	2.13	2.80	169.6	163.0	0.0	0.0
	Mapleton	2.25	2.90	175.0	175.0	0.0	0.0
	Average	2.51a	3.04b	161.0a	155.8a	7.9a	31.3a

NCR damage was present each year in fields with a previous history of the problem. Untreated injury levels varied considerably but averaged near 3.0 each year. At these injury levels, lodging begins to occur and yield losses begin to be detected. Despite a previous history of the problem, severe damage like that noticed in Minnesota in 1985 was not the norm among fields in this study. Counter 15G significantly reduced root injury each year but did not significantly affect yield or lodging. A trend for Counter 15G to reduce lodging and increase yields is evident but not significant with such small sample sizes within years. A quick economic analysis indicates that at least 7 bu/acre are required to breakeven at the current corn loan rate and insecticide price. During the three years of this study, only 2 of the 13 farmers would have used a soil insecticide profitably. Clearly, previous history of the problem does not quarantee a severe reoccurrence or profitable use of a soil insecticide.

Adult Scouting as a Tool for Predicting Extended Diapause Problems

Although damage tends to repeat in problem fields, it is difficult to predict the degree of damage from corn crop to corn crop and, thus, the need for a soil insecticide. My observations over the last three years indicates growers have very little initial warning before a problem occurs. The evidence just presented indicates that even after the problem first occurs its difficult to predict its subsequent severity. In this situation, how can a farmer make a sound judgement about soil insecticide use against CRW in first-year corn? One potential solution, which showed promise in 1986, would be to scout adult populations.

To determine if adult CRW counts have any predictive value, I examined root damage in 11 first-year corn fields in 1986 and 16 fields in 1987 that were in corn/soybean rotations and had been scouted 2 years previously. Field locations and adult counts were generously supplied by Paul Miller, AgroEconomics, Inc. of Waseca. Analysis of 1986 root injury ratings indicated a strong correlation between counts taken in 1984 and injury in 1986. Crw injury and adult counts were related by the following equation (Fig. 3): 1986 Root rating = 2.28 + 0.18*(1984 adult count) $p<0.008$ $R^2=0.55$. Using this relationship, I calculated that at least 4.0 NCR beetles were required before damage exceeded a root rating of 3.0 two years later. Attempts to verify this relationship with 1987 data proved fruitless. The correlation between CRW adult counts in 1985 and damage in 1986 was not significant. This suggests that another factor such as weather exerted an overriding effect.

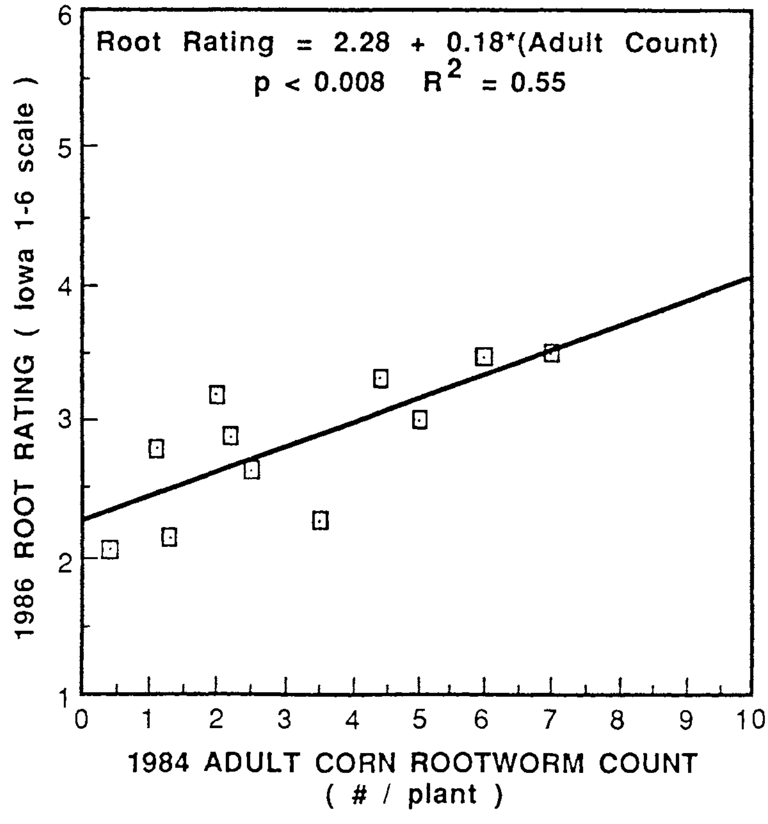

Fig. 3. 1986 root damage in first year corn fields as a function of northern corn rootworm adult populations in 1984.

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The research reported in this paper would not have been possible without the generous support of the people of Minnesota through the Minnesota Agricultural Experiment Station and the agrichemical companies whose products were evaluated in this research. In the CRW economic threshold studies, I especially appreciate the generous help of the following crop consultants and area CPM agents: Dean Herzfeld - CPM, Paul Gronenberg - Centrol, Gene & Maggie Alms - Alms & Alms Agricultural Consulting, Paul Miller - AgroEconomics, Fritz Breitenbach - CPM, Jay Zielske - Stuart & Armstrong, Bryce Nelson - Advantage Crop Consulting. In the first-year corn studies, I especially value the efforts of Paul Miller, Agroeconomics and the farmers who offered their fields for study: Bill Daly, Steve Dimmel, Rick Hoehn, Joe Kluender, Ambrose Sonnick, Dan Stevermer, The Trams, Danny Trio. Special recognition is given for the support of Dow and American Cyanamid in supporting my research on extended diapause of northern corn rootworm and its management.

THE EUROPEAN CORN BORER IN MINNESOTA: ARE WE COMING FULL CIRCLE?

Kenneth R. Ostlie
Extension Entomologist
Department of Entomology
University of Minnesota

INTRODUCTION

The European corn borer (ECB) in Minnesota is historically underrated. The destructive potential of this stalk boring insect is largely ignored and unappreciated until damage and strong winds combine to wreak local havoc in the form of dropped ears, broken stalks, and increased harvesting time. In 1983 record ECB populations produced large unexpected yield losses. Yet, two short years later in 1985, the ECB population in Minnesota reached a record low. These dramatic flucuations in abundance in the span of a few years highlight the need for the two key ingredients to successfully managing ECB populations in corn; field scouting and economic thresholds.

When will the next major ECB outbreak occur? Will we be ready to scout, make a decision, and, if necessary, select an appropriate insecticide? Understanding ECB population dynamics holds the ultimate key to predicting future outbreaks and minimizing unnecessary yield losses. Over the last 25 years, ECB populations have peaked statewide ca. every 6-7 years (1963, 1970, 1977, 1983). While it is tempting to consider the 1987-1988 overwintering population, rely on historical trends and predict an imminent outbreak., reliance in this prediction without understanding its causes would be foolhardy. Populations flucuations represent the interaction of ECB with weather, crop phenology, varietal resistance, natural enemies, and cultural practices. Right now, our knowledge of what governs these population dynamics is too limited for predictive purposes. The best safeguard we have against surprise by an ECB population hinges on scouting and decisions based on economic thresholds.

STATUS OF EUROPEAN CORN BORER IN 1987 AND POTENTIAL FOR PROBLEMS IN 1988

Populations dynamics during the last two years have been extremely similar. Warm, early springs seemed to throw off the normal synchrony between ECB and corn development. Unusually warm spring weather accelerated ECB development beyond its normal point by the time of corn planting occurred. The majority of corn, consequently, was too young to be attractive to ECB adults. Even when egg laying occurred in more advanced corn fields, survival was poor because resistance levels were extremely high. For these reasons, first generation populations were generally subeconomic throughout most of the state.

In contrast, second generation was extremely successful. The flight was very extended and because of the warm summer overlapped with a third flight throughout southern Minnesota. Extremely high ECB populations in the ear during Augustevoked concern about shank damage and potential ear loss. During 1986 this fear was never realized. In 1987 warnings of potential harvest loss combined with excellent dry down and harvesting conditions minimized field losses. In WC and SE Minnesota, however, some late harvested fields suffered field losses when strong winds hit dry brittle stalks and shanks damaged by ECB or invaded by associated stalk rots (Table 1). A strong third flight of ECB adults, nicknamed a suicide flight, effectively diminished numbers of overwintering borers. Enough borers remain (Table 1), however, to cause problems next spring. The severity of the threat they pose will be limited by overwintering mortality and spring weather that affects mating, egg laying, and larval establishment.

Table 1. Results of Minnesota's fall survey for European corn borer, Sept. 29-Oct. 16, 1987. Data supplied by the Minnesota Department of Agriculture Plant-Industry Division.

District	% Plants Infested	# ECB larvae per 100 plants	% Broken stalks	% Shanks infested	% Ears on ground
NW	42.0	59	3.0	11.3	0.1
WC	86.3	190	10.4	41.0	7.2
C	58.2	110	4.9	16.1	1.9
EC	54.4	101	5.0	9.4	0.5
SW	31.0	34	3.8	3.0	0.0
SC	60.3	82	2.8	8.3	0.9
SE	83.8	195	8.0	32.0	4.3
Average	59.4	110	5.5	17.3	2.1

THE ECONOMIC THRESHOLD CONCEPT FOR THE EUROPEAN CORN BORER

The objective of my research on the ECB is to improve management of this pest by developing the information necessary for sampling and using an economic threshold. The economic threshold for ECB represents the breakeven point for insecticide use and takes the following form:

$$\text{Economic Threshold} = \frac{\text{Control Costs (\$/acre)}}{\text{Preventable Loss (\$/acre)}}$$

where preventable loss = Yield X Price X % Loss/Borer X % Control. The economic threshold is based on two types of information that allow the farmer to tailor the decision to his fields: economic variables (control costs, expected yield and expected corn price) and biological variables (% loss per borer and % control). In contrast, the nominal threshold currently used for ECB management, e.g., 50% shotholing, cannot respond to changing economic conditions.

This summer provided the perfect situation to highlight the differences between calculated and nominal economic thresholds. As discussed earlier, survival was extremely poor and counts of larvae per shotholed plant averaged ca. 1.0 or even less. Let's assume the grower's field was expected to produce 130 bushels per acre at a price of $1.75 per bushel. A granular insecticide such as Pounce 1.5G would costs ca. $12.00 per acre and provide 90% control. The expected loss per larva is assumed to be 5%. Using these values in the economic threshold formula: ET = $12.00 / (130 X 1.75 X 0.05 X 0.90)= 1.17 borers per plant. In other words, if the field averaged 1.17 borers per plant, then we could prevent enough damage to break even with the insecticide cost. If survival in our hypothetical field was 1 larva per plant, then even at 100% infestation we would not reach the breakeven point. Under 1987 conditions survival would have to be much higher for a economic infestation to occur. Yet, the nominal threshold of 50% shotholing would encourage us to treat the field because the value does not change with economic variables or with survival. That's why estimating larvae per plant and using an economic threshold makes more sense!

INSECTICIDE PERFORMANCE AGAINST FIRST-GENERATION EUROPEAN CORN BORER

One key element in the economic threshold formula is an estimate of percent control. The purpose of this research on insecticides performance is to generate performance data with sufficient reliability under Minnesota situations. Two situations warrant our attention: first generation on whorl stage corn (typical of the southern 2/3 of Minnesota) and first generation on pretassel to tassel stage corn (typical of the northern 1/3 of Minnesota).

Whorl Stage Corn

Foster and co-workers in Iowa have conducted two excellent granular insecticide trials against ECB. The results of these trials are summarized in Table 2. Note the performance of Pounce 1.5G, a relatively new pyrethroid granule, and Dipel 10G, a biological insecticide containing the toxins of a bacteria, *Bacillus thuringiensis*, that has relatively high mammalian safety and is fairly specific to Lepidopteran (moth, butterfly) larvae.

Table 2. Performance of aerially applied insecticides against first-generation ECB larvae. D. Foster, W. Winterstein, and J. Bing. Iowa, 1986-87.

Treatment	Rate (lb ai/A)	Cavities per plant[a] 1986	1987	Percent Control 1986	1987
Furadan 15G	1.00	0.26 a	0.10 a	91.0	96.7
Diazinon 14G	1.00	0.45 a	--	84.4	--
Pounce 1.5G	0.10	0.49 a	0.10 a	83.0	96.7
Pounce 1.5G	0.15	--	0.30 a	--	90.1
Dyfonate 20G	1.00	0.57 ab	0.375 a	80.2	87.6
Dipel 10G	1.00	0.71 b	0.37 a	75.4	87.8
Lorsban 15G	1.00	0.51 ab	0.575 a	82.3	80.0
Dyfonate 20GM	1.00	--	0.625 a	--	79.4
Thimet 20G	1.00	0.70 b	1.70 b	75.7	43.9
Check	--	2.88 c	3.03 c	--	--

[a] Means based on 30 plants per plot. Means followed by the same letter do not differ significantly ($p < 0.05$, DMRT). All data transformed before statistical analysis using square root transformation.

Pretassel and Tassel Stage Corn

Insecticide performance in northern Minnesota was evaluated in two aerial trials and 2 small plot trials. The aerial trials were conducted near Callaway, Becker Co., and near Crookston, Polk Co (Table 3). The small plot trials included on focusing on granular insecticides (Table 4) and the second focusing on liquid insecticides (Table 5). The results of these trials will be combined with those of trials conducted the last 3 years to generate reliable insecticide performance estimates that can be used in economic thresholds.

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Table 3. Effectiveness of aerially applied insecticides against first-generation ECB in northern Minnesota, 1987.

Treatment	Rate (lb ai/A)	Damage sites/infested plant[a] Crookston	Callaway	Percent control Crookston	Callaway
Pounce 3.2E	0.20	0.48	0.48	66.7	80.6
Penncap-M 2FM	1.00	0.45	0.55	68.4	77.6
Pounce 3.2E	0.15	0.53	--	63.2	--
Lorsban 4E	0.75	0.53	--	63.2	--
Penncap-M 2FM	0.50	0.68	0.75	52.6	69.4
Pounce 3.2E	0.10	0.43	1.25	70.2	49.0
Asana 1.9E	0.045	--	1.10	--	55.1
Pounce 3.2E	0.05	0.65	--	54.4	--
Asana 1.9E	0.05	0.85	--	40.4	--
Penncap-M 2FM	0.25	0.85	--	40.4	--
Lorsban 4E	1.00	0.85	2.15	40.4	12.2
Check		1.43	2.45	--	--

[a] Means based on 4 replicate samples of 10 infested plants.

Table 4. Performance of granular insecticides against first-generation ECB in late-whorl corn. Crookston - 1987.

Insecticide	Rate[a] (lb ai/A)	Damage Sites[b] (#/10 infested plants)	% Control
Baythroid 0.4G	0.05	0.63 f	93.4
Force 1.5G	0.125	0.75 ef	92.1
Dipel 10G	1.00	1.00 def	89.4
Pounce 1.5G	0.15	1.25 bcdef	86.8
Dyfonate 20G	1.00	1.50 cdef	84.2
Lorsban 15G	1.00	1.50 bcdef	84.2
Baythroid 0.4G	0.0375	1.75 bcdef	81.5
Pounce 1.5G	0.10	1.75 bcdef	81.5
Furadon 15G	1.00	2.50 bcdef	73.6
Force 1.5G	0.075	2.50 bcdef	73.6
Force 1.5G	0.10	2.75 bcdef	71.0
Dyfonate 20G	1.00	3.25 bcde	65.7
Fortress 15G	0.50	3.50 bcdef	63.1
San 415I	10.00*	3.75 bcd	60.4
Thimet 20G	1.00	4.25 bc	55.1
San 415I	7.50*	4.75 b	49.9
Untreated Check	--	9.48 a	--

[a] San 415I rates are expressed as lbs formulated product per acre NOT lb ai per acre.
[b] Damage sites include tunnels in stalk, ear shank and ear. Means followed by the same letter do not differ significantly ($p < 0.05$, DMRT). All data transformed using squart root transformation before statistical analysis.

Table 5. Performance of liquid insecticides against first-generation ECB in pretassel corn, Crookston - 1987.

Insecticides	Rate (lb ai/A)	Damage Sites[a] (No./10 infested plants)	% Control
Capture 2E	0.05	1.00 e	92.0
Penncap-M 2F	0.50	2.75 de	77.9
Baythroid 2E	0.05	3.38 cde	72.9
Lorsban 4E	1.00	4.75 cd	61.9
Asana 1.9E	0.04	6.75 bcd	45.9
Asana 1.9E	0.05	6.94 bcd	44.4
Furadan 4F	1.00	7.25 abcd	41.9
Pounce 3.2E	0.15	7.25 abc	41.9
Sevin XLR	2.00	10.25 ab	17.8
Check	--	12.47 a	--

[a] Damage sites include tunnels in stalk, ear shank, and ear. Means followed by the same letter do not differ significantly ($p < 0.05$, DMRT). Data transformed with square root transformation before statistical analysis.

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