Sustainable weed control system using natural product allelochemicals to replace conventional herbicides in maize

Principal investigator
Jack Dekker
Agronomy
Iowa State University

Budget
$35,000 for year one
$35,000 for year two
$35,000 for year three

Background and goals

Weed control in crops should rely first on tillage and later on the crop as competition. But a "window of opportunity" still exists during which weeds are difficult to control without the use of herbicides. No dependable, long-term, sustainable weed control systems currently exist. The consequent widespread use of the herbicides atrazine and alachlor for corn production in Iowa poses a serious environmental concern because of their potential to pollute drinking water. Because of this possible hazard, an alternative weed control system is clearly desirable. However, any alternative practice must be developed in accordance with when yield losses due to weeds begin and when that weed interference ends.

One alternative approach that depends on such information involves exploiting naturally occurring plant inhibition in a controlled manner. Allelopathy, the production and activity of naturally occurring toxins that interfere with plant growth and development, was discovered many years ago. But only during the past ten years has the research methodology been sufficiently developed to yield information about allelopathy chemistry, occurrence, and modes of synthesis. Now, abundant information exists about this complex area of biology, and many naturally occurring allelochemicals have been discovered and characterized.

This project sought to investigate their relative efficacy. Thus, the objectives of this work were

1. to define and develop a systematic approach to identifying and evaluating potential natural product allelochemicals; and
2. to implement and refine this system through evaluation of candidate natural products by
   - identifying and obtaining candidate allelochemicals;
   - evaluating these allelochemicals in terms of (1) plant response, (2) user safety and natural product toxicology, and (3) environmental fate and impact; and
   - determining the feasibility of exploiting allelopathy for weed control in corn production.

Approach and methods

The investigators based their work on allelochemical studies conducted over the past several years. They compiled a database of 18 major families of candidate allelochemicals along with miscellaneous other toxins. This database included information on each allelochemical's toxicity level, cost, efficacy, and testing status.

To begin, investigators spent considerable time and effort identifying potential allelopathic chemicals from the literature and other sources. After compiling the database list, they screened it for three criteria, any one of which was sufficient to eliminate a chemical. The first of these was preliminary toxicological data that revealed chemicals with known problems; the second was the availability of the chemical from one of the many chemical and natural product supply companies. Lastly, the investigators eliminated chemicals that were relatively high in cost. The resulting chemicals that underwent testing included corn gluten meal as well as several chemicals from each of three different chemical families: the flavones, phenolic acids, and alkaloids. The initial discovery of corn gluten meal's chemical identity by Dr. Nick Christians of ISU's Horticulture Department laid the groundwork for evaluating corn gluten meal to assess its allelochemical and weed control properties.

On the basis of favorable greenhouse results, corn gluten meal was evaluated in the field in 1990 through 1992. Small-plot research took place at four locations on the ISU Experiment Station Agronomy and Agricultural Engineering Research Center and on several other farms throughout Iowa. Experiments to isolate the active fraction of corn gluten meal in Dr. Christians' lab had not been completed at that time, so concentrated forms of the allelochemical were not available for field work. Thus, the investigator used raw corn gluten meal in these trials. Some of the trials were conducted under conditions where crops were not truly competing with weeds on the plot. Additionally, many of these trials were conducted in research areas with unusually high weed populations—much higher, in fact, than in most Iowa production fields. The one-month evaluations resulting from this work generally presented a "worst case" scenario.

Records kept by the investigators for some 18 analyses generally include date of the experiment, its purpose, the researcher(s) in charge, the plant description, plant growth conditions, name of the chemical being tested, the experiment's environment (if different from the plant growth conditions), the data obtained, and any additional comments about the materials and methods specific to each experiment.

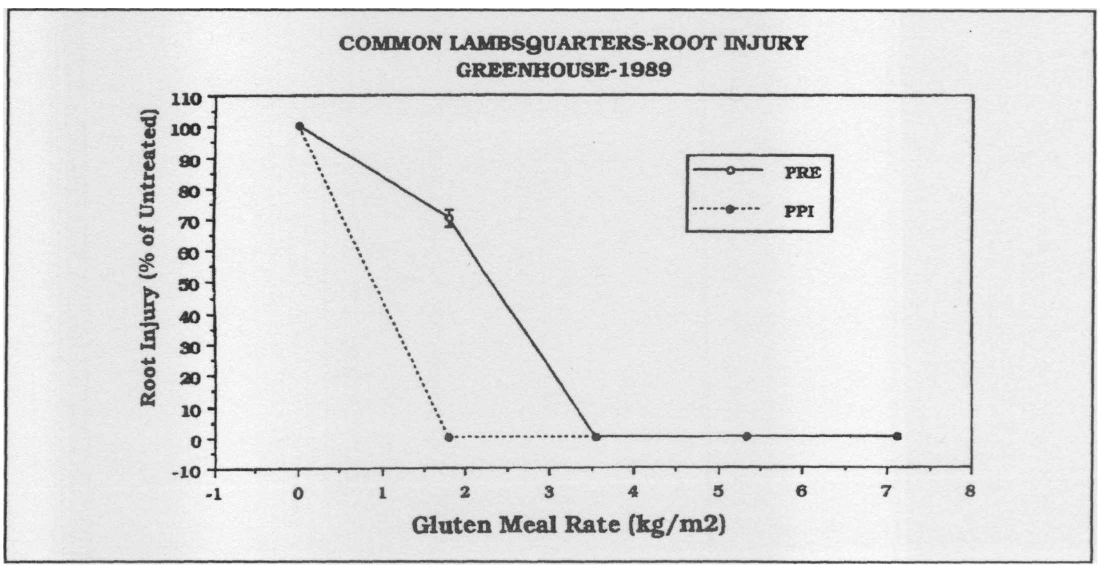
Findings

1. Corn gluten meal: Overall, corn gluten meal provided excellent weed control in both greenhouse and field conditions. Environmental factors such as rainfall and soil moisture had considerable impact on the efficacy of this compound because moisture is needed for uptake into plants. Greenhouse assays evaluated the effects and dosages of corn gluten meal, and the results were favorable.

Field trials under "worst case scenario" conditions suggested that corn gluten meal, in amounts from 0.01 kilograms per square meter (kg/m^2) to as high as 4.0 kg/m^2, may provide effective weed control in corn; in typical conditions, the upper limit of the range for an effective use rate might be 0.01 to 1.0 kg/m^2.

Corn was the most resistant species tested overall—a promising factor for development of selective weed control systems. Surface-applied corn gluten meal was in general less injurious than soil-incorporated treatments (see Fig. 1). All rates tested injured corn, but the lower rates did so to a lesser extent. Overall, corn did not exhibit the crop tolerance desired for immediate use, but the lower rates were less injurious to corn than the other species. These results indicate that there may be some

Fig. 1. Effects of surface-applied (PRE) and soil-incorporated (PPI) corn gluten meal on the roots of common lambs-quarters, a typical weed in Iowa corn fields.



natural tolerance in corn to its own product. The investigators are exploring this possibility further by evaluating development of a resistant corn line along with the inheritance of that resistance in corn.

A laboratory test was also developed to evaluate corn germplasm to determine the range of resistance in corn to corn gluten meal as an allelochemical. A crucial question was whether there were differences in resistance among corn genotypes. If differences were minor or resistances were low, trying to improve corn for this type of resistance would be impractical. However, investigators found a relatively wide range in resistance among lines tested.

Thus far, corn gluten meal appears to affect the corn root system first; this finding suggests which cultivars should be studied in the future. Shoot weight was another good indicator of resistance level, unlike seed germination, which was more variable in response. Within a wide range of resistance no corn lines were killed, but none were left uninjured. A few show particular promise as resistant lines.

<u>Soybean crop tolerance</u> was poor. Even the lowest rates injured soybean shoots and suppressed seed germination. Both field and greenhouse results suggest that corn gluten meal weed management in soybean production is probably not feasible until soybean resistance is significantly enhanced.

<u>Common lambsquarters</u> was sensitive to lower rates of soil surface applications and soil-incorporated applications in terms of seed germination, while soil-incorporated applications were more injurious to shoots and roots. Overall, lambsquarters was one of the most sensitive species tested.

<u>Creeping bentgrass</u> was, overall, one of the most sensitive species tested in terms of shoot, root, and seed germination inhibition from soil surface applications; in this respect it differed from the other species tested.

<u>Giant foxtail</u> responded more to soil-incorporated than soil surface treatments for shoot and root control, and the treatments were similar in suppression of weed seed germination. Foxtail responses, primarily those of giant foxtail in the field, differed among trials. In the earlier trial, low rates stimulated weed growth, but in a later trial, foxtail was very sensitive to corn gluten meal. As with pigweed, environmental conditions mitigated the observed responses between trials. Foxtail is sensitive relative to other species.

<u>Pennsylvania smartweed</u> reacted similarly to soil-incorporated and soil surface treatments in inhibiting seed germination and in growth of shoots and roots, unlike the other species, which were injured more by soil-incorporated treatments. This weed was possibly the second most tolerant species after corn.

<u>Redroot pigwee</u>d was controlled well, both in seed germination and in shoot and root control, at all soil-incorporated application rates; soil surface treatments were less effective in inhibiting shoots. Pigweed was possibly the most sensitive species tested, although responses differed between the field trials. Apparently, environmental conditions can alter control, even in a wet year when results are harder to interpret.

<u>Shattercane</u> had good shoot and root control with low soil incorporated-applied rates and with intermediate rates applied on the soil surface. Corn gluten meal provided excellent shoot and seed germination control of <u>velvetleaf</u>. It was one of the most sensitive weed species tested with this allelochemical.

2. Flavone allelochemicals: Quercetin is probably the most ubiquitous flavone in the plant kingdom. It is only moderately toxic, and it is easily and inexpensively obtained. For these reasons, several trials assessed this allelochemical's potential as a weed control agent, specifically by evaluating the effect of this compound when applied to several species—soybeans, corn, velvetleaf, redroot pigweed, common lambsquarters, shattercane, Pennsylvania smartweed, creeping bentgrass, and giant foxtail—as a foliar application and as a soil treatment. Ample application rates caused no visible foliar effects on any of the species tested. Apparently, quercetin is ineffective when applied in this manner, despite assays indicating it inhibits plant function at the cell or lower level of organization.

Several plant species were evaluated in a second set of experiments to determine if quercetin incorporated into the soil would show promise as a weed control agent. Again, use of ample concentrations applied to the entire soil volume showed toxic effects of quercetin on most species' shoot portions, but only corn and soybean roots appeared affected. Apparently quercetin is translocated via root uptake from the soil to injure the more sensitive shoot organs of the plants. Species showing stunting and yellow coloration injury symptoms were velvetleaf, creeping bentgrass, redroot pigweed, soybeans, Pennsylvania smartweed, giant foxtail, shattercane, and corn. Common lambsquarters seed germination was inhibited. The rates used to effect promising responses were probably too high to be of practical utility; even then, control was incomplete. Soil-applied quercetin may have potential if these limitations could be overcome.

3. Phenolic acid allelochemicals: Several phenolic acid compounds appeared to inhibit plant growth in controlled laboratory studies. But associated work at ISU indicated that these compounds would be ineffective if used as soil-applied allelochemicals. Trials were to determine if these compounds had potential as foliar-applied allelochemical agents. Concentrations up to the saturation level of eight acids applied individually to several different solvent-carrier systems had no visible effect on leaves of soybean, shattercane, creeping bentgrass, redroot pigweed, common lambsquarters, Pennsylvania smartweed, velvetleaf, giant foxtail, and corn.

4. Alkaloid allelochemicals: Four alkaloids were evaluated on several plant indicator species. These materials in general showed no toxic effects on the foliage of these plants. When soil applied, several good candidates, especially caffeine, were identified. Overall, however, the amount of chemical needed for desirable toxic effects was too high, and too expensive, for practical use. If these drawbacks could be overcome, perhaps by deriving the substances as a waste product of some industrial process, some of these allelochemicals could be used to control weeds in crops.

Implications

The results of these assays indicate that corn gluten meal is a highly favorable candidate for weed control in corn. While it is difficult to determine the long-term impact of this research, this project has developed a solid core of information about application rates, timing, species affected, corn crop tolerance, environmental effects on control, and preliminary physiological information on how these allelochemicals affect plants. This information constitutes the first major step toward transferring the technology of corn gluten meal as a weed control tool. Although corn tolerance is not perfect, it is promising.

Ultimately, it would be very inconvenient to apply large volumes of raw corn gluten meal to corn fields. The active principle in corn gluten meal is only a very small fraction of the raw product, and using the allelochemical in this concentrated form is a goal for future research. Cooperative work between Dr. Christians and the corn milling/processing industry is leading to a convenient form of this chemical; extensive evaluations are needed now to show if this concentrated form is as effective as the raw meal. Iowa State University now has a patent on this material.

Once the chemical identity of the corn gluten meal allelochemical is made available, researchers can make rapid progress in defining its mode of action and its basis for crop selectivity. More on-farm trials can be conducted that can then lead to actual application recommendations. In addition, environmental and toxicological studies can then be performed.

The investigators and other researchers involved in this project continue to work on a corn line that is resistant to corn gluten meal; a number of publications have resulted from this work.

For more information contact J. Dekker, Agronomy, Iowa State University, Ames, Iowa, 50011, (515)294-8229.