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HERBICIDE TOLERANT SOYBEANS: WHY GROWERS ARE ADOPTING ROUNDUP READY VARIETIES

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Soybean growers have adopted herbicide tolerant varieties at a rapid rate. While some potential cost savings may have driven adoption, the primary reason growers are switching to new programs is the simplicity and flexibility of a weed control program that relies on one herbicide to control a broad spectrum of weeds without crop injury or crop rotation restrictions. Roundup Ready weed control programs for soybeans fit into on-going trends towards postemergence weed control, adoption of conservation tillage practices and narrow row spacing. Roundup Ready systems have also solved some of the problems growers faced in conventional weed management systems.

Key words: biotechnology; Roundup Ready soybeans; weed control.

Adoption of recently introduced herbicide tolerant soybean varieties has been extremely rapid. By 1998, approximately 38% of the total U.S. soybean acreage was planted to varieties developed through the use of biotechnology methods to be tolerant to various herbicides. The first herbicide tolerant varieties, sulfonylurea tolerant soybeans, were introduced in 1993 and were developed to tolerate higher rates of some of the herbicides that were already being used in soybeans. Three years later, in 1996, Roundup Ready soybean varieties became available, allowing the use of glyphosate (Roundup) as a postemergence herbicide over the top of growing soybeans. In 1998, Liberty Link soybeans became available in a limited release intended for experimental uses. Liberty Link varieties incorporate tolerance to the herbicide glufosinate.

The vast majority of adoption of biotech-developed varieties, and the most rapidly adopted, has been due to the introduction of Roundup Ready varieties. Roundup Ready soybeans are expected to account for over 50% of planted soybean acreage in 1999. By most accounts, the popularity of Roundup Ready soybeans is primarily due to the simplicity and flexibility of a weed control program that provides broad spectrum weed control with one product that can be applied over the soybean crop at any stage of growth without causing crop injury.

In many ways, the introduction of varieties with increased tolerance to postemergence herbicides reinforced existing herbicide use trends in soybean production, while allowing growers to avoid

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some drawbacks of conventional programs. The focus of this article is on Roundup Ready soybeans, due to its widespread adoption by growers. This new technology is viewed in the context of existing weed control practices in order to illuminate the issues influencing grower decisions to plant Roundup Ready soybeans.

Conventional Weed Control

Weed control practices in soybeans have evolved over the past several decades. Before the introduction of herbicides, weed control was achieved by mechanical and cultural means. Herbicides began to replace tillage and cultivation practices as the primary weed control method for soybeans in the 1960's, at which time, soil-incorporated and preemergence herbicides became the dominant chemical weed control methods. Chloramben was the first herbicide to dominate the soybean herbicide market, providing effective control of both grasses and broadleaf weeds. Metribuzin replaced chloramben use for broadleaf control, and was commonly combined in tank mixes with trifluralin to control grass weeds. Alachlor was also commonly used for grass control. All of these herbicides are applied before or at planting. Often farmers would follow these treatments with mechanical cultivation until soybean canopies closed and shaded competitive weeds (Pike, McGlamery, & Knake, 1991).

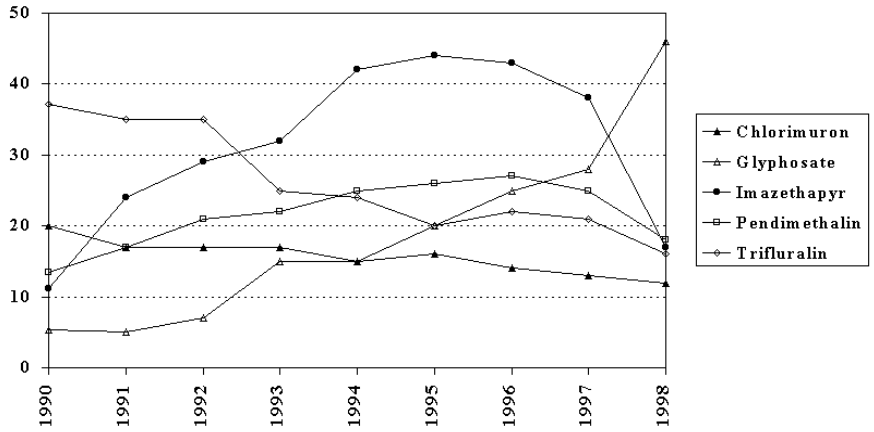
The development of selective postemergence herbicides for soybeans gave farmers an alternative weed control tool. Postemergence herbicides became widely available to soybean growers in the 1980's. With these additional materials, farmers could use pre-plant herbicides either surface applied or incorporated for early-season weed control and could then apply postemergence herbicides in lieu of tillage to control weeds in-season. The use of postemergence herbicides in crop production allowed growers to tend larger acreage, as herbicide-based weed control is faster than cultivation.

Postemergence herbicide use has been steadily increasing since these materials became available in the 1980's. In 1988, 44% of soybean acres were treated with postemergence herbicides (USDA/ERS 1989). By 1994, 72% of soybean acres were treated with a postemergence herbicide (USDA/ERS 1995). These figures include acreage treated with both pre-plant followed by postemergence herbicides and those treated with postemergence herbicides alone. Postemergence broadleaf herbicides, such as chlorimuron (Classic), imazaquin (Scepter) and imazethapyr (Pursuit) are often used in programs with preemergence materials such as trifluralin (Treflan) or pendimethalin (Prowl) to broaden the spectrum of weed control.

Postemergence grass herbicides, such as sethoxydim (Poast), fluazifop (Fusilade), and quizalofop (Assure) have also become available in recent years, but their use has been somewhat limited due to price, reliability, and antagonism when tank mixing with broadleaf herbicides (Pike, McGlamery, & Knake, 1991; Krumm & Martin, 1999). If postemergence treatments are needed for both broadleaf and grass weeds, two passes over the field or increased rates of the grass herbicide may be necessary to avoid this antagonism. Conversion to total postemergence programs has been limited by these factors.

Figure 1 shows trends in soybean herbicide use since 1990, for herbicides that were used on more than 10% of the soybean acreage in 1998. Imazethapyr was introduced for broadleaf control in the early 1990s, as both a pre-plant treatment as well as postemergence treatment. It rapidly dominated the soybean broadleaf herbicide market, approaching use on 45% of soybean acreage within a few years of introduction. Its success is due to the convenience offered to the grower as a result of good crop safety and excellent weed spectrum and efficacy.

Figure 1. Selected Herbicide Use In U.S. Soybeans (Percent Of Acres Treated)



Availability of postemergence herbicides that could be applied over the crop during the growing season has influenced production practices in soybeans. First, it has facilitated the adoption of conservation tillage practices. The level and consistency of weed control in no-till systems improved with the development and use of herbicides such as chlorimuron, clomazone and imazaquin (Kapusta & Krausz, 1993). Approximately 54% of soybeans were planted under conservation tillage conditions in 1998, up from 30% in 1989 (Conservation Tillage Information Center, 1999). In some conservation tillage systems, it is not possible to incorporate herbicides into the soil as a preplant treatment. In conservation tillage systems, growers use a burndown treatment to control existing vegetation before planting, growers may use a soil applied treatment at planting time, and rely upon postemergence treatments to control weeds during the season.

The availability of postemergence herbicides has also made narrow row spacing possible. With rows that may be as narrow as 7.5 inches cultivation becomes impossible. Postemergence herbicides eliminate the need for cultivation and allow growers to space rows more closely. Narrow row plantings result in higher yields due to a more efficient use of space. Also, narrow row systems may result in better weed control, as the canopy closes more quickly providing earlier competition against weeds.

Growers have many weed control options to choose from and tailor programs to fit their specific needs based on weed species and densities, as well as management and equipment constraints. There are at least 70 registrations for herbicides or packaged herbicide mixtures for weed management in soybean. Most weeds in soybean can be adequately controlled with existing conventional herbicides in well-planned management systems (Wilcut, *et al*., 1996). Choosing the right program for a particular situation may be complicated, as a result of this wide range of options, and most growers apply several different herbicides on a particular field. In 1994, the average number of active ingredients applied per acre was 2.7. Twenty one percent of soybean acreage was treated with four or more active ingredients (USDA/ERS 1995). Crop losses due to weeds were estimated at 7% in 1992 (Bridges & Anderson).

Although there are many weed control options for soybean growers, the conventional materials are limited by several factors. The main drawback of a conventional herbicide program is potential for crop injury (Rawlinson & Martin 1998; Padgette *et al*., 1996). Crop injury resulting from commonly

used herbicides include stunted growth, yellowing of leaves, reddening of leaf veins, and speckling, bronzing or burning of leaves. While these symptoms do not always reduce yield, they sometimes delay canopy closure and increase weed competition with the crop (Padgette, *et al*.,1996). As a result, herbicide rates are kept low to reduce the possibility of crop injury. In order to achieve adequate weed control at low rates, weeds must be relatively small at the time of treatment. In some cases, low herbicide rates may result in incomplete weed control in heavily infested sites (Rawlinson & Martin 1998).

Another limitation to conventional programs is the development of herbicide resistant weeds. The imidazolinone, sulfonylurea, and sulfonamide herbicides all have the same mode of action, inhibiting the acetolactate synthase (ALS) enzyme (U of I). ALS-inhibiting herbicides, such as imazethapyr (Pursuit) and chlorimuron (Classic), are widely used in soybeans (USDA/NASS, 1991-1999). Several ALS-resistant weed populations have developed in various areas of the Midwest, e.g., waterhemp, shattercane, cocklebur and kochia (Hartzler 1997; Rawlinson & Martin, 1998) which limits the effectiveness of these compounds.

Finally, some herbicides that are used in soybeans have residual deleterious effects on rotation crops due to persistence of the materials in soil. For instance, corn, which is commonly rotated with soybeans in the Midwestern states, is susceptible to damage from several of the imidazolinone herbicides that are commonly used in soybean production. Guidelines for rotational crops following application of Pursuit Plus (imazethapyr + pendimethalin) specify a waiting period of up to forty months before planting other crops, such as canola, sugarbeets and many vegetables (Rohm & Haas, 1998). The potential for a rotational crop to suffer damage from carry over is dependent upon soil type and environmental conditions, such as rainfall which impact degradation of the materials. In some areas, this carryover effect has limited potential rotations.

Roundup Ready Soybeans

Since their introduction in 1996, Roundup Ready soybeans have been adopted by growers at a rapid rate, believed to be limited only by the availability of seed. There are several factors that contribute to the popularity of this new weed control technology. The primary reason is believed to be the simplicity of the Roundup Ready weed control program, which allows growers to use one product to control a wide range of both broadleaf and grass weeds without sustaining crop injury, instead of using several herbicides to achieve adequate weed control.

As growers have adopted Roundup Ready soybeans, the use of other herbicides has been affected. Roundup was first introduced for use on soybean acreage in the 1970s as a burndown treatment, used to kill existing vegetation before planting. Its use was already increasing when Roundup Ready soybeans were introduced in 1996 (see figure 1). Since 1996, the percentage of acres treated with other herbicides has declined. In particular, the use of imazethapyr has declined precipitously, from a high of 44% of soybean acres treated in 1995 to 17% in 1998 (USDA/NASS; 1991-1999). The use of pre-plant herbicides such as trifluralin and pendimethalin has also declined, but not as dramatically, as growers may still choose to use these herbicides as part of their Roundup Ready program.

Roundup Ready weed control programs for soybeans fit into on-going trends towards postemergence weed control, adoption of conservation tillage practices and narrow row spacing. Roundup Ready systems have also solved some of the problems growers faced in conventional weed management systems.

In addition, the window of application for Roundup is wider than for other postemergence herbicides currently used in soybeans, both in terms of the stage of soybean growth and the ability to achieve effective control of larger weeds. No yield penalty is observed from glyphosate applications up to and beyond soybean flowering (Padgette, *et al*., 1996). Maximum weed sizes at which Roundup is effective are generally higher than with other postemergence herbicides (University of Illinois). This flexibility allows growers to treat later with less concern about getting poor weed control or injuring the crop. Because Roundup has no residual activity, the Roundup Ready program does not have any carryover restrictions, which gives growers more rotation options. Finally, Roundup is effective at controlling weeds where resistance to other classes of herbicides has developed.

Costs And Yields Using Roundup Ready Soybeans

Growers may have responded to the potential for savings using a Roundup Ready weed control system. Potential savings would depend on how many applications of Roundup were made during the season, as well as if any additional materials were used. A program using one application of Roundup over Roundup Ready soybeans cost $16.45 in 1998, including a $7/acre technology fee. Additional applications of Roundup or other herbicides would increase this cost. A conventional herbicide program may cost as little as $13.50 for a pre-plant treatment alone, or around $25 for programs using combinations of herbicides (Rawlinson & Martin, 1998). Some growers who were using high cost conventional programs may have switched to a Roundup Ready program with one application, thereby reducing their costs. More than one application may be necessary to control weeds emerging after the Roundup treatment, due to the non-residual nature of Roundup, especially in more southern production areas, like Missouri and Arkansas. Also, as weed populations shift towards species that are not controlled well by Roundup, either due to late emergence or higher tolerance to glyphosate, growers will likely need to modify their program. This may mean additional applications of either Roundup or other materials.

Recent price cuts by DuPont and American Cyanamid have made some conventional programs price competitive. In addition, Monsanto recently reduced the price of Roundup, while increasing the technology fee that is included in the price of seed to growers. Monsanto's patent on glyphosate expires later this year, and the price is expected to decline further. While there may have been an early price advantage for some growers in the Roundup system, that seems to be disappearing.

Determining the impact that Roundup Ready soybeans have had on yields is somewhat problematic at this stage. With such a new technology, field data on yields are scarce. However, some expectations may be developed from available research results. Two areas of research are most relevant to answering the question of whether yields of Roundup Ready soybeans would be generally higher, lower or about the same as yields of conventional varieties of soybeans. The first is weed control research, comparing weed control strategies. The second type of research is variety trials, where the yield potential of conventional and Roundup Ready varieties have been compared.

In weed control trials, several programs are compared as to their efficacy in controlling weeds, and yields are often recorded. Several herbicides are usually included in these trials, alone or in combination, at variable rates and application timing. The purpose of these types of studies is to determine optimal rates and timing to achieve control of various weeds. In general, these tests are conducted using one variety in order to eliminate variety as a variable. Recently, many researchers have chosen to use Roundup Ready varieties in their trials in order to include Roundup treatments in their studies.

Yield differences in these studies are due to more effective weed control and from avoiding crop injury due to conventional materials. However, these studies do not take into account the yield potential of the variety used in the study. It is difficult to generalize about the results from the weed control studies, except to note that at this point there seems to be no resounding yield advantage or disadvantage in Roundup Ready systems compared to conventional programs. Researchers in Minnesota conclude that yields in a Roundup system compared to conventional herbicide systems were equal (Breitenbach & Hoverstad, 1998). In a summary of weed control research published in the 1997 North Central Weed Science Society Research Report, in which Roundup-only treatments were compared to conventional programs, Roundup-only plots out-yielded conventional plots by 5.3 bushels per acre (Fawcett, 1997). However, some conventional treatments in those comparisons may have been tested against weeds they do not control, whereas Roundup has a broad weed spectrum. This may make Roundup Ready systems appear to be more effective in these types of studies than they would be in reality, where a grower would tailor a weed control program for the particular weed species present in the field.

Variety trials are different than weed control trials, both in the way that they are conducted and the questions they are intended to answer. Traditionally, variety trials are conducted by state universities to assess the characteristics of varieties that will be available to growers the following year. Both publicly and privately developed varieties are included in the trials, entered by the seed companies on a fee basis, while some states will choose to enter additional varieties. Most states stipulate that variety entries should either be currently marketed or that the company intends to begin marketing that variety in the upcoming season. The trials assess yield, maturity, lodging, protein and oil content, and resistance to pathogens and soybean cyst nematode, and are generally treated with herbicides in order to maintain weed free conditions.

The manner in which the Roundup Ready varieties have been incorporated into the state variety trials differs in whether the Roundup varieties are treated with Roundup or conventional materials and whether tests with Roundup Ready varieties include conventional varieties. Despite these differences, it appears that Roundup Ready varieties generally yield lower on average than the conventional varieties (Oplinger, Martinka, & Schmitz; Minor, 1998). This is believed to be due to the introduction of the Roundup Ready gene into varieties with lower yield potential. However, it is unclear which of the Roundup Ready varieties from the variety tests are the most commonly planted, and not all seed companies enter their Roundup Ready varieties in the trials. As the genetics are introduced into more and more varieties, this apparent “yield lag” is anticipated to disappear.

From the weed control trials and the variety trials, it would appear that average yields in fields planted to Roundup Ready varieties should be about the same or less than field planted to conventional varieties. If Roundup Ready varieties are found to perform better in the field than conventional varieties, it would likely be due to achieving better weed control and avoiding crop injury, though researchers seem to believe that crop injury does not currently reduce yields. Monsanto recently reported that Roundup Ready soybeans out yielded the national average soybean yield by more than four bushels in 1998 (Monsanto; 1999). A possible explanation for Roundup Ready fields to be yielding more than the conventional fields would be if there were some other factor influencing yields that was associated more with Roundup Ready acreage than conventional acreage. For instance, some believe that Roundup Ready soybeans are being adopted in narrow row production systems more quickly than in wide row acreages. If narrow row acreage has higher yields than wide rows, then it might be this difference that is driving an observed difference in yields.

Conclusion

Roundup Ready soybeans will be planted on 35 million acres in 1999. The soybean herbicide market is highly competitive. The fact that Roundup Ready soybeans have captured such an enormous share of this market indicates that this new technology is delivering benefits to growers. As illustrated above, the primary reasons growers are adopting Roundup Ready soybeans are the simplicity and flexibility of the program. Understanding these benefits is critical in an evaluation of the impact that the introduction of this technology has had on U.S. agriculture.

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