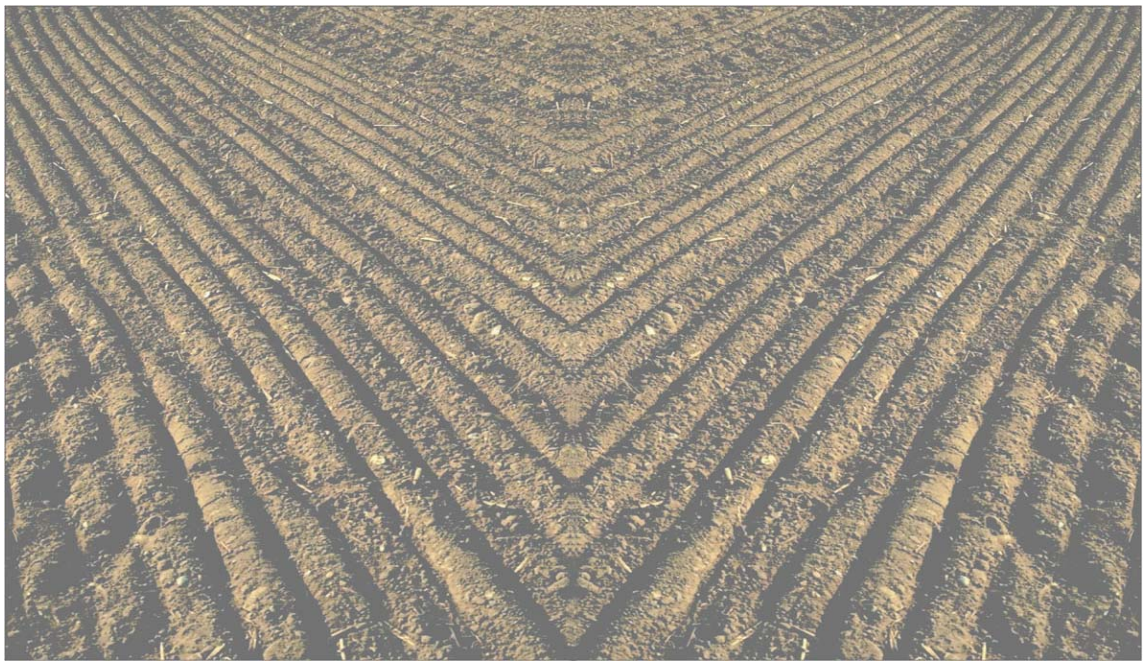
Troubled Times Amid Commercial Success for Roundup Ready Soybeans

Glyphosate Efficacy is Slipping and Unstable Transgene Expression Erodes Plant Defenses and Yields



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Executive Summary

Roundup Ready soybeans have clearly been a great commercial success. Over 60 percent of soybeans in the United States this year will be planted to RR varieties, just five years after introduction in 1996.

Despite costing more, farmers have eagerly adopted Roundup Ready soybean technology because it greatly simplifies weed management. RR systems do so by allowing the farmer to spray a single broad-spectrum herbicide active ingredient – glyphosate (Roundup) – over the top of growing soybeans, killing most weeds but leaving genetically engineered Roundup Ready (RR) soybeans largely unharmed.

RR soybeans make it possible for farmers to avoid or cut back use of persistent, highly active low-dose herbicides, many of which can injure soybean plants and depress yields. A last and major advantage -- RR soybean-based weed management systems are forgiving. They provide farmers a wider window of opportunity to deal with problem weeds and extra chances to make up for delays in field operations or for an untimely rain that washes herbicides off weeds before they are absorbed. On some farms these advantages add up to slightly more bushels harvested per acre than when conventional soybean varieties were planted.

Still, Roundup Ready soybean systems are costly in more ways than one and some costs are rising.

Herbicide Use

RR soybeans clearly require more herbicides than conventional soybeans, despite claims to the contrary. This conclusion is firmly supported by unbiased field-level comparisons of the total pounds of herbicide active ingredient applied on an average acre of RR soybeans in contrast to conventional soybeans. Part I presents such field-level data for 1998, drawing on official U.S. Department of Agriculture pesticide use data. It also explains how Monsanto has manipulated comparative data on RR and conventional soybean herbicide use in ways that fall between misleading and dishonest.

Rates of application per acre are the key variable that explains why RR soybeans require more herbicides than other varieties. More than a dozen soybean herbicides are applied at an average rate of less than 0.1 pound active ingredient per acre. Roundup, on the other hand, is usually applied on soybeans at about 0.75 pounds per acre in a single spray and most acres are now treated more than once. According to Monsanto, about one-quarter of RR soybean acres will be treated three times with glyphosate, in systems requiring well over 1.5 pounds of herbicides.

Total herbicide use on RR soybeans in 1998 was 30 percent or more greater on average than on conventional varieties in six states, including Iowa where about one-sixth of the nation's soybeans are grown. RR soybean herbicide use was 10 percent or more great in three more states. Use on RR soybeans was modestly lower in five states. Use

was significantly lower only in Michigan, where less than 3 percent of the nation's soybeans are grown.

Actual per acre herbicide use data in 1998, as measured field-by-field by USDA, was used to assess the distribution of herbicide use along a continuum from the most herbicide dependent systems to the least dependent. On the 30 percent of soybean fields managed with the most herbicide-intensive systems under conventional/conservation tillage, including essentially all RR soybeans planted under conventional/conservation tillage, at least 1.7 times more herbicide was applied per acre compared to the 30 percent of soybean acres that required the least amount of herbicides – fields where farmers relied mostly on the low-dose sulfonylurea and imidazolinone herbicides and which were clearly ***not*** planted to RR soybeans.

When total herbicide use per acre is compared at the tail ends of the distribution (i.e., the top10 percent of acres versus the bottom 10 percent), the difference is much more striking, especially on fields under conventional/conservation tillage. The most heavily treated fields, most of which were planted to RR soybeans, required at least 34 times more herbicide than fields planted to non-RR varieties at the low-end of the distribution.

Under no-till the most heavily treated 30 percent of fields required twice the herbicide as the 30 percent of acres at the low-end of the distribution. Most RR fields fall in this top 30 percent and essentially none are in the lower 30 percent.

Looking ahead to crop year 2001, it is likely that the average acre of RR soybeans will be treated with about 0.5 pounds more herbicide active ingredient than conventional soybeans. As a result over 20 million more pounds of herbicides will be applied this crop year. In addition, the difference between herbicide use on RR and conventional soybean varieties is clearly growing and for several reasons.

Intense herbicide price competition, triggered by the commercial success of RR soybeans, has reduced the average cost per acre treated with most of today's popular herbicides by close to 50 percent since the introduction of RR soybeans. In response farmers are applying more active ingredients at generally higher rates. But heightened reliance on herbicides, especially Roundup, has accelerated the shift in weed species in ways that is undermining the efficacy of Roundup and requiring farmers to add new products to their control programs. These trends increase the risk of resistance and will ultimately lead to less reliable and more costly systems.

RR Soybean Yield Drag

There is voluminous and clear evidence that RR soybean cultivars produce 5 percent to 10 percent fewer bushels per acre in contrast to otherwise identical varieties grown under comparable field conditions. Recent evidence of the magnitude of the Roundup Ready yield drag is summarized in part II, along with the results of studies that have begun to isolate the genetic basis of the RR yield drag.

The yield drag between the top five leading RR varieties in a maturity group in contrast to the top five conventional varieties in the same maturity group is assessed in three to four locations in each of three states. In Illinois the top-five yield drag averaged 2.3 percent. In Minnesota the top-five yield drag averaged 6.1 percent and in Nebraska, 2.9 percent. A special study by a team at the University of Nebraska study estimated that the genetic differences between RR varieties and otherwise similar varieties, when grown under comparable conditions, is about 6 percent.

In a January 2001 story on corn and soybean seed selection, *Farm Journal* magazine shared with its readers the results of independent soybean yield trials in three states conducted under conditions designed to match those on commercial farms. In Indiana, the top RR variety offered by three seed companies yielded, on average, 15.5 percent fewer bushels than the top conventional variety from the same company. In Illinois plots, however, the top RR to top conventional yield drag across eight companies was less than 1 percent. In Iowa trials, the RR yield drag was just under 19 percent across 17 companies.

New Science Traces the RR Yield Drag to Its Roots

Soybean yields have been increasingly erratic across the Cornbelt in recent years. Many fields have suffered yield losses far greater than expected given the magnitude of the RR yield drag. The search is on for answers and recently some have emerged.

University of Arkansas scientists have shown that root development, nodulation and nitrogen fixation is impaired in some RR soybean varieties and that the effects are worse under conditions of drought stress or in relatively infertile fields. This problem arises because the bacterial symbiont responsible for nitrogen fixation in soybeans, *Bradyrhizobium japonicum*, is very sensitive to both Roundup and drought. The combination of Roundup and drought is clearly not unusual across the 65-70 million acres planted to soybeans each year.

Soybean compositional studies carried out by Monsanto have documented a modest but statistically significant decrease in the levels of two key aromatic amino acids, phenylalanine and tyrosine, in harvested soybeans. Phenylalanine serves as a sort of "master control switch" for a range of soybean plant defense responses that must unfold in a timely and properly targeted way when the plant is attacked by pests or stressed by drought or other abiotic factors.

New evidence suggests that levels of these regulatory proteins are being depressed more substantially for a few days to a week or more after Roundup is sprayed on fields planted to RR soybeans. In years or regions with modest pest pressure and where moisture supplies and growing conditions are optimal, RR soybean plants restore phenylalanine and other regulatory proteins to normal levels quickly and suffer no long-term consequences. But where growing conditions are less than optimal, even temporary depression of RR soybean plant defense mechanisms can give pathogens a chance to

multiple largely unchecked and initiate infections. This head start forces the plant to invest energy over an extended period of time in repairing and containing the damage. While regulatory protein levels in the harvested soybeans from such fields often return to, or nearly to normal levels, the temporal diversion of plant energy extracts an essentially irreversible tax on yields.

Troubled Times will Trigger Changes in Soybean Weed Management

As new soybean weed control options emerge and are integrated into multitactic soybean weed management systems, fewer farmers will be willing to accept the trade-offs and costs now inherent in selection of a RR variety. There are two major factors on the plus side of RR soybean trade-offs -- weed management is simplified and soybean crop injury is avoided. But troubled times lie ahead for RR soybeans because the efficacy of glyphosate is clearly slipping in managing weeds and because unanticipated yield penalties are surfacing in some RR fields, traced to how genetic engineers have modified soybean plants to make them Roundup Ready. As farmers begin to understand the practical implications of what researchers have recently discovered, interest will grow in other less costly ways to manage soybean weeds.

The U.S. agricultural biotechnology industry and the farm community should heed three important lessons in the rapid adoption and now shaky future of RR soybeans.

1. Any biotechnology that heightens reliance on a single pest management tool, and especially a single herbicide, is headed for trouble.

Herbicide-tolerant crop technologies are designed to allow farmers to increase their reliance on herbicides. It is therefore not surprising that RR soybeans require more herbicides than other weed management systems, especially those that incorporate "many little hammers" in combinations that change from year-to-year.

Spraying Roundup two or three times on a RR soybean field, often at steadily higher rates and sometimes followed the next crop season with two or three more applications on RR corn, has imposed on weed populations unprecedented levels of selection pressure, leading to shifts in weed species composition and resistance or lost sensitivity in other target weeds.

Roundup Ready soybean technology is, to a large extent, a victim of its own success. Excessive reliance on Roundup as the major, if not sole means of weed management unleashes basic evolutionary forces that farmers – and agribusiness – ignore at their peril.

2. Inserting transgenes into major plant metabolic pathways is a risky proposition that is likely to lead to unanticipated consequences, especially when plants are stressed by unusual weather, pests, or infertile or imbalanced soils.

When plants are stressed, transgene expression may be silenced or otherwise disrupted as a secondary consequence of the plant's normal physiological response to the source (or sources) of stress. Even modest and short-term depression in the production of key regulatory aromatic amino acids in RR soybean varieties can tip the competitive edge toward opportunistic pathogens.

Once pathogens gain a head start, the plant will have to invest energy in fighting them back and containing their spread. This diversion of energy sometimes extracts an irrevocable yield penalty, despite the fact that the plants and the harvested soybeans appear perfectly normal and "substantially equivalent" upon harvest at the end of the season.

3. The lack of independent research on the ecological, agronomic and plant defense consequences of RR soybeans, until well after regulatory approvals and widespread market penetration, blindsided regulators and has heightened the vulnerability of farmers.

It is remarkable that over 100 million acres of Roundup Ready soybeans were planted in America before publication in 2001 of the first university data documenting the sometimes-serious depression of nitrogen fixation in RR soybean fields.

Ignorance creates a false sense of security and sets the stage for trouble. The U.S. regulatory system is better at avoiding problems that dealing with them once a technology is entrenched, with profits and market share to defend. In the case of RR soybeans, the regulatory system's ability to ferret out risks and resolve uncertainties was, in effect, silenced because regulators had little to go on in formulating questions.

Moving On

Understanding should evolve quickly now that several independent research teams have started to publish results on the downsides of the RR soybean system. But the mechanisms leading to RR soybean yield losses are many, complex and highly variable. Scientists will struggle to just keep pace with soybean weed management changes and many problems will come and go before anyone understands fully where they came from and why.

New technologies in the future will have a better chance of sustaining a place in U.S. soybean weed management systems if the above three lessons are heeded. The fuller the soybean weed management toolkit, the easier time farmers will have in keeping their fields clean and yields up. In managing weeds, keeping a few steps ahead of Mother Nature is the ultimate measure of success, and a standard of performance that appears beyond the reach of today's RR soybean system.