I. Herbicides Applied to Conventional and Roundup Ready Soybeans

Herbicides have done the heavy lifting in soybean weed management systems since the early 1970s. Compared to corn, soybean plants do not produce nearly as much foliage, and hence soybean fields are more susceptible to high rates of soil erosion. For this reason, farmers have tried to minimize tillage in the years they are planting soybeans.

While good for the soil and for water quality, reduced tillage soybean systems are, in general, more reliant on herbicides in keeping weeds under control. (For a more detailed discussion of the evolution in weed management systems in the United States and impacts on herbicide use, see *Pest Management at the Crossroads* [Benbrook, et al., 1996]).

A. Historical Overview of Herbicide Use in Soybean Production

In the early to mid-1980s, most soybean herbicides were applied in combinations and tillage and cultivation still played a significant role in weed management systems on many farms. Combined herbicide rates typically fell between 0.75 to 1.5 pounds per acre. Many of the products that dominated soybean herbicide use in the 1980s are still popular today. They remain widely used because they still work reasonably well and are one-half or less the cost per acre treated relative to the newer, lower-dose products that started to hit the market in the mid-1980s. These older products include trifluralin, pendimethalin, 2,4-D, sethoxydim, and alachlor/metalochlor.

There is now a dizzying array of soybean herbicides on the market. Many are sold in combination products containing two or three active ingredients at rates designed to fit with today's popular tillage and planting systems. Most of the newest combination products have been introduced specifically to augment weed control in fields planted to Roundup varieties.

A detailed study of RR soybean production, herbicide use, and profitability in 1998 was carried out by the National Center for Food and Agricultural Policy, or NCFAP (Gianessi and Carpenter, 2000). The report, "Agricultural Biotechnology: Benefits of Transgenic Soybeans," provides a thorough discussion of historical soybean weed management and the aggregate impacts of RR soybeans. The authors analyzed aggregate USDA herbicide use data in soybeans and concluded that introduction of RR soybeans had little net effect on total herbicide use, measured in pounds applied per acre.

In the NCFAP report, the authors acknowledge they lacked access to detailed soybean field-by-field herbicide use data – the information any analyst would need to definitively assess differences in average per acre pounds of herbicides applied on RR planted fields in contrast to the average pounds applied to other fields. The original analytical results reported in this chapter are based on such field-by-field comparisons of herbicide use and required special tabulations of herbicide use by sample point (a field),

drawing on the raw data files collected by USDA in its 1998 soybean agrichemical use survey.

RR Soybeans Trigger Herbicide Price War

While the NCFAP report does not address field-level differences in per acre herbicide use, it contains a wealth of other data and results. For example, it fully documents the reductions in herbicide prices triggered by the need for other companies to compete with the RR soybean system.

Dupont, the major manufacturer of the sulfonylurea herbicides, was the first to pull the plug on prices in an attempt to slow their loss of soybean herbicide market share. Prices of 42 herbicide products were cut (Reeves, 1997). In 1996, farmers paid $1,220.00 per pound of the very low-dose sulfonylurea herbicide chlorimuron (Classic), or about $15.00 per acre treated (Table 16, Gianessi and Carpenter, 2000). In 1997, Dupont slashed the price to $620.00 per pound, reducing the cost per acre treated at full rates to under $8.00 – about the average cost of an acre-treatment with Roundup. Dupont also cut the price of metribuzin (Sencor) from $40.00 per pound in 1995 to just over $26.70 now, a 33 percent decrease, bringing average per acre treatment costs down from $9.30 to $6.20.

Dupont's price reductions were widely covered in the farm press and widely emulated in the herbicide industry. The November 1997 issue of *Dealer Progress* included a story entitled "Caught in the Crossfire: Roundup Ready Soybeans Trigger a Herbicide Price War that could Wound Your Profits" (Reeve, 1997). It begins with the passage –

> "Roundup Ready soybeans have seized the hearts, minds and fields of U.S. farmers with the kind of speed that would make Norman Schwartzkopf proud."

American Cyanamid, the major manufacturer of the popular imidazolinone herbicides, underestimated the appeal of RR soybeans and lost major market share as a result. Unlike Dupont, American Cyanamid delayed an extra year before dropping the price of its flagship product – imazethapyr (Pursuit). This herbicide was the most widely used throughout the early 1990s. It was applied to 44 percent of soybean acres in 1995, the year before the introduction of RR soybeans. In crop year 1997, its market share had declined just 6 percent, but in the fall of 1997, the competitive threat posed by RR beans was clear to everyone in the industry (Gianessi and Carpenter, 2000).

In early 1998, American Cyanamid announced across-the-board soybean herbicide price reductions. The price per pound of imazethapyr dropped from $340.00 to $200.00, a 42 percent drop. The cost per acre treated fell from $13.60 in 1997 to $8.00, again very competitive with Roundup. Even so, imazethapyr's market share declined from 38 percent of acres treated in 1997 to just 17 percent in 1998.

In the late winter and spring of 1999, American Cyanamid cut prices, intensified advertising and offered all sorts of creative rebates and guarantees to try to slow its slipping share of the soybean herbicide market. In March, they issued a press release that began by asserting –

> "America's farmers could experience yield losses up to $43 per acre when choosing Monsanto's Roundup Ready soybean program." American Cyanamid, 1999)

The huge and rapid erosion in Cyanamid's soybean herbicide market share had a serious adverse impact on the parent company's stock performance and was a major factor triggering the sale of the American Cyanamid agricultural chemical and seed division to the German-based company BASF in 2000.

Monsanto added to the downward pressure on herbicide prices in 1998 by reducing the price of Roundup from $18.00 per pound to $14.00, about a 22 percent price drop. This year Roundup is selling for about $10.00 per pound active ingredient, and often lower as a result of volume discounts and other incentive programs. Since the introduction of RR soybeans, the average price of Roundup has fallen about 44 percent.

Together these soybean price reductions saved farmers an estimated $220 million in 1998, according to the NCFAP study. There was a net $360 million reduction is the cost of herbicides and a $160 million increase in RR soybean technology fees (at about $6.00 per acre), producing the estimated reduction of $220 million (Gianessi and Carpenter, 2000). The cost savings were significant -- close to $8.00 per acre across the approximate 27 million acres planted in 1998 to RR varieties.

Low-Dose Options Proliferate

In the last decade the pesticide industry has developed and marketed dozens of new, low-dose soybean herbicides in the imidazolinone and sulfonylurea classes. These products are applied typically in the range 0.004 pounds to 0.125 pounds of active ingredient per acre (page 44, Gianessi and Carpenter, 2000), between six and 187 times lower than the common rate of glyphosate application (0.75 pound per application).

Each year the U.S. Department of Agriculture carries out a field crop pesticide use survey. Soybean herbicide use data are collected and reported by state as part of the survey and summarized nationally (percent acres treated, average one-time rate of application, rate per crop year [the average number of applications times the average rate per application], and pounds applied). All herbicides applied to 1 percent of more of the soybean acres in a state are included in the annual reports, all of which are accessible on the USDA website (see references for urls).

Of the 34-herbicide active ingredients applied to 1 percent of more of national soybean acres in 1999, there were 13 applied at an average rate less than 0.1 pounds of active ingredient per acre. Just five were applied at one pound or more per acre.

USDA's pesticide use data also show that the average rate of glyphosate per crop year was 0.92 pounds of active ingredient. About 30 percent of the acres treated with glyphosate received two Roundup applications.

Soybean Herbicide Use Trends

Prior to the introduction of Roundup Ready soybeans, most farmers applied two to three active ingredients in managing soybean weeds. It usually took about one-half an additional spray, on average, to deal with weeds in no-till systems compared to conventional tillage systems.

Some soybean acres are still treated with the old conventional herbicides applied at rates between 0.8 and 1.5 pounds per acre, again mostly in combinations. Combinations of one or two old herbicides, tank mixed with one or two of the new, low-dose products are increasingly popular. Several new combination herbicide product formulations have been introduced in the last two years in an attempt by manufacturers to make it easier for farmers to purchase and apply two of the company's products, thereby broadening the range of weeds that are adequately controlled – and perhaps competing with or fitting into a RR soybean program.

In studying the impacts of RR soybeans on average herbicide rates, it is important to be careful in assuring that valid comparisons are being made. Throughout this report, remember that –

- Comparisons should not be based on aggregate state or national level data that encompass all sorts of changes in the combinations of soybean herbicides used, individual product rates of application per acre, and the number of times each active ingredient is applied.

- Average total herbicide use in RR planted fields should be compared to average total herbicide use in fields in the same general region planted to conventional varieties in the same year. Comparisons across years can be misleading and are often not valid because of different levels of weed pressure and weather patterns.

- Comparisons should be made within tillage systems; no-till system rates should not be compared to conventional/conservational tillage rates, and vice versa. Resolution is lost when herbicide use data are averaged across all tillage systems.

Table 1.1 reports basic trends in soybean herbicide use per acre across all soybean acres in 1992, 1995, and 1998, as well as use on those acres grown with conventional/ conservation tillage systems and under no-till systems. Throughout this chapter, data on herbicide use in 1995 represents pre-RR soybeans and 1998 data reflects changes after the widespread adoption of RR soybeans, which were planted on about 38 percent of soybean acres that year.

Table 1.1. Trends in U.S. Herbicide Use in Soybean Production Systems

	1992	1995	1998
All Soybeans			
Area Planted (1,000 acres)	52,830	51,840	65,745
Average Number of Herbicides Applied	2.4	2.8	2.2
Total Pounds Active Ingredient Applied	1.16	1.13	1.17
Conventional / Conservation Tillage Systems			
Area Planted (1,000 acres)	45,911	36,879	47,457
Average Number of Herbicides Applied	2.3	2.6	2.1
Total Pounds Active Ingredient Applied	1.13	1.03	1.11
Glyphosate Applied	.56	.56	.92
No-Till Systems			
Area Planted (1,000 acres)	6,919	14,961	18,288
Average Number of Herbicides Applied	2.8	3.3	2.6
Total Pounds Active Ingredient Applied	1.33	1.36	1.32
Glyphosate Applied	.63	.61	.96

Source: USDA Economic Research Service Special Tabulation Number 1, based on soybean field-level sample data collected as part of the "Agricultural Chemicals Usage" survey (National Agricultural Statistics Service, 1999).

Under conventional/conservation tillage, the number of herbicide active ingredients applied rose from 1992 to 1995, but then dropped in 1998 as a result of the emergence of RR soybeans. The trend in total pounds applied fluctuated modestly, dropping about 10 percent from 1992 to 1995 and then increasing in 1998 as RR soybeans gained popularity, and with them higher rate herbicide systems.

In 1998 farmers required on average 3.3 different herbicides in no-till systems to manage weeds (bottom four lines Table 1.1). Again, the introduction of RR soybeans made it possible for farmers to apply markedly fewer herbicides on the average acre. But because moderate-rate glyphosate applications were typically replacing applications of two lower-dose products, there was almost no change in the total pounds applied from 1995 to 1998.

Tables 1.2 and 1.3 show the number of acres, average number of herbicide active ingredients, and differences in herbicide use on fields planted to conventional, non-GMO varieties in contrast to herbicide-tolerant varieties in 1998, the third year of RR soybean variety sales. Not surprisingly, RR soybeans account for the majority of herbicide-tolerant acres treated, about 87 percent.

The first table presents these data on fields managed with conventional/ conservation tillage and the second table covers land planted using the no-tillage system.

Farmers managed weeds on RR soybean fields under conventional/conservation tillage with more than one less herbicide active ingredient; applications of Roundup took the place of applications of two or more other herbicides (Table 1.2).

Table 1.2. Herbicide Use in Fields Planted to Conventional and Herbicide-Tolerant Soybean Varieties in Conventional / Conservation Tillage Production Systems, 1998

	Number Acres Treated (1,000 acres)	Number of Active Ingredients	Pounds Applied Per Acre
Conventional Soybean Varieties	28,340	2.5	1.10
RR Varieties	16,452	1.3	1.14
Other Herbicide-Tolerant Varieties	2,665	2.5	0.97

Source: USDA Economic Research Service Special Tabulation Number 1, based on soybean field-level sample data collected as part of the "Agricultural Chemicals Usage" survey (National Agricultural Statistics Service, 1999).

The tables confirm that no-tillage systems are more herbicide dependent than conventional/conservation tillage systems and that heightened reliance on herbicides is consistent in both fields planted to conventional and herbicide tolerant varieties. No-till systems require about one additional herbicide active ingredient in contrast to conventional/conservation tillage systems and between 10 percent and 20 percent more total herbicide per acre.

The tables also show that at this aggregate level, the average pounds of herbicides applied per acre on RR soybean fields exceed the average pounds applied on conventional varieties by a small margin. But such aggregate data mask more significant differences which will become clear when we turn to assessment of the distribution of herbicide use rates at the field level.

Table 1.3. Herbicide Use in Fields Planted to Conventional and Herbicide-Tolerant Soybean Varieties in No-Till Production Systems, 1998

	Number Acres Treated (1,000 acres)	Number of Active Ingredients	Pounds Applied Per Acre
Conventional Soybean Varieties	8,359	3.6	1.27
RR Varieties	9,042	1.7	1.36
Other Herbicide-Tolerant Varieties	888	3.7	1.42

Source: USDA Economic Research Service Special Tabulation Number 1, based on soybean field-level sample data collected as part of the "Agricultural Chemicals Usage" survey (National Agricultural Statistics Service, 1999).

B. Detailed Examination of Soybean Herbicide Use in 1998

Many people have claimed that Roundup Ready soybeans reduce herbicide use. Such claims can be true in a narrow and selective – and therefore biased -- sense. For example, many RR soybean fields in the first two years of adoption required only a single application of Roundup at a rate of about 0.75 pounds per acre. Many other conventional soybean fields were treated with combinations of moderate to high-dose herbicides at an average combined rate of about 1 pound per acre. In such a comparison, one can conclude accurately that RR soybeans reduced average per acre herbicide use by perhaps 25 percent. But such a selective comparison is no more or less valid than comparing the same RR soybean fields with other fields treated with very-low dose herbicides accounting for a total of just 0.2 pounds of active ingredient – one-fifth the rate on RR soybean acres.

The lack of rigor in analyzing herbicide use rates in RR soybean systems has helped enable the high degree of "spin" that has permeated public discussion of the benefits of RR and other herbicide-tolerant soybean varieties. To develop fair and credible comparisons, we developed a methodology based on actual herbicide use in a specific field, drawing on raw data collected by USDA through its annual pesticide use surveys.

Our estimates count all active ingredients applied on RR soybean acres in contrast to all herbicides applied on fields planted to conventional varieties and other herbicide-tolerant varieties. In two of three special tabulations, we also disaggregated herbicide use data by conventional/ conservation tillage systems in contrast to no-till, to avoid the confusion that arises from mixing tillage systems in a comparison of herbicide use.

To take the analysis one step further, we describe herbicide use along the distribution of soybean fields arrayed by the intensity of herbicide use. This special tabulation allows comparisons of total herbicide use at the low and high ends of this distribution, the first such analysis we know of based on a large sample of actual field-level soybean herbicide use data.

To generate the data in this section comparing field level herbicide use in 1998, we commissioned the USDA's Economic Research Service (ERS) to carry out three special tabulations, since the raw NASS data file needed to carry out such an analysis is not available to the public. The special tabulations were done and paid for by Benbrook Consulting Services under the ERS's "Policy and Procedures on Providing Special Tables or Analyses." Our agreement was dated March 10, 2000 and the data were provided April 11, 2000.

The analysis and results reported here are just a first step in what should be a series of in depth assessments of per acre herbicide use patterns in conventional versus herbicide-tolerant soybean varieties. The same sorts of detailed, field-by-field comparisons are also needed to settle controversy over whether *Bt* corn has reduced insecticide use. Unfortunately, the USDA has not yet carried out such detailed

assessments of herbicide use on RR versus conventional fields, despite the intense interest in the results. The special tabulations we commissioned demonstrate how important – and revealing – such in depth analyses will be.

Herbicide Use on Conventional and RR Soybeans

In selected states and nationally, Table 1.4 summarizes total herbicide use measured in total pounds of active ingredient applied per acre in 1998. The tabulation was structured to separate out all survey sample points (fields) planted to a herbicide tolerant variety, in contrast to a conventional variety. Within these two groups of sample points, acres where further divided into those treated with Roundup and those not treated.

Acres Planted Nationally, there was a total of 65.7 million acres of soybeans planted in 1998.

Of these, 36.7 million, or 55.8 percent, were planted to conventional varieties. About 5.2 million were treated with glyphosate applied pre-plant or at-plant as a burndown herbicide. Most of these acres were planted using the no-till system.

RR varieties accounted for 25.4 million acres, or 38.8 percent of total soybean acres planted. There were 3.5 million acres of other herbicide tolerant varieties planted, or about 5.4 percent of total soybean acreage.

Number of Herbicides Applied There were on average 2.2 herbicide active ingredients applied on 65.7 million soybean acres nationwide. On Roundup Ready acres, there were 1.4 products applied, while on other herbicide tolerant varieties, 2.8 products were applied on average.

On conventional varieties on which no glyphosate was applied, 2.7 active ingredients were used, whereas on conventional acres treated with glyphosate, 3.2 herbicides were used on average. Accordingly, the RR system makes it possible for farmers to reduce the average number of herbicides applied by about one-half. Put another way, the ability to apply Roundup post-emergence over soybeans makes it possible for farmers to eliminate applications of about 1.5 other herbicides.

Pounds of Herbicide Applied On the average soybean acre nationwide, farmers applied 1.17 pounds of herbicide active ingredient in 1998. The average glyphosate rate on the 30.7 million soybean acres treated was 0.92 pounds. This rate includes both acres of RR and conventional soybeans.

On Roundup Ready soybeans, the average total amount of herbicides applied was 1.22 pounds per acre and on average, 1.0 pound of glyphosate was applied. On other herbicide tolerant varieties, the average was 1.06 pounds, about 13 percent less.

On acres planted to conventional soybean varieties and not treated with glyphosate, there were an average 1.08 pounds of herbicide applied, 11.4 percent less than on Roundup Ready acres.

Table 1.4. Herbicide Use on Conventional and Herbicide-Tolerant Soybean Varieties in the U.S. and Selected States, 1998

Location	Percent Area Treated	Average Number of Herbicides Applied	All Herbicides Rate Per Acre
National			
Conventional Varieties, no glyphosate applied	47.9%	2.7	1.08
Conventional Varieties, glyphosate applied	8.0%	3.2	1.45
RR Varieties	38.8%	1.4	1.22
Other herbicide-tolerant varieties	5.4%	2.8	1.06
Arkansas			
Conventional Varieties, no glyphosate applied	50.5%	2.5	0.92
RR Varieties	25.5%	1.5	1.50
Iowa			
Conventional Varieties, no glyphosate applied	60.4%	2.4	1.08
RR Varieties	33.8%	1.3	1.40
Illinois			
Conventional Varieties, no glyphosate applied	35.2%	2.8	1.15
RR Varieties	49.9%	1.4	1.09
Minnesota			
Conventional Varieties, no glyphosate applied	71.6%	2.2	0.84
RR Varieties	25.3%	1.2	1.15
Missouri			
Conventional Varieties, no glyphosate applied	57.0%	3.1	1.34
RR Varieties	33.9%	1.4	1.23

Source: USDA Economic Research Service Special Tabulation Number 2, based on soybean field-level sample data collected as part of the "Agricultural Chemicals Usage" survey (National Agricultural Statistics Service, 1999).

National level data masks significant differences across regions. In Arkansas, herbicide use on RR soybeans exceeded conventional soybeans by 63 percent. In Iowa, the margin was 30 percent and in Minnesota, 37 percent. Yet in Missouri and Illinois, herbicide use on conventional soybeans exceeded use on RR varieties by 9 percent and 5.5 percent. Table 1.5 summarizes these differences across all major soybean producing states.

Table 1.5. Differences in Herbicides Applied per Acre Between Roundup Ready and Conventional Soybean Varieties in States Surveyed by USDA, 1998

State	Total Herbicides Per Acre		Ratio RR Soybean Herbicide Rate to Conventional Rate
	RR Soybean	Conventional	
Arkansas	1.50	0.92	1.63
South Dakota	1.42	0.96	1.48
Minnesota	1.15	0.84	1.37
Tenessee	1.78	1.37	1.30
Iowa	1.40	1.08	1.30
Indiana	1.06	0.93	1.14
Ohio	1.17	1.04	1.13
All Surveyed States	1.22	1.08	1.13
Mississippi	1.42	1.38	1.03
Kentucky	1.12	1.09	1.03
Louisiana	1.35	1.34	1.01
Illinois	1.09	1.15	0.95
Kansas	0.85	0.92	0.92
Missouri	1.23	1.34	0.92
North Carolina	1.14	1.30	0.88
Nebraska	1.24	1.45	0.86
Michigan	1.03	1.47	0.70

Source: USDA Economic Research Service Special Tabulation Number 2, based on soybean field-level sample data collected as part of the "Agricultural Chemicals Usage" survey (National Agricultural Statistics Service, 1999).

Distribution of Herbicide Rates

Our third special tabulation of field-level soybean herbicide use data in 1998 focuses on the distribution of herbicide application rates from those farms using the least herbicide to those applying the most. This analysis was run across all soybean acres, as well as all acres broken into conventional/conservation tillage acres versus no-till acres.

Three distributions were developed from field level sample data: one ranked by total pounds of herbicides applied from most pounds to least; a second based on number of herbicide active ingredients applied; and the third, pounds of glyphosate applied from most to least.

Each of the three distributions was divided into 10 deciles representing an equal number of soybean acres. The values at the 90th decile for total pounds of herbicide applied, for example, can be interpreted to mean that 90 percent of soybean acres were treated with herbicides at or below the reported rate; or conversely, that 10 percent of the soybeans were treated at a higher rate than the value reported in the 90^{th} decile.

Table 1.6 shows the distribution of herbicide use rates under conventional/ conservation tillage, representing 47.5 million of the 65.7 million acres of soybeans planted in 1998. At the high end of the distribution, 10 percent of acres were treated with 1.987 or more pounds. At least three herbicides were applied on the 10 percent of the acres treated with the highest number of herbicides. Fields in the top decile were treated with at least 1.13 pounds of Roundup.

At the low-end of the distribution, 10 percent of soybean acres under conventional tillage were treated with 0.058 pounds or less of herbicide, most likely one of the very low dose sulfonylurea or imidazolinone products. These data on total herbicide use make very clear the enormous range in per acre herbicide use -- soybean fields at the top-end of the distribution were treated with at least 34 times more herbicide than fields in the low-end decile.

Table 1.7 presents the same data on no-till acres. There were close to 8 times more total herbicides applied at the top end of the no-till distribution in contrast to the bottom-end. The difference between the top and bottom deciles is less than in the case of conventional/conservation tillage because all no-till acres require a typically intensive pre-plant application of herbicides.

Table 1.6. Distribution of Soybean Herbicide Use Patterns in 1998, Conventional and Conservation Tillage Systems

Indicator of Use	← Lower Herbicide Use Higher Herbicide Use →								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Total Pounds Herbicide Applied Per Acre	0.06	0.47	0.75	0.75	0.95	1.13	1.31	1.57	1.99
Number of Herbicides Applied	1	1	1	1	2	2	2	3	3
Pounds Glyphosate Applied Per Acre	0	0	0	0	0	0	0.75	0.75	1.13

Source: USDA Economic Research Service Special Tabulation Number 3, based on soybean field-level sample data collected as part of the "Agricultural Chemicals Usage" survey (National Agricultural Statistics Service, 1999).

Table 1.7. Distribution of Soybean Herbicide Use Patterns in 1998, No Till Systems

Indicator of Use	← Lower Herbicide Use Higher Herbicide Use →								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Total Pounds Herbicide Applied Per Acre	0.31	0.60	0.75	0.94	1.13	1.34	1.50	1.73	2.34
Number of Herbicides Applied	1	1	1	1	2	3	3	4	5
Pounds Glyphosate Applied Per Acre	0	0	0	0.50	0.75	0.75	0.75	1.13	1.50

Source: USDA Economic Research Service Special Tabulation Number 3, based on soybean field-level sample data collected as part of the "Agricultural Chemicals Usage" survey (National Agricultural Statistics Service, 1999).

In Tables 1.6 and 1.7, fields treated with Roundup, including of course all RR soybean acres, are clustered in the top three (conventional tillage) and top six deciles (no-till systems). In the no-till table, fields under an intensive Roundup program (90th decile) were treated with at least 1.5 pounds of glyphosate, at least three times more than fields in the 40th decile. Roundup use in the 40th decile almost certainly reflects a low-dose of glyphosate added to tank mixes for pre- or at plant applications on fields planted to conventional varieties. (This rate is far below the minimum needed on RR soybean fields, hence the applications must be made pre- or at planting on conventional varieties).

Table 1.8 and 1.9 summarize the differences by tillage system in herbicide use rates along the distribution of all ranked soybean fields. This is done by calculating the

ratio of the minimum total pounds of herbicide pounds applied in the top decile compared to the maximum pounds applied in the bottom decile. The next two lines in Tables 1.8 and 1.9 encompass herbicide use in the top two deciles compared to the bottom two, and the bottom two lines cover the top three deciles compared to the bottom three.

For conventional/conservation tillage soybeans, the ratios in Table 1.8 fall from 34 to 3 to 1.7 in comparing the top 10^{th} decile to the bottom 10^{th}, the top 20^{th} to the bottom 20^{th}, and the top 30^{th} to bottom 30^{th}. Since RR soybean acres are concentrated in the top three deciles in both distributions and are largely absent from the bottom three, these comparisons provide a rough approximation of the differences in herbicide use along the distribution of all soybean fields ranked by total pounds of herbicide applied.

The differences in total herbicide use in the top deciles compared to the bottom deciles are less dramatic on fields planted using no-till systems (Table 1.9) compared to conventional/conservation tillage (Table 1.8). This is because all no-till fields have to be treated with a relatively heavy pre- or at plant burndown application, as well as during the growing season. Still, 7.5 times or more herbicide are used in the top decile compared to the bottom and twice or more in the 70^{th} decile compared to the 30^{th}.

Much more accurate and interesting results could be generated by calculating mean herbicide use across all sample points (fields) falling within the deciles and by carrying out the same sort of distributional analyses for soybean fields planted to conventional versus herbicide-tolerant varieties. The cost to commission such more extensive and complicated tabulations was, however, prohibitive.

Table 1.8. The Relative Intensity of Herbicide Use Along the Distribution of All Soybean Fields Surveyed in 1998, Conventional / Conservation Tillage Systems

Decile	Number of Active Ingredients	Total Pounds Applied per Acre	Ratio Top Decile to Bottom Decile Total Pounds Applied Per Acre
Top 10%	3	1.99	34.3
Bottom 10%	1	0.06	
Top 20%	3	1.57	3.3
Bottom 20%	1	0.47	
Top 30%	2	1.31	1.7
Bottom 30%	1	0.75	

Source: USDA Economic Research Service Special Tabulation Number 3, based on soybean field-level sample data collected as part of the "Agricultural Chemicals Usage" survey (National Agricultural Statistics Service, 1999).

Table 1.9. The Relative Intensity of Herbicide Use Along the Distribution of All Soybean Fields Surveyed in 1998, No Till Systems

Decile	Number of Active Ingredients	Total Pounds Applied per Acre	Ratio Top Decile to Bottom Decile Total Pounds Applied Per Acre
Top 10%	5	2.34	7.5
Bottom 10%	1	0.31	
Top 20%	4	1.73	2.9
Bottom 20%	1	0.60	
Top 30%	3	1.50	2.0
Bottom 30%	1	0.75	

Source: USDA Economic Research Service Special Tabulation Number 3, based on soybean field-level sample data collected as part of the "Agricultural Chemicals Usage" survey (National Agricultural Statistics Service, 1999).

C. Representative Major Herbicide Use Programs in 2000 and 2001 on RR Soybeans and Conventional Varieties

Significant shifts have already occurred in herbicide use on fields planted to Roundup Ready soybeans since their commercial introduction in 1996. Several factors have driven the changes, most triggered in one way or another by the remarkable commercial success of this technology.

Rapid increases in the acreage planted to RR soybeans forced other herbicide manufacturers to cut their prices and look for ways to formulate their existing herbicide product lines into combination products that were compatible with RR soybeans and convenient for the farmers planting them. Today, there are more than a dozen new combination products on the market specifically marketed for RR soybean producers.

As noted above, the popularity of RR soybean systems forced other herbicide companies to lower prices, making it possible for farmers to make an additional spray or add in a new active ingredient without increasing per acre herbicide costs. The generally lower prices today have encouraged heavier reliance on herbicides. In the early 1990s in states like Iowa, many farmers were open to sustainable agriculture systems and methods, largely because of potential to lower per acre cash costs. The costs of seed plus herbicides were growing the fastest of any major category of production input (Benbrook, 2000). Up through about 1993 the acreage of row crops planted under ridge till and/or treated with banded (in the row only) applications of herbicides in conjunction with mechanical cultivation had risen steadily.

The introduction of several new soybean herbicides in the mid-1990s, and then RR soybeans in 1996, quickly refocused most farmers on largely herbicide-dependent systems. In the last few years, the percent of soybean acres managed under multitactic weed management systems with lessened reliance on herbicides has shrunk back to a fraction of the level in 1993. The falling cost per acre of herbicide-dependent systems and the simplicity of the RR system have been the major reason why.

Resistance and Weed Shifts

Well before the introduction of RR soybeans, it was known that heavy reliance on any single herbicide, class of herbicides, or weed management tactic in a given field will trigger a shift in the composition of weeds commonly found (Ghersa et al., 1994). Roundup Ready soybean systems are no exception.

Recurrent applications of glyphosate in many corn-soybean production regions in the U.S. have brought about a shift in weed species (Owen, 1999; Hartzler, 1999). Waterhemp, velvetleaf, horseweed, yellow nutsedge and nightshade are more common and difficult to control, especially in RR fields. (Scientists at Iowa State University have done an excellent job tracking and explaining the factors giving rise to weed shifts. These factors include the time period over which weed seeds in the soil are able to germinate and how susceptible a weed is to glyphosate. For more information see http://www.weeds.iastate.edu/).

Some weeds have developed resistance to glyphosate (Horstmeier, April 2001) and others are displaying rising tolerance (Hartzler, 1999). As a result, farmers are compensating by adding additional herbicide active ingredients into their control programs, while others are increasing the rates of Roundup applied in the hope of getting ahead of even tough to control weeds. The dramatic price reductions in recent years have accommodated increased rates without much, if any increase in per acre herbicide expenditures. (For more on resistance to herbicides, see the "International Survey of Herbicide Resistant Weeds" accessible at http://www.weedscience.org/in.asp; or several items on Ag BioTech InfoNet at http://www.biotech-info.net/herbicide-tolerance.html#soy).

As a result of weed shifts and slipping efficacy of Roundup in the control of some weeds, most farmers growing RR soybeans now apply one to three additional active ingredients. An effective pre-plant burndown application is critical in no-till and conservation tillage systems to give RR soybeans a good jump on weeds. Cost-conscious farmers typically include about 0.5 pounds of 2,4-D in a pre-plant or at plant tank mix. The 2,4-D helps manage broadleaf weeds. Another product is typically applied to provide some residual grass control. Popular products include pendimethalin, imazethapry, and treflan. Table 1.10 displays just a few of the popular combinations of products used on conventional and RR soybean varieties. Among post-application programs on conventional soybeans, farmers applying Classic and Assure use only 0.08 pounds of active ingredient at a cost of $24.51 per acre.

Table 1.10 Popular Soybean Herbicide Control Programs Used on Conventional and Roundup Ready Soybean Varieties Under Conventional Tillage, 2000-2001

Type of Program	Herbicides	Pounds applied per Acre	Average Cost ($/lb ai or ae)	Cost per Acre
Conventional Varieties				
PRE	Command (clomazone)	0.65	21.00	13.65
	Choransulam-methyl (FirstRate)	0.04	494.60	19.78
Total program		**0.69**		**$33.43**
POST	Classic (Chlorimuron-ethyl)	0.02	762.30	15.25
	Assure II (quizalofop-ethyl)	0.06	154.40	9.26
Total program		**0.08**		**$24.51**
PPI/POST	Treflan (trifluralin)	0.75	6.90	5.18
	Basagran (bentazon)	0.75	19.30	14.48
Total program		**1.5**		**$19.65**
PPI / POST	Prowl (pendimethalin)	0.85	6.30	5.36
	Pursuit (Imazethapyr)	0.04	248.50	9.94
Total program		**0.89**		**$15.30**
Roundup Ready Varieties				
PRE/POST	2,4-D	0.5	3.00	1.50
	Glyphosate (Roundup Ultra)	0.75	12.80	9.60
	Dual or Lasso (metolachlor or alachlor)	1.6	13.70	21.92
Total program		**2.35**		**$33.02**
PRE/POST	Glyphosate (Roundup Ultra)	0.75	12.80	9.60
	Prowl (pendimethalin)	0.8	6.30	5.04
	Glyphosate (Roundup Ultra)	0.75	12.80	9.60
Total program		**2.30**		**$24.24**
POST	Glyphosate (Roundup Ultra)	0.75	12.80	9.60
	Glyphosate (Roundup Ultra)	0.56	12.80	7.17
Total program		**1.31**		**$16.77**
PRE/POST	2,4-D	0.5	3.00	1.50
	Glyphosate (Roundup Ultra)	0.75	12.80	9.60
Total program		**1.25**		**$11.10**
POST	Glyphosate (Roundup Ultra)	0.75	12.80	9.60
		0.75		**$9.60**

Notes: In "POST" systems, all herbicides are applied at or after planting. All herbicides are applied before planting in "PRE" systems. Herbicides are worked into the soil before planting in a "PPI" (pre-plant incorporated) system.

The cost of this very-low dose program actually compares favorably to a Roundup-based program with RR varieties when the technology fee is counted as a cost of the herbicide program. Under the best of circumstances, farmers in 2001 might get through the season with two applications of Roundup, the second at a reduced rate. This program will cost about $23.00 with the technology fee ($16.77 plus about $6.00 for the technology fee) and results in the application of 1.3 pounds of active ingredient. A typical PRE/POST program in RR soybeans would include two applications of glyphosate and a single application of pendimethalin. This program costs about $30.00 with the technology fee and results in application of about 2.3 pounds of herbicides.

While the "best case scenario" RR system requires less herbicide than the highest-rate conventional systems, it is clear that most RR soybeans will be sprayed with about 0.5 pounds more herbicide than most conventional soybeans in crop season 2001.

There will be exceptions, but the number of conventional, non-GMO acres sprayed with very low rates of herbicides will almost certainly exceed the number of RR soybean acres treated with less than 1.0 pound of herbicides.

D. Roundup Ready Soybean Herbicide Use Reduction Claims by Monsanto and USDA are Deceiving

In the last few years Monsanto, the biotechnology industry, and the U.S. Department of Agriculture have claimed repeatedly that Roundup Ready soybeans reduce herbicide use. As the data cited above shows clearly, this is certainly not the case on the majority of RR soybean acres grown in the United States, nor is it true "on average." Plus, extensive evidence shows that the effectiveness of the Roundup applied in the RR soybean system is slipping. This technology is, to a large extent, a victim of its own success.

In the first few years of commercial RR soybean use, many farmers got through the season with a single application of just one herbicide – Roundup. Between 0.75 and 1.1 pounds of glyphosate active ingredient were applied per acre, clearly not a low rate compared to sulfonylurea or imidazolinone weed management systems requiring between 0.1 and 0.3 pounds of herbicide active ingredient, but about mid-range across all systems. Four years later almost no farmer can get by with just one application of Roundup.

Farmers who applied one application of Roundup on RR beans in 1996 and 1997 are likely to be making two or three in crop year 2001. They will also be applying at least one, and more likely two additional herbicide active ingredients. Some are applying three additional herbicides. Why? Again, the evidence is voluminous, consistent and compellingly clear. Heavy reliance on Roundup in RR soybeans has --

- Triggered significant weed species shifts, favoring those weeds that are not as sensitive to Roundup, as well as those that tend to emerge over extended periods of time, so that some weeds emerge outside the window of time when Roundup applications deliver good control.

- The emergence of resistance in some of the nation's most common, tough to control soybean weeds like waterhemp, coupled with modest to moderate slippage in efficacy in a growing number of other weeds. Slipping efficacy increases the number of escapes and then requires higher application rates to knock back the escaped weeds when a subsequent application is made.

Despite these widely recognized facts, it is still common to encounter claims by Monsanto, the biotechnology industry, the U.S. Department of Agriculture (USDA), and others that RR soybeans reduce herbicide use. How can major companies and a government agency get away with making such claims? It takes a certain amount of care coupled with a little misinformation and a major dose of missing information.

A November 30, 1999 Monsanto document entitled "Chemical Reduction Benefits of Biotechnology Crops" was prepared for the press, political leaders, and PR purposes (Monsanto, 1999). It states that --

> "In a Sparks Commodities, Inc. study conducted in 1996 and 1997, in-season herbicide use in Roundup Ready soybean fields was shown to be less than ***traditional soybean varieties*** by an average of 26 percent and 22 percent respectively, over four regions of the United States." [Emphasis added]

No doubt Sparks Commodities had access to data supporting the above-stated conclusion. Still, this statement falls somewhere between misleading and dishonest. Clearly, the statement leaves much to the imagination. Unless a person knows a lot about contemporary soybean herbicide use patterns, one would conclude from such a statement that RR soybeans make it possible for farmers to reduce per acre herbicide use by about one-quarter on a per acre basis.

But that is not what the statement actually says. Note that the reduced herbicide use claim is based on a comparison to ***"traditional soybean varieties."*** Even this caveat is less than truthful. What Sparks Commodities and Monsanto really mean is that herbicide use in RR soybean fields was 22 to 26 percent less than a selected number of other fields producing conventional soybean varieties.

But not any random set of fields producing conventional soybean varieties, nor even the average field producing conventional varieties; they really mean, in all likelihood, fields planted to conventional varieties on which farmers primarily used conventional, high-dose rate herbicides. Only on such fields would there be a 22 to 25 percent reduction in herbicide use. They surely do not mean the approximate 20 percent (see above data) of fields treated predominantly with combinations of modern, low-dose herbicides applied at a rate of 0.5 pounds or less of herbicide active ingredient per acre (see Table 1.6).

Nor do they mean the approximately 25 percent of RR soybean fields under a Roundup-only program that will, according to Monsanto itself, likely require three

applications of Roundup at 32 ounces per acre to achieve satisfactory control (Dunn, 1998). Such a program in 1999 cost about $30.00 per acre for the herbicide and resulted in application of 3.0 pounds of Roundup.

The above data show clearly that much more herbicide is applied to the average RR soybean field compared to the 20 percent of fields reliant largely on low-dose products. Indeed, when compared to soybean weed management systems utilizing the really low-dose herbicides, Roundup Ready fields require more than 10 times the herbicide. But it is inappropriate and misleading to pass off such a selective comparison as representative of the average field, at least in the view of this analyst.

USDA Claims

An April 2000 USDA report, *Genetically Engineered Crops for Pest Management in U.S. Agriculture: Farm-Level Effects* (Fernandez-Cornejo, et al., 2000), makes the following statement in its abstract –

> "...increases in adoption of herbicide-tolerant soybeans led to small but significant increases in yields, no changes in returns, and significant decreases in herbicide use."

It is widely recognized that adopters of RR soybeans are large-scale operators who are aggressive managers. The land they farm is, on average, more productive than land managed by those who are slower to try new technologies. Hence, it is no surprise that on average, RR soybean adopters harvested more bushels per acre than non-adopters. They harvested more bushels before RR varieties hit the market, as well (Economic Research Service, 1999; Miller, 2000; Fernandez-Cornejo et al., 2000; Duffy, 1999). It is unfounded to equate the slightly higher soybean yield on GMO acres as a sign of a "yield advantage," or evidence suggesting the absence of a genetic yield drag.

The slightly higher yields are largely driven by differences in management skills and soil productivity. A third factor is the likely higher degree of herbicide injury on some farms where conventional soybeans are planted and farmers apply modern, low-dose herbicides without adequate care in calibrating equipment to assure that maximum, safe application rates for a given farm's soils are not exceeded.

The claimed "significant decrease in herbicide use" is based on two measures. The first – a decline in herbicide acre-treatments -- has nothing to do with pounds applied. The second measure is the net change in conventional and herbicide-tolerant application rates over time, taking into account the increase in average rates of glyphosate use per acre and the decrease in use of other herbicides. But as explained in more detail below, this comparison encompasses so many changing variables that it is impossible to tell exactly what it means.

The claim founded on reduction in herbicide acre-treatments is fleshed out in a summary article published in Agricultural Outlook, one of USDA's most widely read publications. The August 2000 article states that –

> "In 1998, adopters of herbicide-tolerant soybeans accounted for the largest share of the difference in acre-treatments (54 percent [decrease]), with most of the reduction occurring in the Heartland region." (*Agricultural Outlook*, August 2000, page 13-14).

This decline is the result of one of the major advantages of RR soybeans – the simplicity of the RR system and its reliance on a single herbicide for multiple weed management challenges. But it has little to do with changes in the pounds of herbicides applied per acre, since different soybean herbicides are sprayed at such different rates. In the USDA report, the authors state correctly –

> "...since average application rates vary across pesticide active ingredients, the net effect of substituting one for another may be an increase or decrease in total pounds used." (*Agricultural Outlook*, August 2000, page 15).

On the key question of whether herbicide-tolerant soybeans reduced herbicide use, the August 2000 article states –

> "...as adoption of herbicide-tolerant soybean varieties increased from 7 to 45 percent, the average annual rate of glyphosate application increased from 0.17 pounds per acre in 1996 to 0.43 pounds per acre in 1998, while all other herbicides combined dropped from about 1 pound per acre to 0.57 pounds per acre. That translates into a decline of nearly 10 percent in the overall rate of herbicide use on soybeans during that period." (*Agricultural Outlook*, August 2000, page 14-15).

This statement does ***not*** mean that RR soybeans reduce per acre herbicide use by nearly 10 percent. It refers to aggregate estimates of total herbicide use, not clean comparisons of an acre planted to RR soybeans in contrast to conventional varieties planted on similar soils under the same tillage system. It also does not correct for the timeliness of field operators and the quality of management, nor differences in soil quality.

It also mixes together RR soybeans and two other types of herbicide-tolerant varieties – those engineered to be resistant to the very low-dose sulfonylurea herbicides and those resistant to the low-moderate dose imidazolinone herbicides. While these other herbicide-tolerant varieties account for a relatively small share of total herbicide-tolerant acres, they clearly improve the average performance of all herbicide tolerant varieties in terms of reducing average rates of herbicide use.

Last, the above USDA estimate of a nearly 10 percent decline includes a myriad of changes in herbicide use on the approximate 50 percent of acres not planted to any herbicide tolerant variety.

If reducing the pounds of herbicides applied per acre was among the important goals shaping U.S. soybean weed management systems in the 1990s, the introduction of RR soybean varieties was a major step backwards. It is clear that the average pounds of herbicides applied on soybeans in the U.S. would have dropped by far more than 10 percent from 1995 through 1998 in the absence of RR soybeans. This is because it is likely that the majority of farmers planting RR soybeans – typically top-notch, aggressive managers – would have planted either other varieties tolerant to much lower dose herbicides, or conventional beans in conjunction with mixtures of low- and moderate dose products, or mixtures of low-dose and higher dose "standbys."

With the wide selection of today's very competitively priced low-dose soybean herbicides, farmers could easily reduce average application rates to no more than 0.5 pounds per acre, if there were incentives offered to do so. This would cut average soybean herbicide rates about two-thirds from today's levels and would indeed be a major accomplishment. It also would probably not prove sustainable nor would it prove beneficial because of other agronomic and environmental problems associated with use of many of today's low-dose herbicides.