Sustainability and the Roundup Ready® Soybean System: An Analysis of Economic and Environmental Issues

A Study Prepared for Monsanto

by

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Funded by Monsanto's Public Policy Institute and
Sustainable Development Center of Excellence

March 31, 1998

Acknowledgements

This report was funded by the Public Policy Institute and the Sustainable Development Center of Excellence, Monsanto Company. It is based in part on an earlier draft report by John Schnittker, Ph.D., and Bruce Babcock, Ph.D. Thanks are due to Barry Ryan for data analysis and research assistance and to Judy Berdahl for editorial assistance and manuscript preparation.

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Runge received his Ph.D. in agricultural economics at the University of Wisconsin, a M.A. in economics as a Rhodes Scholar at Oxford University, and a B.A. at University of North Carolina - Chapel Hill. He has served on the staff of the House Committee on Agriculture and as a Science and Diplomacy Fellow of the American Association for the Advancement of Science working at U.S. Agency for International Development (AID). on food aid and trade. He served as Chairman of the Governor's Farm Crisis Commission in 1985, structuring recommendations on farm credit and land markets in Minnesota.

In 1986, he was awarded an International Affairs Fellowship by the Council on Foreign Relations and was selected as a Bush Foundation Leadership Fellow and Ford Foundation Economist in 1987. He spent 1998 as a special assistant to the U.S. Ambassador to the General Agreement on Trade and Tariffs (GATT) in Geneva, Switzerland, working under Trade Representative and former Agriculture Secretary Clayton Yuetter. In 1988, he was named a member of the Council on Foreign Relations in New York and, in 1990, a Fulbright Scholar for study in Western Europe. From 1988 to 1991, he served as the first director of the Center for International Food and Agricultural Policy at the University of Minnesota. He continues as subdirector in charge of Commodities and Trade Policy of the Center. During 1991, he research ed European trade reform and environmental policy as a Fulbright Research Fellow, visiting at the Universities of Padova (Italy) and Dijon (France). He has consulted for the Organization for Economic Cooperation and Development in Paris, the Ford Motor Company, Monsanto Company, the Environmental Defense Fund, the World Wildlife Fund, the World Resources Institute and the Wilderness Society. He currently serves as an advisory member of the Board of Directors of Land O'Lakes and the Board of the Great Plains Institute for Sustainable Development.

Runge's publications include four books and a wide range of articles concentrating on trade and natural resources policy. In 1992, Iowa State University Press published *Reforming Farm Policy: Toward a National Agenda*, which he wrote with Willard W. Cochrane. In 1994, the Council on Foreign Relations published *Freer Trade, Protected Environment: Balancing Trade Liberalization and Environmental Issues.* He is married and lives in Stillwater, Minnesota with his wife, daughter and son. He owns and operates a small farm in Wisconsin.

Richard S. Fawcett, Ph.D. is an independent consultant specializing in agriculture-environmental issues and is the Farm Journal Staff Environmental Specialist. He is a nationally recognized expert on ground and surface water protection and agricultural sustainability issues. He is known for his ability to take complicated technical issues and interpret them using an understanding of agriculture and farmers to develop practical solutions to environmental concerns. Fawcett holds a Ph.D. in Agronomy from University of Illinois and a B.S. in Agronomy from Iowa State University.

Prior to founding his consulting firm in 1989, he was a Professor and Extension Weed Control Specialist for 13 years at Iowa State University, following three years on the staff at the University of Wisconsin as an Assistant Professor of Agronomy. While at Iowa State, he was also responsible for Extension programs to reduce contamination of ground and surface water by pesticides and conducted research on groundwater contamination mechanisms. He was the Coordinator of Extension Pesticide-Water Quality Programs and was responsible for developing best management practices to protect ground and surface water.

Fawcett's research areas have included weed control systems for conservation tillage, degradation mechanisms of herbicides in soil, mechanisms of groundwater contamination by pesticides and nitrates including point sources, macropore flow and the impact of tillage on pesticide leaching potential. He is a member of the U.S. Congress Office of Technology Assessment Scientific Advisory Panel on Groundwater and has served as a consultant to the U.S. Environmental Protection Agency. Fawcett is a member of the Scientific and Policy Board of the American Council on Science and Health and is past member of the Boards of Directors of the Weed Science Society of America, the North Central Weed Science Society and the Iowa Fertilizer and Chemical Association. He also maintains a direct involvement in farming as a stockholder in his family's grain and livestock farm operations near West Branch, Iowa.

Awards recognizing Fawcett's accomplishments include: American Soybean Association - ICI Americas Research Award 1981; Iowa State University Excellence in Research and Extension Award 1982; Weed Science Society of America Outstanding Extension Worker Award 1985; Midwest Agricultural Chemicals Association Educators Award 1988; Iowa Fertilizer and Chemical Association Man of the Year Award 1989.

Glossary

Absorption The process of taking in or making part of an existing whole.

Adjuvant An ingredient that modifies the action of the principal ingredient.

Adsorption The adhesion in an extremely thin layer of molecules (as of gases, solutes, or liquids) to the surface of solid bodies or liquids with which they are in contact.

ALS inhibitors Compounds inhibiting acetohydroxyacid synthase (AHAS, acetolactate synthase, ALS E.C. 4.1.318), a key enzyme in the biosynthetic pathway of branched-chain amino acids.

Arthropod Any of a phylum of invertebrate animals (e.g., insects, arachnids and crustaceans) that have a jointed body and limbs, usually a chitinous shell mounted at intervals and the brain dorsal to the alimentary canal and connected with a ventral chain of ganglia.

Avian species Species that are of, relating to, or derived from birds.

Bioassay The determination of relative strength of a substance by comparing its effect on a test organisms with that of standard preparation.

Biodiversity Number and variety of organisms; includes genetic diversity, species diversity and ecological diversity. Also called biological diversity.

Biotechnology The application of living organisms to develop new products. The science that makes it possible to transfer a gene for a specific trait from one species to another. The ability to take a specific gene from one cell and place it in another cell where it is expressed. Also called genetic engineering.

Carbon dioxide (CO_2) A colorless gas that is released by animal respiration, fermentation and the burning of hydrocarbons. It is taken up by plants in photosynthesis.

Carbon emissions Release of carbon as a gas – carbon dioxide (CO_2) – into the atmosphere. Occurs when hydrocarbons are burned, carbon in the soil is oxidized and humans respire.

Carbon fixation The process of converting inorganic carbon into a more usable form for organisms (e.g., carbon dioxide).

Carbon sequestration The act of holding carbon in the soil and preventing its fixation and release as CO_2 into the atmosphere. It includes the processes of humification, aggregation, translocation within the pedosphere and pedogenic carbonates that keep carbon in balance with the soil.

Carbon sink A portion of the biosphere in which carbon dioxide is absorbed faster than it is released, and which tends to keep carbon bound up for relatively long periods of time.

Conservation tillage (a.k.a. conservation-till) Any tillage and planting system that covers more than 30 percent of the soil surface with crop residue, after planting, to reduce soil erosion by water. Where soil erosion by wind is the primary concern, any system that maintains at least 1,000 pounds per acre of flat, small grain residue equivalent on the surface throughout the critical wind erosion period. No-till, ridge-till and mulch-till are types of conservation tillage.

Conventional tillage (a.k.a. conventional-till) Any tillage type that leave less than 15 percent residue cover after planting, or less than 500 pounds per acre of small grain residue equivalent throughout the critical wind erosion period. Generally involves plowing or intensive tillage.

Crop canopy The top layer of crop foliage that shades the under-branches and area between plants, is the key to successful weed management in soybeans. Canopy closure allows the crop to act as its own herbicide by shading out weeds. Narrower rows of plants improves the opportunity for faster canopy closure.

Crop injury The stunting of crop growth resulting from herbicide applications.

Crop safety The absence of crop response from agri-chemical applications (e.g., fertilizers, herbicides, insecticides, surfactants).

Cultivation A mechanical weed control method that uses a cultivator to remove weeds in between the rows of the crop.

Disking A tillage procedure used to smooth and level the field after plowing.

DNA Deoxyribonucleic acid, a compound of deoxyribose (a sugar), phosphoric acid and nitrogen bases. Each DNA molecule consists of two strands in the shape of a double helix. DNA is responsible for the transfer of genetic information from one generation to the next.

Emergence the stage between germination and reproductive development in plant growth. Plant appears one to two weeks after planting depending on soil and air temperatures.

Erosion The physical removal of soil particles by a transport agent such as rain water and wind.

Foreign matter Weed seeds and other crop debris found in grain.

Fungicide An agent that destroys fungi that cause plant disease or inhibits growth of fungi.

Gene A portion of a chromosome that contains the hereditary information for the production of the protein.

Genetic engineering The technique of removing, modifying or adding genes to a living organisms. Also called gene splicing, recombinant DNA (rDNA) technology, or genetic modification.

Germination Emergence of primary root system, elongation of the hypocotyl (stem between the cotyledon and the primary root) to the surface.

Glyphosate The active ingredient in Roundup herbicide, kills plants and bacteria by inhibiting the biosynthesis of essential amino acids.

Herbicide Any substance used to kill unwanted plants. Herbicides work in different ways – some sterilize the soil, others prevent seeds from germinating, others kill plants once they have germinated.

In-crop application Any application made to plants between first emergence and flowering (e.g., herbicides, insecticides, nutrients).

In-crop weed control Removal of weeds with herbicides or cultivation during the growing phase of a crop as opposed to in the pre-plant burndown or tillage stages.

In-season weed control Weed control that occurs after planting through harvest. Includes pre-plant soil-incorporated herbicides and preemergence herbicides, and postemergence herbicides that control weeds throughout the growing season.

Insecticide Any natural or synthetic compound used to kill insects.

Integrated Pest Management (IPM) A sustainable, ecological approach to pest control that includes biological, mechanical and chemical means. IPM maximizes natural pest control factors and minimizes the need for measures such as chemical insecticides. The goal of IPM is to produce a healthy crop in an economically efficient and environmentally sound manner.

Invertebrate species Any species lacking a spinal column.

Moldboard plowing A type of tillage method that turns the soil over at 12 to18 inches down in the soil profile and eliminates surface residue.

Mulch-till A type of conservation tillage that disturbs the soil prior to planting but leaves at least 30 percent of the soil surface covered with crop residue. Tillage tools such as chisels, field cultivators, disks, sweeps and blades are used. Weed control is accomplished with herbicides and/or mechanical cultivation.

Non-selective herbicide Generally controls or kills all plants. Roundup herbicide is an example.

No-till A type of conservation tillage that leaves the soil undisturbed expect for planting and nutrient injection. Planting or drilling is accomplished in narrow seedbed or slots created by coulters, row cleaners, disk openers, in-row chisels or rototillers. Weed control is accomplished primarily by herbicides. Cultivation may be used for emergency weed control.

Pesticide A substance used to kill or to control harmful or destructive organisms. Insecticides, herbicides, germicides, fungicides and rodenticides are all types of pesticides.

Plant biotechnology The addition of selected traits to plants to develop new plant varieties. An extension of traditional plant breeding, it allows for the transfer of a greater variety of genetic information in a more controlled manner.

Postemergence herbicide Herbicide applied over the top of the crop after emergence of weeds and the crop.

Post-direct spraying Herbicide applied with farm implements that keeps the herbicide off the crop.

Preemergence herbicide Herbicide applied to the soil prior to the emergence of a specified weed or crop.

Pre-harvest application Any application made when all pods have lost their color.

Pre-plant application Any application of herbicide made before crop emergence.

Pre-plant burndown An application of herbicide to remove weeds from a field before planting; used in place of mechanical weed control (e.g., tillage, cultivation).

Product treatment acres The total number of herbicide applications on each acre. It is calculated by multiplying the number of applications by number of acres receiving treatment.

Reduced-till A type of conventional tillage that leaves 15 to 30 percent residue cover after planting or 500 to 1,000 pounds per acre of small grain residue equivalent throughout the critical wind erosion period.

Ridge-till A type of conservation tillage that leaves the soil undisturbed except for planting, nutrient injection and cultivation to build the ridges. Planting is completed in a seedbed prepared on ridges with sweeps, disk openers, coulters or row cleaners. Residue is left on the surface between the ridges. Weed control is accomplished with herbicides and/or mechanical cultivation. Ridges are rebuilt during cultivation.

Roundup® herbicide A non-selective herbicide that is a preemergence herbicide when weeds are controlled as part of a pre-plant burndown, or is a postemergence herbicide when combined with Roundup Ready soybeans.

Roundup Ready® soybeans Soybeans with an added glyphosate-tolerant enzyme (CP4-EPSPS), which allows Roundup herbicide to kill weeds by inhibiting EPSPS (enolpyruvylshikimate-phosphate-synthase). The Roundup Ready soybean plant makes two different EPSPSs: one plant EPSPS (inhibited by Roundup) and one bacterial CP4-EPSPS (not inhibited by Roundup). The Roundup-tolerant CP4-EPSPS thus allows the plant to continue making amino acids, even after application of Roundup.

Roundup Ready soybean system Roundup Ready soybeans combined with Roundup herbicide.

Selective herbicide Herbicide that controls or kills some plant species but does not damage others. Selectivity is based on the crop such that it is not damaged by the herbicide, but certain weed species are controlled or killed.

Soil compaction The act of compressing the soil horizons with heavy farm equipment, decreasing porosity and tilth.

Soil erosion The loss or removal of soil material by a transport process, such as water erosion (e.g., rill erosion, gully erosion, sheet erosion) and wind erosion.

Soil-incorporated herbicide Preemergence herbicide applied to the soil and then tilled to mix the herbicide into the soil before seeding.

Soil moisture The amount of water held in the voids between soil particles as determined by weight and volume.

Soil organic matter Material derived from decaying organic molecules of natural organisms (the remains of plants and of animals), primarily composed of carbon. Organic matter is essential for healthy soil. It may be partially recognizable, as in rough compost or leaves on their way to becoming leaf mold. When fully broken down, organic matter in soils is called humus.

Soil porosity A measure of the percentage of soil volume occupied by voids between soil particles.

Soil structure A description of soil particle aggregates or compound particles.

Soybean (*Glycine max)* A type of legume that provides protein and oil. Soybeans are used in oil products (e.g., glycerol, refined soyoil, soybean lecithin), whole soybean products (e.g., tofu), and soybean protein products (e.g., soy flour concentrates and isolates, soybean meal).

Sustainability The ability of the environment to function indefinitely without going into a decline from the overuse of natural systems (such as soil, water, air, biological diversity) that maintain life (also called environmental sustainability).

Sustainable agriculture An economically viable method of agriculture that emphasizes stewardship (long-term rather than short-term returns), soil conservation and integrated pest management to ensure that there is no degradation of the environmental quality or the capacity of the system to continue to produce.

Sustainable development Economic growth and activities that do not deplete or degrade the environmental resources upon which present and future economic growth depends.

Tilth A state of aggregation of soil especially in relation to its suitability to grow crops. Soil tilth is a traditional term referring to the structural tendency of a soil to fracture. Soil structure can be more technically defined in terms of form, stability and resilience. Form refers to the architecture of the soil, including the arrangement of solid and void space, affected by climate, tillage, biological processes and management. Soil stability refers to the capacity of a soil to retain its form when exposed to stresses such as tillage, rain and root growth. Soil resiliency refers to the soil's ability to recover a structural form when these stresses are removed (Kay, 1995, p. 7).

Toxicity Of, relating to, or caused by a poison.

Transgenic plant A plant that has been modified genetically.

Introduction

Three forces are dramatically redefining U.S. soybean production. First, soybeans are one of the fastest growing commodity markets for U.S. producers, especially in the North Central United States, making their economic importance critical to future agricultural production. Second, changes in soybean tillage practices promise major improvements in environmental benefits, consistent with trends toward more sustainable agriculture. Third, after decades of research, biotechnology now is helping to bring soybean production and sustainability together in a single system. The purpose of this investigation was to compile and review the current literature related to the Roundup Ready® soybean system, conservation tillage and sustainability.

Monsanto Company's Roundup Ready soybean was the first genetically engineered product in the soybean market. When coupled with Roundup® herbicide, the two products form the Roundup Ready soybean system. Roundup Ready soybeans are genetically improved to be tolerant to Roundup herbicide. This means farmers can apply Roundup herbicide over the top of Roundup Ready soybeans from emergence through flowering, providing excellent weed control, crop safety and no yield reduction without detrimental effects to the soybean plant.

Due to the superior weed control, the Roundup Ready soybean system is highly compatible with conservation tillage methods, especially no-till. When combined with an integrated, whole-farm strategy, the Roundup Ready soybean system promotes both economic and environmental sustainability for American farmers and the non-farm public.

This report is divided into three main sections. Chapter I considers the changing character of U.S. soybean production, examining trends in policy, production, environmental quality and the role of sustainability. Chapter II focuses on the agronomics and production economics of the Roundup Ready soybean system, including herbicide use and weed control. It examines costs of production, fuel, time and labor inputs, yield advantages and the rate at which farmers are adopting the Roundup Ready soybean system. Chapter III presents a detailed assessment of the five environmental factors related to no-till:

- soil quality and soil conservation;
- water quality and quantity,
- wildlife habitat,
- carbon sequestration, and
- fuel use and farm equipment emissions.

In relation to these five environmental factors, the environmental profile of the Roundup Ready soybean system is examined in both conventional and conservation tillage. Finally, the key findings are summarized in the Summary and Conclusions section.

Chapter I. Sustainability and Soybean Production

Sustainable Agriculture

The remarkable gains in U.S. food and fiber output in the twentieth century have been driven by new technologies. Despite this success, some agricultural practices have stressed the environment. As the twenty-first century approaches, a new philosophy is emerging from the agricultural community – a focus on economic and environmental strategies that promote long-term sustainability. Sustainability is the ability of the environment to function indefinitely without overusing natural systems – soil, water, air, biological diversity – that maintain life (Raven et al. 1995). Applying the ideas of sustainability to agriculture requires integrated economic and environmental approaches. The success of sustainable agriculture[1] will be driven by innovative technologies that are profitable to farmers and society as well as environmentally sound.

Within a sustainable agriculture framework, farmers will reap financial rewards from new technologies in proportion to their environmental stewardship. Future farm programs will tie economic incentives to improvements in conservation methods. This unity can be achieved, in part, through methods that optimize productivity and profits while reducing inefficient farm practices. Research into new biotechnologies in agriculture is focused on products that enhance productivity and reduce negative environmental effects. Over time, this approach will strengthen

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[1] The 1990 Farm Bill, The Food, Agriculture, Conservation and Trade Act of 1990, P.L. 101-624, Title XVI, Subtitle A, Section 1603 defines sustainable agriculture as "an integrated system of plant and animal production practices having a site-specific application that will, over the long term: (A) satisfy human food and fiber needs; (B) enhance environmental quality and the natural resource base upon which the agricultural economy depends; (C) make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and

the financial performance of the agricultural sector and will produce valuable new technologies based on the principles of life science. Overall, both private and public benefits will be reaped as the agricultural system moves toward greater sustainability.

The Roundup Ready soybean system furthers this sustainability strategy for both economic and environmental reasons. Economically, the system reduces production costs by reducing inputs while optimizing yields, making it highly attractive on economic grounds alone. These economic benefits are enriched by the inherent environmental benefits of the system, which are further enhanced when the Roundup Ready soybean system is used in conjunction with conservation tillage (CT). First, soil erosion is reduced and soil qualities – organic matter, tilth, moisture – are improved. Second, due to reduced runoff, the system improves water quality and conserves water quantity. Third, wildlife habitat is improved, especially for aquatic and avian species. Fourth, this system helps the soil sequester carbon dioxide (CO_2). Fifth, the Roundup Ready soybean system reduces fuel use and mitigates CO_2 emissions from farm equipment, which has implications for global climate change.

Agricultural Policy

There is strong reason to believe that farm and environmental policies, as well as global market trends, are reinforcing the growth in the soybean market in general, and the Roundup Ready soybean system in particular. The Federal Agriculture Improvement Reform (FAIR) Act of 1996 broke new ground by removing restrictions on the farmer’s ability to plant a diversity of crops. FAIR promotes soybean farming by reducing the advantage of planting only a few crops

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controls; (D) sustain the economic viability of farm operations; and (E) enhance the quality of life for such as corn, wheat and cotton. This legislation also set new soybean marketing loan rates, which secured the price of soybeans.[2] This legislative support and subsequent strong market prices have increased the incentive to plant soybeans, as well as to rotate soybeans more often with crops such as corn, wheat or cotton. There is evidence that these policies are having an immediate effect. In crop year 1997, total soybean acreage was estimated at 70.9 million acres (28.7 million hectares), up 10 percent from 1996 and 13 percent from 1995 (USDA, NASS, 1997).

Another aspect of the 1996 "Freedom to Farm" law is the changes to the Conservation Reserve Program (CRP). Many CRP contracts will not be renewed and stricter environmental criteria will be applied to new CRP contracts. Much of the land coming out of the CRP, especially in the North Central states, will be planted with soybeans because they require less investment than corn and therefore pose less of a risk on unpredictable land. Figure 1 shows the geographic orientation of the CRP as of December 1996. The concentration of enrolled lands is in the North Central states, where soybean production is centered. The schedule of CRP contract expirations will lead most of the enrolled lands to come out of the program in the next three years (USDA, ERS, 1997), thus further encouraging soybean production.

Bringing CRP lands back into production will require that conservation compliance be retained at the same time that weeds are controlled. Although deep plowing can control weeds, it

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farmers and society as a whole."

[2] The FAIR Act establishes nonrecourse marketing loans for crop years 1996 through 2002. Rather than being frozen at $4.92/bushel, ($180.76/MT), the national average soybean loan will be set at 85 percent of average prices received by farmers in the previous five years, disregarding the high and low years. This improves the safety net for soybean growers. The soybean loan has a floor of $4.92/bushel ($180.76/MT) (the rate for 1995) and a cap of $5.26/bushel ($193.25/MT). The average loan rate established for 1996 crop soybeans of $4.97/bushel ($182.60/MT) will increase to the $5.26/bushel ($193.25/MT) cap for the 1997 crop (*Soy Stats*, 1997, p. 37).

threatens conservation gains. In contrast, conservation tillage in combination with Roundup herbicide provides both effective weed control with minimal conservation loss. As a result, the Roundup Ready soybean system is an ideal fit for former CRP acres. The Roundup Ready soybean system controls weeds without deep plowing, cuts cost, reduces erosion and enhances other environmental benefits.

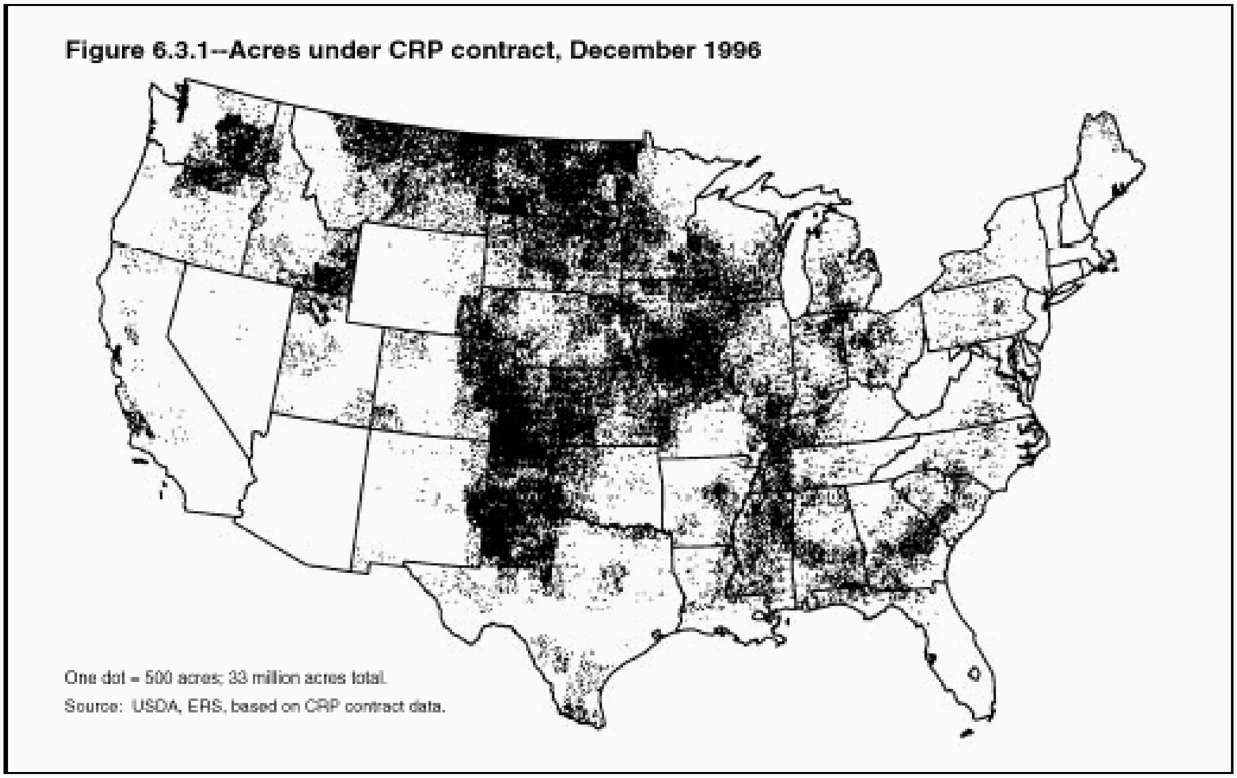

Figure 6.3.1--Acres under CRP contract, December 1996

One dot = 500 acres; 33 million acres total.
Source: USDA, ERS, based on CRP contract data.

Figure 1: Acres under CRP Contract, December 1996
Source: USDA, July 1997, p. 288.

Soybean Production: Economic Statistics and Trends

Despite the significance of U.S. farm and environmental policy, production possibilities for soybeans are driven primarily by prices in the world market. Soybeans (*Glycine max*) provide more of the world vegetable oil and protein than any other single crop. Soybean oil is used directly in margarine, salad dressings and cooking oil for human consumption. Lecithin, a soybean byproduct, is a primary constituent of many industrial coatings, pharmaceuticals and foods. Soybean meal is used primarily as a high protein feed ingredient. One bushel (0.027 metric tons) of soybeans equals 60 pounds (27.2 kilograms)and translates into 10.7 pounds (4.85 kilograms) of crude soy oil, or 47.5 pounds (21.5 kilograms) of soybean meal, or 39 pounds (17.7 kilograms) of soy flour. A metric ton of soybeans equals 36.74 bushels. Soybeans accounted for 27 percent of world vegetable oil consumption (including marine or fish oils) in 1996. In the global protein meal market, soybeans are even more dominant, accounting for 62 percent of world protein meal consumption in 1996 (*Soy Stats*, 1997, pp. 29; 33).

More soybeans are grown in the United States than anywhere else in the world. The area devoted to soybeans accounts for more than 20 percent of all U.S. crop acres. Changes in soybean technology thus affect a vast land area, with major economic and environmental consequences. The area planted to soybeans in the United States grew to 71.4 million acres (29 million hectares) by 1979, then slowly declined to 57.8 million acres (23.4 million hectares) in 1990[3]. Since then, acreage has climbed steadily, reaching 70.9 million acres (28.7 million hectares) in 1997. (See Figure 2). The largest area planted to soybeans by state in 1996 was in

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[3] see web site -- www.ag.uiuc.edu/~stratsoy/96soystats/pg4.html

Illinois, followed by Iowa, Minnesota, Indiana and Ohio. Areas planted by state in 1996 are summarized in Table 1.

Table 1: Soybean Area Planted, Yield, Production, Value ($ million) 1996

State	Area Planted Thousand Acres (Thousand Hectares)		Yield Bushels per Acre (Metric Tons per Hectare)		Production Million Bushels (Million Metric Tons)		Value $ Million
Alabama	330	(134)	34.0	(2.28)	11	(0.29)	72
Arkansas	3,550	(1,437)	32.0	(2.15)	112	(3.05)	795
Delaware	220	(89)	35.0	(2.35)	8	(0.21)	52
Florida	35	(14)	32.0	(2.15)	1	(0.03)	7
Georgia	400	(162)	26.0	(1.75)	10	(0.28)	67
Illinois	9,900	(4,008)	40.5	(2.72)	399	(10.86)	2,773
Indiana	5,400	(2,186)	38.0	(2.55)	204	(5.54)	1,395
Iowa	9,500	(3,846)	44.0	(2.96)	416	(11.32)	2,827
Kansas	2,050	(830)	37.0	(2.49)	74	(2.01)	492
Kentucky	1,200	(486)	38.0	(2.55)	45	(1.22)	309
Louisiana	1,100	(445)	33.0	(2.22)	36	(0.97)	262
Maryland	490	(198)	37.0	(2.49)	18	(0.48)	123
Michigan	1,650	(668)	28.5	(1.92)	47	(1.27)	313
Minnesota	5,950	(2,409)	38.0	(2.55)	224	(6.10)	1,513
Mississippi	1,800	(729)	31.0	(2.08)	54	(1.48)	385
Missouri	4,100	(1,660)	37.0	(2.49)	150	(4.08)	1,004
Nebraska	3,050	(1,235)	45.0	(3.02)	135	(3.69)	914
New Jersey	120	(49)	37.0	(2.49)	4	(0.12)	31
N. Carolina	1,250	(506)	29.0	(1.95)	35	(0.95)	233
N. Dakota	850	(344)	29.0	(1.95)	25	(0.67)	167
Ohio	4,500	(1,822)	35.0	(2.35)	157	(4.28)	1,076
Oklahoma	300	(121)	26.0	(1.75)	7	(0.20)	50
Pennsylvania	290	(117)	40.0	(2.69)	11	(0.31)	76
S. Carolina	560	(227)	25.0	(1.68)	14	(0.37)	95
S. Dakota	2,700	(1,093)	34.0	(2.28)	91	(2.47)	590
Tennessee	1,200	(486)	35.0	(2.35)	40	(1.10)	282
Texas	290	(117)	26.0	(1.75)	7	(0.19)	48
Virginia	500	(202)	34.0	(2.28)	16	(0.44)	111
Wisconsin	920	(372)	37.0	(2.49)	32	(0.88)	214

Source: *Soy Stats*, 1997, pp. 5, 7, 9, and 13.

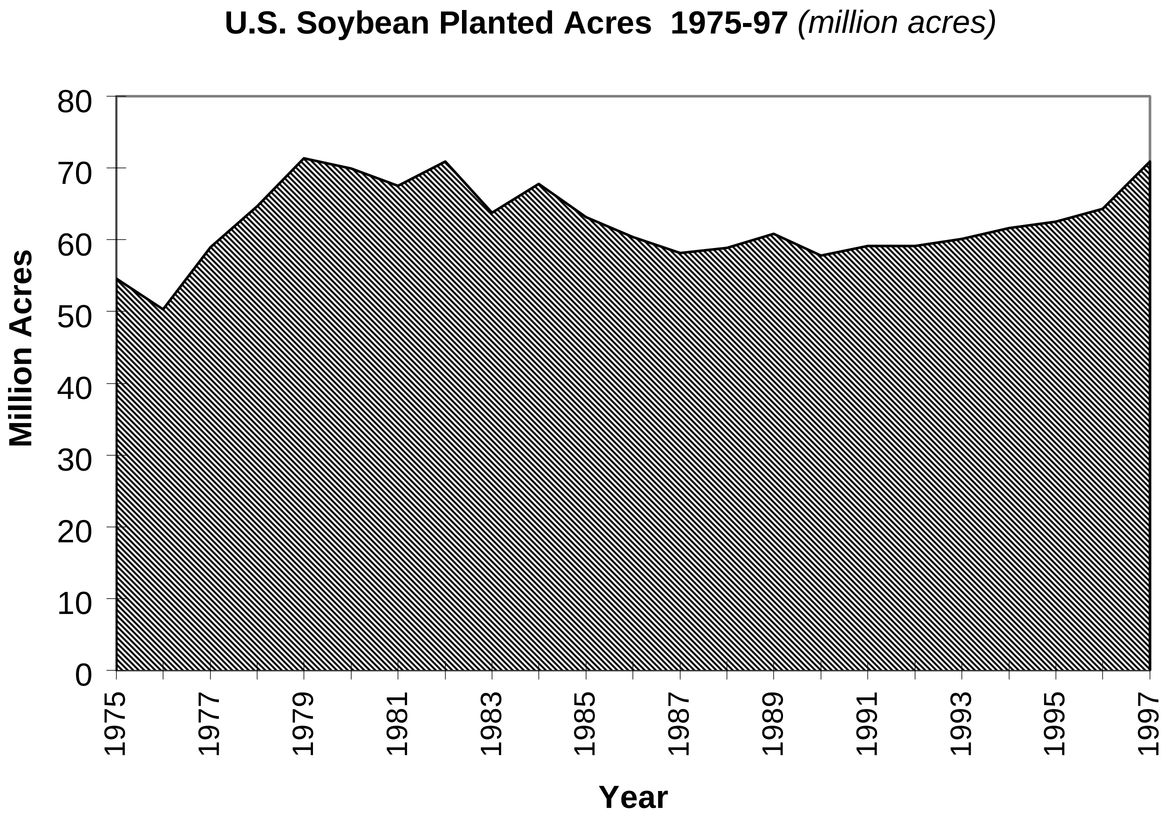

Figure 2: U.S. Soybean Planted Acres 1975-97 (million acres)
Source: USDA, June 30, 1997.

Based on area planted and average yields, the following five states dominate production levels: Iowa, Illinois, Minnesota, Indiana and Ohio, respectively. When considered in value terms, in 1996, state revenue from soybeans ranged from $1.0 to $2.8 billion in Ohio, Indiana, Minnesota, Illinois and Iowa. These figures, together with soybean value by state for 1996, are shown in Table 1.

The geographic distribution of soybeans is heavily concentrated in the North Central region,[4] including Iowa, Minnesota, Illinois, Indiana, Ohio, Nebraska, and Missouri. Other key states are found in the Delta region – Arkansas, Mississippi and Louisiana. Much of the production in the North Central states occurs in regular rotation with corn. In Iowa, some combination of corn and soybean rotations account for 95 percent of soybeans grown. Altogether, soybean production in the states of Illinois, Indiana, Iowa, Minnesota, Missouri, Nebraska, Ohio and South Dakota account for more than three-quarters of total U.S. production (USDA, NASS, 1996).

In response to global demand, U.S. soybean exports have shown steady gains since the late 1980s driven by increases in the demand for animal protein. Soybeans are exported directly, as meal and oil, and exported indirectly when U.S. meat fed with soybeans is sent overseas. A 1997 report by the University of Tennessee Agricultural Policy Analysis Center (APAC) estimated that by 1998, more than 10 percent of U.S. soybean exports will be through exported U.S. livestock (*Policy Matters*, 1997). Direct soybean export statistics thus understate the trade-dependency of the industry and its role in adding value to exports of livestock products. Table 2 shows direct U.S. soybean exports from 1971-1996, which reached 895 million bushels (24.36 million metric tons) in 1996. The top U.S. soybean export customers in that year were led by the European Union, Japan, Taiwan and Mexico. Preliminary forecasts for 1997/98 estimate U.S. soybean exports at 960 million bushels (26.13 million metric tons). Global trade for major

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[4] The North Central Region has different geographical boundaries depending on which group is defining it. The major focus of this report will be on Iowa, Minnesota, North Dakota, South Dakota, Nebraska, Missouri, Illinois, Indiana, Ohio and Wisconsin. However, the report draws from various studies that overlap in their regional definitions, in order to achieve as broad a base of data and analysis possible.

oilseeds and products is expected to rise from 1,723 million bushels (46.9 million metric tons) in 1996 to 1,848 million bushels (50.3 million metric tons) in 1997/98, with soybeans trading at 1,396 million bushels (38 million metric tons) for 1997/98 (USDA, ERS, 1997), although the financial crisis in Asia may dampen some of this demand.

Table 2: U.S. Soybean Exports 1971-1996

Million Bushels **(Million Metric Tons)**								
1971	417	(11.35)	1981	929	(25.29)	1991	684	(18.62)
1972	479	(13.04)	1982	905	(24.63)	1992	770	(20.96)
1973	539	(14.67)	1983	743	(20.22)	1993	589	(16.03)
1974	421	(11.46)	1984	598	(16.28)	1994	838	(22.81)
1975	555	(15.11)	1985	740	(20.14)	1995	851	(23.16)
1976	564	(15.35)	1986	757	(20.60)	1996	895	(24.36)
1977	701	(19.08)	1987	802	(21.83)	1997	960	(26.13)
1978	739	(20.11)	1988	527	(14.34)			
1979	875	(23.82)	1989	623	(16.96)			
1980	724	(19.71)	1990	557	(15.16)			

Source: *Soy Stats*, 1997, p. 22.

Chapter II. Agronomics and Production Economics

In 1996, Monsanto Company commercialized Roundup Ready soybeans after nine years of testing. In the first year, seed was available for one million acres (404,700 hectares). By 1997, seed was available for eight to 10 million acres (3.2 to 4.1 million hectares) and was planted on 15 percent of all U.S. soybean acres, indicating rapid adoption of the Roundup Ready soybean system by farmers. The reasons for the popularity of this product lie in its agronomics and economics (i.e., assured yields and cost-effective weed control) (Carlson, et al., 1997; Delannay, et al., 1995), with seed availability being the only limiting factor for adoption (Fritsch and Killman, 1997). A number of factors affect the agronomic and economic success, as well as the sustainability, of the Roundup Ready soybean system. These factors include tillage practices, weed control, yields and production costs.

Tillage Practices in Soybean Production

Tillage encompasses a range of farm practices, equipment and implements that disturb the soil for field preparation, planting and weed control. Soybeans are grown in a variety of tillage systems depending on the location and topography of the farm, soil quality and weather conditions. The two major categories of tillage are conventional and conservation tillage. There are key distinctions between these two tillage systems. The Conservation Technology Information Center (CTIC) provides the following definitions:

Conservation tillage -- Any tillage and planting system that covers more than 30 percent of the soil surface with crop residue, after planting, to reduce soil erosion by water. Where soil erosion by wind is the primary concern, any system that maintains at least 1,000 pounds per acre of flat, small grain residue equivalent on the surface throughout the critical wind erosion period. No-till, ridge-till and mulch-till are types of conservation tillage.

- *No-till* – The soil is left undisturbed from harvest to planting expect for planting and nutrient injection. Planting or drilling is accomplished in narrow seedbed or slots created by coulters, row cleaners, disk openers, in-row chisels or rototillers. Weed control is accomplished primarily by herbicides. Cultivation may be used for emergency weed control.

- *Ridge-till* – The soil is left undisturbed from harvest to planting except for nutrient injection. Planting is completed in a seedbed prepared on ridges with sweeps, disk openers, coulters or row cleaners. Residue is left on the surface between the ridges. Weed control is accomplished with herbicides and/or mechanical cultivation. Ridges are rebuilt during cultivation.

- *Mulch-till* – The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps and blades are used. Weed control is accomplished with herbicides and/or mechanical cultivation.

Conventional tillage has 30 percent or less residue left on the field after planting. *Reduced-till* (15-30 percent) and *conventional-till* (0-15 percent) are included.

- *Reduced-till* – Tillage types that leave 15 to 30 percent residue cover after planting or 500 to 1,000 pounds per acre of small grain residue equivalent throughout the critical wind erosion period.

- *Conventional-till* – Tillage types that leave less than 15 percent residue cover after planting, or less than 500 pounds per acre of small grain residue equivalent throughout the critical wind erosion period. Generally involves plowing or intensive tillage. (CTIC 1996)

In the case of soybeans, the CTIC reported that more than half of the planted acres of full season U.S. soybeans[5] were in some form of conservation tillage in 1997. In soybeans, conservation tillage accounted for 51.9 percent – 33.8 million acres (13.68 million hectares) – of U.S. full-season soybean acres in 1997 with no-till accounting for 27.5 percent – 17.9 million acres (7.24 million hectares) (Table 3). The remaining half of soybean acreage was in conventional tillage – 21 percent with 15-30 percent residue and 28 percent with 0-15 percent residue. Figure 3 shows the 1997 percentage of U.S. soybean acres by tillage type and Figure 4 shows the number of acres in conservation tillage versus conventional tillage from 1990 to 1997.

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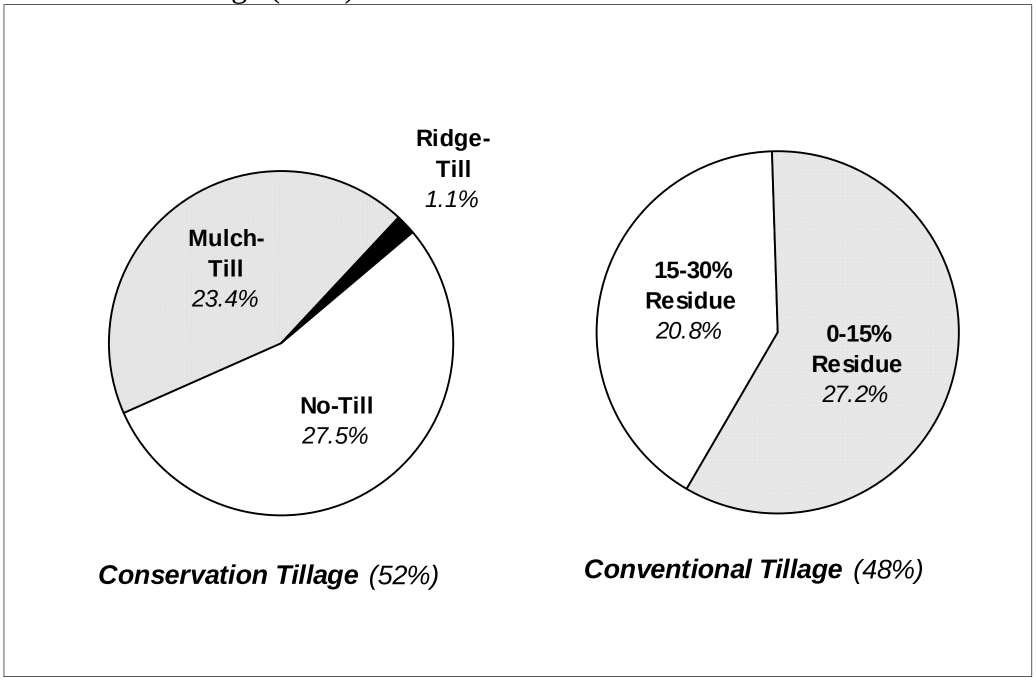
[5] Soybeans are generally divided into full season and double cropped. In 1996, of the 65 million planted acres (26.3 million hectares) of U.S. soybeans, 5.9 million acres (2.4 million hectares) were double cropped and the remainder full season. Full season soybeans are grown in the North Central region; double-cropped soybeans are grown in the South.

Table 3: Soybean Tillage Practices in the United States 1990-1997

	1990	1991	1992	1993	1994	1995	1996	1997
	(million acres)							
Total Soybean Acres*	55.39	56.15	55.34	55.12	57.11	58.74	60.60	65.14
Conservation Tillage Acres	**15.04**	**17.10**	**21.54**	**26.02**	**26.47**	**28.56**	**29.67**	**33.82**
No-till	3.03	4.66	8.22	12.01	13.85	15.88	16.16	17.90
Mulch-till	11.16	11.59	12.50	13.20	11.89	12.01	12.96	15.22
Ridge-till	0.85	0.85	0.82	0.81	0.73	0.67	0.55	0.70
Conventional Tillage	**40.35**	**39.05**	**33.80**	**29.10**	**30.64**	**30.18**	**30.93**	**31.32**
Reduced (15-30%)	13.95	14.85	13.39	12.36	12.88	12.62	12.73	13.58
Conventional (<15%)	26.40	24.20	20.41	16.74	17.76	17.56	18.20	17.74

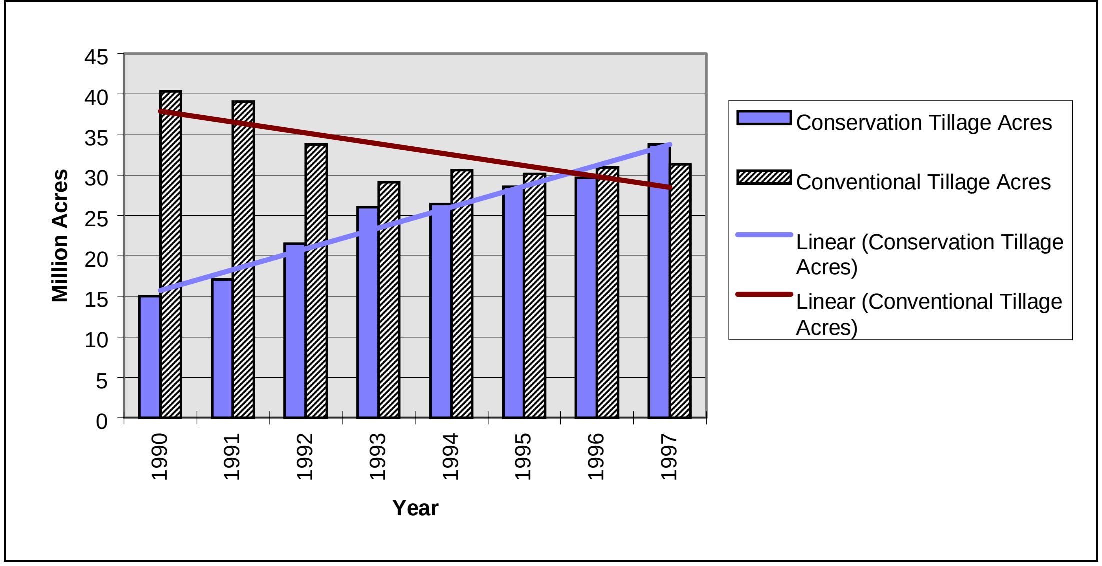
* full season cropping Source: CTIC, National Residue Crop Management Survey, 1997; @ www.ctic.purdue.edu

Figure 3: United States: Percent of US Soybeans by Tillage Type -- Conservation Tillage versus Conventional Tillage (1997)



Source: CTIC, National Residue Management Survey 1997, www.ctic.purdue.edu

Figure 4: United States: 1997 Full-Season Soybeans – Conservation Tillage versus Conventional Tillage (million acres)



Source: CTIC, National Residue Management Survey 1997, www.ctic.purdue.edu

Steady gains in conservation tillage, especially no-till, are recognized as a major shift in farm-level production technology (see USDA, 1997 pp. 155-174). CTIC reported in October 1997 that U.S. conservation tillage increased in crop year 1997 by six million acres (2.43 million hectares), based on U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) surveys (CTIC, 1997c). No-till acres increased most in the states of Illinois, Iowa, Indiana, Ohio, Missouri and Nebraska. The major effect of this shift in tillage practices is that farmers rely less on tillage and mechanical cultivation to manage crops. From an agronomic perspective, no-till has complementary effects, which conserve resources, resulting in systemic changes in whole-farm resource conservation.

In conservation tillage, plant residues (e.g., stems, stalks and leaves) are left on the surface of the field after harvest. The crop residue protects the soil against erosion by holding the soil in place with the remaining root systems and by providing a roughness factor to dissipate water flowing across the field surface. The decomposition of plant residue adds organic matter to the soil. Increased organic matter contributes to soil fertility, decreases soil compaction and improves soil structure. A larger aggregate soil size (tilth) characterizes soil with high organic matter, thus enhancing crop rooting ability. This type of soil has a desirable mix of air and water due to the particle size and spacing, which enhances crop rooting ability. The result is improved water infiltration, as crop residues impede water from running off fields. Erosion can decrease by 90 percent or more, as soil moisture rises due to increased absorption of water, cutting runoff into surface water bodies (CTIC, 1997a). Finally, the combination of increased organic matter with decreased tillage allows the soil to sequester carbon (Reicosky 1995, Reicosky et al. 1994) . When added to reduced emissions from farm equipment due to fewer passes on the field, this also further reduces CO_2 emissions.

Weed Control in Soybean Production

Weed control is a critical component of crop production no matter what tillage practice is used, because weed pressure strongly influences yield. Farmers start with clean fields – either through tillage or pre-plant burndown herbicides – and then employ a variety of methods to control weeds in-crop and after harvest. They scout for weeds, use pre-plant herbicide treatments, employ mechanical cultivation, apply directed or over-the-top postemergence herbicide treatments, disk after harvest, and rotate crops to reduce weed pressure. Each requires machinery, fuel, labor and time commitments.

Herbicides typically are used as a substitute in part or in whole for mechanical cultivation. Depending on their mode of action, they prevent weeds from germinating, kill newly germinated weeds, or kill the weed by contacting the weed leaf surface. If mechanical cultivation is used instead of herbicide treatments, a number of important tradeoffs result. First, cultivation is not usually as effective as chemical weed control. Second, fields may be too wet for tractors and cultivators, allowing weeds to become established and making later cultivation more difficult. Third, cultivation results in much greater soil moisture losses than herbicide treatment. Fourth, cultivation, especially over large soybean acreage, consumes labor, machinery hours and fuel. Finally, cultivation of row crops contributes to water erosion.

Herbicides have been the fastest growing agricultural production input since World War II. On soybeans, estimated quantities of herbicide active ingredient applied rose from 4.2 million pounds (1.91 million kg) in 1964 to 68.1 million pounds (30.92 million kg) in 1995 (USDA, 1997, p. 119). The USDA Cropping Practices Survey indicates that more than 98 percent of soybean acres receive herbicide treatments, making it the most frequently employed weed management practice regardless of tillage system (Daberkow, 1997, p. 29).

Herbicides are not only almost universally applied to U.S. soybeans; they are virtually the only pesticide applied, since insecticide and fungicide applications are rare. In 1995, 23 percent of herbicides were applied in the pre-plant stage or at planting; 32 percent were applied after planting only; and 42 percent were applied at both times (see Figure 5). Average treatments per acre were 1.7 times a season, equal to 1.09 pounds of active ingredient (ai) per acre (1.22 kilograms per hectare) (USDA, 1997, p. 186). The most commonly used pesticides on soybeans, by tillage system, are shown in Table 4. These include glyphosate, imazethapyr, 2,4-D, and chlorimuron-ethyl.

Herbicides began to replace tillage and cultivation practices as the primary weed control method for soybeans in the 1960s. Herbicides can be described as selective or non-selective and pre-plant incorporated or pre or post emergent. Selective herbicides control or kill some plant species but do not damage others. Selectivity is based on the crop such that it is not damaged by the herbicide, and selective herbicides typically control only certain weeds. Non-selective herbicides generally control or kill all plants. Roundup herbicide is an example. Preemergence herbicides are applied to the soil prior to the emergence of a specified weed or crop. Postemergence herbicides are applied over the top of the crop while it is growing – typically from emergence to flowering. Soil-incorporated herbicides are preemergence herbicides that are applied to and worked into the soil from 45 days before planting, until planting or slightly thereafter.

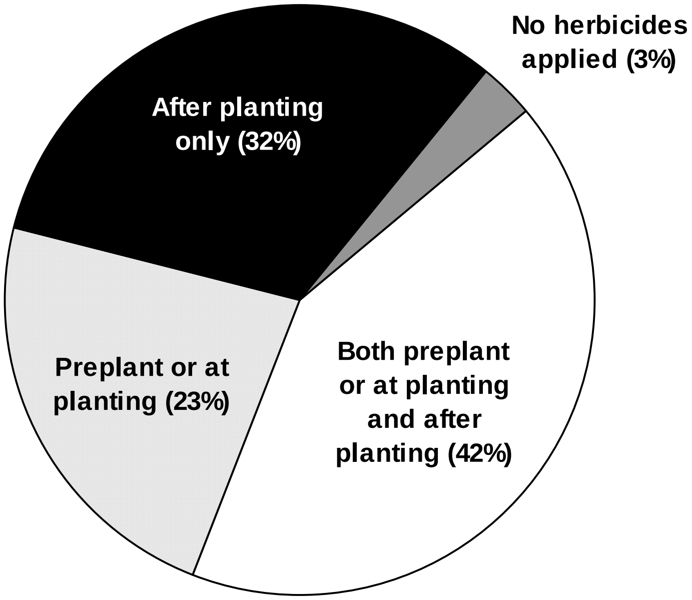


Figure 5: Herbicide Use Based on Field Data for Soybeans, 1996
Based on a brand use survey of 7,100 growers, and herbicide use calculations by Sparks Companies, Inc., for Monsanto. Based on a survey of 1,058 growers conducted by Marketing Horizons for Monsanto. Source: Sparks Companies, Inc., 1997.

Table 4: Herbicide Use on Soybeans by Tillage System, Eight Major Producing States, 1994

	Conventional Tillage		*Conservation Tillage*		
Herbicides	With moldboard plow	Without moldboard plow	Mulch tillage	No tillage	Ridge tillage
	Treated acres as a percent of total planted				
Any herbicide	97.9	98.1	99.4	98.0	94.1
(Average. pounds per treated acre)	(1.0)	(1.1)	(1.1)	(1.3)	(0.9)
Major active ingredients:					
Alachlor	6.9	7.0	6.1	6.8	31.4
Metolachlor	8.2	8.1	6.8	9.3	10.1
2,4-D	0.5	1.2	3.9	35.4	25.3
Acifluorfen	4.4	12.1	8.7	8.0	nr
Fenoxaprop-ethyl	5.5	4.8	3.3	6.1	5.1
Fluazifop-P-butyl	7.7	7.4	6.9	9.9	4.1
Quizalofop-ethyl	5.2	5.6	6.2	8.6	nr
Chlorimuron-ethyl	13.6	14.4	13.0	20.1	5.1
Thifensulfuron	16.0	11.1	15.2	15.9	10.1
Imazaquin	9.0	22.0	14.2	16.7	nr
Imazethapyr	47.9	36.2	49.9	41.6	54.6
Pendimethalin	14.0	24.9	26.1	26.6	nr
Trifluralin	31.5	31.5	29.1	1.5	nr
Metribuzin	11.0	11.1	6.1	13.2	10.1
Glyphosate	1.2	1.5	4.6	54.5	40.5
Bentazon	16.0	14.0	15.4	12.6	nr
Lactofen	6.5	2.9	4.7	5.0	12.1
Sethoxydim	2.3	5.2	7.6	9.3	8.2

Source: USDA, July 1997, p. 165.

Eight States: AR, IL, IN, IA, MN, MO, NE and OH. Figures include preplant applications; nr = none reported

Before postemergence herbicides became widely available in the 1980s, soil-incorporated and pre-plant emergence herbicides were the dominant chemical weed control methods. While soil-incorporated treatments are applied to and worked into the soil, preemergence herbicide treatments are sprayed before or during planting to control early weed emergence. Both types of herbicides control weeds long enough to allow crops to begin growing. Often, farmers follow these treatments with mechanical cultivation until soybean canopies can close and shade competitive weeds. A drawback of many soil incorporated herbicides is soil persistence. The residual effect of soil-incorporated herbicides can hinder crop rotation flexibility. Such persistence also creates the opportunity for some herbicide active ingredients to run off into surface water, as well as leach into the groundwater.

The development of selective postemergence herbicides for soybeans gave farmers an alternative weed control tool. Farmers could use pre-plant herbicides either sprayed or incorporated for early-season control, and could then apply selective postemergence herbicides in lieu of tillage to control weeds in-season. Soybean acres treated with postemergence herbicides increased from 52 percent in 1990 to 74 percent in 1995 (USDA, 1997, p. 182).

Improvements in weed control through such selective postemergence herbicides facilitated farm-level changes. First, because herbicide-based weed control is faster than mechanical cultivation, farmers can tend more acres and manage larger farms. Second, by improving weed control, herbicides optimize yields because there is less competition from weeds for water and plant nutrients. Third, fewer tillage operations conserve equipment, labor, time and fuel. Fourth, these herbicides make it feasible for more growers to adopt conservation tillage production systems, especially no-till with its lower costs and conservation benefits. Despite these advantages, postemergence herbicides could injure the soybean crop and delay normal plant development. While the slowdown in plant development did not always reduce yield, it sometimes delayed canopy closure and increased weed competition with the crop (Fawcett 1997).

Crops genetically engineered to tolerate herbicides are the most recent development in weed control options. It is now possible to apply non-selective herbicides, that were primarily used in the pre-plant stage, in postemergence situations. Postemergence, non-selective herbicides provide superior weed control and maximize yield without crop injury. Roundup is an example of this type of herbicide. It was restricted primarily to use in the pre-plant stage before the development of Roundup Ready soybean seeds. Within the Roundup Ready soybean system, Roundup herbicide can now be applied to kill a broad spectrum of broadleaf species, grasses, annuals and perennials not only as a pre-plant application, but also in the growing crop without retarding crop development and canopy closure.

The Roundup Ready soybean system is straightforward. Often only one in-crop treatment with Roundup is necessary to control weeds, reducing both the need to mix and match herbicides and the possibility of application error. The system allows growers to replace other herbicides, thus improving efficiency and reducing the overall environmental load. In the two years since commercialization of the Roundup Ready soybean system, it has emerged as an advantageous alternative to traditional herbicide strategies because of crop safety, weed control and yield.

While the Roundup Ready soybean system is effective in conventionally tilled fields, the system has been especially useful in no-till where weeds are more likely to be a problem. The Roundup Ready soybean system offers a wider window for Roundup applications, increases flexibility, allows more optimal timing and controls numerous weed types including larger weeds. Finally, the Roundup Ready soybean system makes the conversion from conventional tillage to no-till more possible because it costs less and gives soybean producers a flexible weed management system.

Roundup® Herbicide: An Environmental Profile

Because herbicides play a critical role in soybean production and because this new seed technology is formulated specifically for use with Roundup herbicide, it is appropriate to discuss the environmental profile of glyphosate[6] – the active ingredient in Roundup herbicide. The profile includes glyphosate's toxicity to non-target organisms, mobility in soil and water, bioaccumulation and biomagnification, efficacy and crop safety.

Roundup has a number of strengths – its non-persistence, limited mobility and low toxicity. It is strongly adsorbed by soil and targeted weeds and converted to products such as CO_2, making it unlikely to move into surface or groundwater. Furthermore, glyphosate does not accumulate in birds, mammals or aquatic species such as fish, clams or shrimp (Wauchope, et al., 1992).

Despite the environmental advantages of glyphosate, there has been concern about the possible overuse of Roundup herbicide due to the introduction of the Roundup Ready soybean system (see Rissler and Mellon, 1996; Snow and Palma, 1997). In response to this issue, Sparks Companies, Inc. (1997,1998) assessed the impact of the system on herbicide use. The Sparks studies were based on actual production and herbicide application data for 1996 and 1997.

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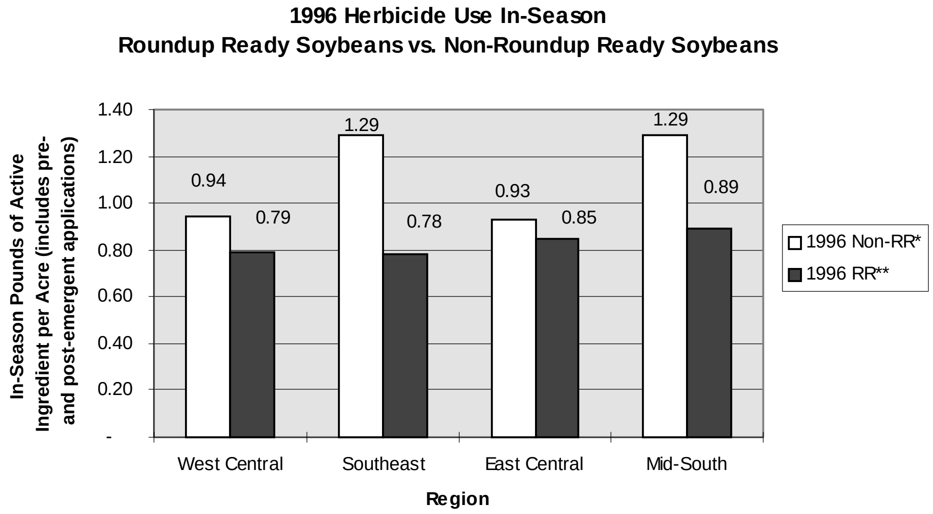
[6] Glyphosate, the active ingredient in Roundup herbicide, kills plants and bacteria by inhibiting the biosynthesis of essential amino acids. Roundup Ready soybeans have an added glyphosate-tolerant enzyme (CP4-EPSPS), which allows Roundup to kill weeds by inhibiting EPSPS (enolpyruvylshikimate-phosphate-synthase). The Roundup Ready soybean plant makes two different EPSPSs: one plant EPSPS (inhibited by Roundup and one bacterial CP4-EPSPS (***not*** inhibited by Roundup). The Roundup tolerant CP4-EPSPS thus allows the plant to continue making amino acids, even after application of Roundup.

The Sparks Companies, Inc. (1997) study examined the 1996 totals for active ingredient use in-crop on areas planted with Roundup Ready soybeans, excluding preplant applications (using a conversion rate of 0.0235 to translate from ounces of Roundup to pounds of active ingredient). The Sparks report compared these results with total active ingredient applied on acres not using the Roundup Ready soybean system. Preplant applications were not included because they would occur whether or not the Roundup Ready soybean system was in use, especially on no-till areas. The field data showed consistent declines in total active ingredient herbicide use in-crop in the Roundup Ready soybean system compared with traditional seed/herbicide programs. Summaries of these findings are shown in Table 5 and Figures 6 and 7.

Table 5: In-Crop Roundup Applications on Roundup Ready Soybean Acres and Regular Soybean Acres, 1996

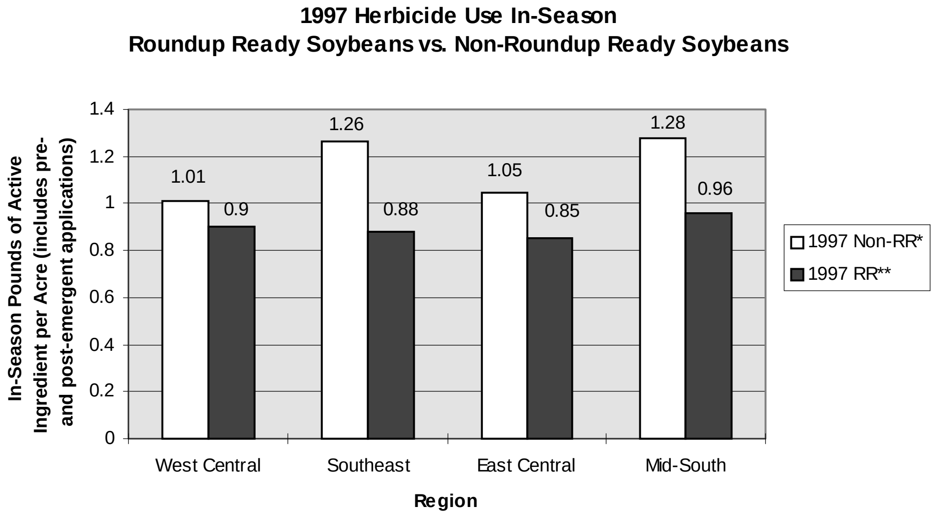
Study Area	***Total Study Area (avg.)***		***West Central***		***Southeast***		***East Central***		***Mid-South***	
	1996	**1997**	**1996**	**1997**	**1996**	**1997**	**1996**	**1997**	**1996**	**1997**
Regular Soybean Acres (pounds a.i. per acre)	1.11	1.15	0.94	1.01	1.29	1.26	0.93	1.05	1.29	1.28
Roundup Ready Soybean Acres (pounds a.i. per acre)	0.83	0.90	0.79	0.9	0.78	0.88	0.85	0.85	0.89	0.96
Net Reduction *(pounds a.i. per acre)*	0.29	0.25	0.15	0.11	.51	0.38	.08	0.20	.40	0.32
Net reductions (percent)	**26%**	**22%**	**16%**	**11%**	**39%**	**30%**	**9%**	**19%**	**31 %**	**25%**

Source: Sparks Companies, Inc., 1997, 1998.



* Based on a proprietary brand use survey of 7,100 growers, calculated by Sparks Companies, Inc. for Monsanto
** Based on a survey of 1,058 growers conducted by Marketing Horizons for Monsanto.

Figure 6: 1996 Herbicide Use In-season
Source: Sparks Companies, Inc. 1997.



* Based on a proprietary brand use survey of 6,869 growers, calculated by Sparks Companies, Inc. for Monsanto
** Based on a survey of 800 growers conducted by Marketing Horizons for Monsanto.

Figure 7: 1997 Herbicide Use In-season
Source: Sparks Companies, Inc. 1998

While assessments of herbicide use in the Roundup Ready soybean system are just beginning, there is evidence that *in-crop* use of herbicide (active ingredient) is lower on Roundup Ready soybean acres than on regular soybean acres. These data showed that Roundup Ready soybean acres used 22 to 26 percent less in-crop active ingredient per acre than regular soybean acres over the total study area in 1996 and 1997. The range of reduction for herbicide in-crop applications across regions was nine to 39 percent for 1996 and 11 to 30 percent for 1997. Such a calculation does not factor in the trend toward postemergence herbicides, long-term herbicide use, or the use of a pre-plant burndown herbicide application as part of no-till.

Herbicide Toxicity to Non-Target Organisms

As with any chemical that is applied in agricultural settings, there is the need to evaluate the impact on organisms in the immediate environment, especially those that were not intended to be affected. The U.S. Environmental Protection Agency (EPA) and the Weed Science Society of America published information on herbicides that detail the physical and toxicological properties of the most widely used soybean herbicide active ingredients (EPA 1986, Ahrens 1994). Acute toxicity is measured by LD_{50} (lethal dose) values, the dose of chemical that kills one half of the test organisms. Lower values mean that less chemical was needed to kill, and so indicate higher toxicity.

Glyphosate, the active ingredient in Roundup, has the lowest mammalian toxicity (based on rats) of any of the widely used soybean herbicides (Table 6). This illustrates its safety to farmers who apply the herbicide according to label directions and to wildlife in the vicinity. In addition, glyphosate’s toxicity to bluegill sunfish (LC_{50} –concentration needed to kill half of the test species over a certain time period) is 120 mg/L, making it among the lowest in fish toxicity

(Table 6). The U.S. EPA determined that glyphosate's toxicity to mammals, fish, and invertebrates was minimal (EPA 1986,1993).

Table 6: Physical and Toxicological Properties of the 12 Most Widely Used Soybean Herbicide Active Ingredients in the United States

Herbicide	K_{ow}*	Average 1/2 Life (days)	LD_{50}** Rat (mg/kg)	96 hr LC_{50}*** Bluegill (mg/L)
Acifluorfen	10.0	37	1,540	62
Bentazon	0.35	20	1,100	616
Chlorimuron-ethyl	2.3	40	4,102	100
2,4-D	--	10	764	263
Glyphosate	0.0017	47	5,600	120
Imazaquin	2.2	60	5,000	100
Imazethapyr	31	75	5,000	420
Metribuzin	44.7	45	1,090	80
Pendimethalin	152,000	44	5,000	0.199
Sethoxydim	45.1	5	2,900	100
Thifensulfuron	0.02	12	5,000	100
Trifluralin	118,000	45	5,000	0.058

*K_{ow} measures bioaccumulation potential, with low values indicating lower propensities to bioaccumulate.
**LD_{50} measures acute lethal doses to mammals (rat) for one-half of test organisms.
***LC_{50} measures concentrations lethal to fish for one-half of a test species for a given time-interval.
Source: Ahrens, 1994

Mobility in Soil and Water

Glyphosate binds tightly to soil particles, making it unavailable to plants and runoff in the dissolved phase once applied to the soil. It has a high adsorption coefficient despite high water solubility of 15,700 parts per million (ppm) (Ahrens 1994). Adsorption occurs through binding of the phosphonic acid portion of the glyphosate molecule. This rapid binding occurs in all soils, with organic matter, clay, silt or sand content and soil pH having small effects on binding. Degree of soil binding is measured by the binding coefficients or "K" values. K_d is a measure of adsorption of chemicals to specific soils. Higher K_d values indicate tighter binding, such that only if the soil particles themselves are eroded will the herbicide be lost to surface water. The average K_d value for glyphosate is 145 (EPA, 1993). In contrast, K_d values for most soybean herbicides are less than five (Ahrens 1994). Table 6 lists the most common herbicides used on soybeans, together with some common indicators of environmental importance.

Strongly adsorbed compounds, like glyphosate, are very unlikely to leach (Baker, 1983). Similarly, little glyphosate can be detected dissolved in water that runs off the surface of treated fields. Comes et al. (1976) found that when glyphosate was applied directly to dry irrigation ditch banks and ditches later flooded, no glyphosate was detected in the water flowing through the ditch. Glyphosate is highly water soluble; however, its tight adsorption to soil means that it is not mobile. It thus retains the rapid degradation and low bioaccumulation of water soluble agents without the usual mobility.

The high water solubility of glyphosate results in other environmental benefits related to the manufacturing of the commercial Roundup herbicide formulations. Because of its solubility, glyphosate can be formulated in water without the addition of petroleum-based solvents. This reduces the introduction of solvents into the environment through the manufacturing process and later application of the product by farmers and other users.

Bioaccumulation

Bioaccumulation is the process by which an organism accumulates compounds from its surrounding environment through processes such as absorption, adsorption or ingestion. It most frequently occurs in aquatic environments. Physical properties, which increase a compound's tendency to bioaccumulate, include low water solubility and high solubility in organic solvents.

Metcalf and Sanborn (1975) evaluated bioaccumulation of 45 pesticides (including herbicides and insecticides) in laboratory model ecosystems. They found an inverse relationship between water solubility and bioaccumulation potential. They classified pesticides according to environmental risk based on water solubility:

1) water solubility less than 0.5 ppm = pesticide likely to bioaccumulate;
2) water solubility between 0.5 and 50 ppm = pesticide to be used with caution and;
3) water solubility more than 50 ppm = pesticide unlikely to bioaccumulate.

Glyphosate's high water solubility of 15,700 ppm makes it among the least likely of any pesticide to bioaccumulate.

Bioaccumulation can also be predicted based on the octanol/water partition coefficient (K_{ow}). Compounds with K_{ow} values of greater than 1,000 are generally accepted as having a high probability of bioaccumulation in aquatic species (Maki and Duthie 1978). Glyphosate’s K_{ow} value is extremely low at 0.0017 – the lowest among the widely used soybean herbicides (Aherns 1994). (See Table 6).

High water solubility confers low bioaccumulation potential. Most compounds that are highly water soluble are mobile in the soil, increasing risk of ground or surface water contamination. However, the strong adsorption of the glyphosate molecule on soil particles prevents leaching or runoff in the dissolved phase. In essence, this combination of properties achieves both low mobility of low solubility compounds and low accumulation of highly soluble compounds.

Roundup Herbicide Efficacy and Crop Safety

Despite the introduction of many new, effective herbicide alternatives over the last two decades, troublesome weed problems continue. Because not all weed control programs are 100 percent effective and most programs utilize selective chemistries, some weed species will mature and form seed. Changes in tillage practices have shifted weed populations towards perennial weeds, which are often difficult to control with selective herbicides. Some weed species have developed biotypes resistant to common selective herbicides. Non-selective herbicides have thus been used to overcome some of the problems associated with selective ones. Roundup herbicide is such a non-selective herbicide. When used as part of the Roundup Ready soybean system, it gives farmers an effective and economical means to control most of these problem weed species.

Roundup herbicide controls most weeds found in soybean fields and is uniquely effective on troublesome perennial weeds that characterize conservation tillage systems. Vegetatively reproducing perennials – plants reproducing by buds on roots and stems that usually survive tillage – such as quackgrass (*Agropyrens repens* L.), hemp dogbane (*Apocynum cannabinum* L.), common milkweed (*Asclepias syriaca* L.), and Canada thistle (*Circlum arvense* (L.) Scop.) have all been shown to increase under conservation tillage (Becker, 1982; Triplett and Little, 1972). Also, simple perennial species – plants that regrow only from single crowns – normally controlled by tillage persist and must be controlled by herbicides. These include dandelions (*Taraxacum officinale* Weber.), forage legumes, forage grasses, and woody species such as sassafras (*Sassafras albidum* L.) and brambles (*Rubrus* sp.) (Williams and Wicks, 1978). Several annual weeds, which are difficult to control with traditional herbicides, also have increased across the United States. In particular, wild proso millet (*Panicum milliaceum* L.), woolly cupgrass (*Erichloa villosa* (Thunb.) Kunth.), and shattercane (*Sorghum bicolor* (L) Moench.) often escape commonly used soybean herbicides.

Development of resistant weed biotypes is of concern because it limits the farmer's ability to control weeds. Several herbicide-resistant biotypes of weeds have become significant problems for farmers. Currently 84 weed species have biotypes that are resistant to one or more herbicides in 14 classes (Shaner 1995).

Considering the widespread use of glyphosate in many cropping systems without appearance of resistant biotypes in the United States, the combination of traits in glyphosate appears unique. The properties of glyphosate and lack of residual activity may explain why resistant biotypes have not appeared. Information obtained in developing glyphosate-resistant crops suggests that alterations in the target site enzyme lead to reduced weed survival. Also, the complex manipulations required to develop glyphosate-resistant crops are unlikely to be duplicated in nature.

Due to Roundup's effectiveness and versatility, it is less affected by weed size, weather and timing issues. This results from Roundup herbicide's high degree of activity and its ability to translocate throughout weeds following application to foliage. Roundup herbicide label directions allow application to most weeds up to 18 inches tall in the Roundup Ready soybean system. It is desirable to make herbicide applications within three to four weeks after soybean planting to prevent significant weed competition (Dierker et al. 1982). However, unlike many other herbicide treatments, Roundup herbicide applications are still effective if they must be delayed for reasons such as adverse weather.

Timing and weather conditions affect the control of weeds. Many herbicides must be applied when weeds are small, with control decreasing rapidly as weeds increase in size. For example, the Basagran®[7] (bentazon active ingredient) label requires application to smartweed, velvetleaf, lambsquarters and jimsonweed having no more than four leaves when applied at the one pint-per-acre-rate. A narrow window of application leaves a farmer susceptible to adverse weather conditions that may prevent application altogether, resulting in unsatisfactory control.

Herbicide application rates can be adjusted to match weed size with Roundup. This application flexibility also should reduce drift problems. Due to narrow application windows for some herbicides, applications are sometimes made when wind is excessive due to fears that delayed applications will be ineffective. Knowledge that delayed Roundup herbicide applications still are effective will reduce the pressure for applicators to apply the herbicide under windy conditions.

Many preemergence herbicide programs have a relatively high failure rate, especially in dry years. As a result, postemergence herbicide treatments are made to control weeds escaping the pre-plant herbicide applications. A 1996 survey by Iowa State

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[7] Basagran in the registered trademark of BASF Corporation.

University showed that 19 percent of Iowa soybeans received an unplanned postemergence herbicide treatment to control weeds missed by pre-plant treatments (Owen and Duffy, 1997). An even higher percentage of re-treatment has been reported in years drier than 1996. More effective herbicide options such as Roundup herbicide could eliminate the need for many of these rescue or resprays. Figure 5 shows the percentage of herbicides applications made in 1996.

The wide variety of weeds found in soybean fields and the limited weed control spectrums of most herbicides have made herbicide programs more complicated. Soybean growers often must apply several different herbicides to control their weed problems. Table 7 shows that 12 percent of U.S. soybean fields receive only a single herbicide active ingredient, while 35 percent receive two, 28 percent receive three, and 22 percent receive four. Use of multiple active ingredients increases the costs and complexity of herbicide applications. Some herbicides are not compatible when tank mixed, with antagonism reducing efficacy. Herbicide adjuvants must be selected according to product labels. Sometimes the appropriate adjuvant for one herbicide tank mix partner may be inappropriate for another, increasing crop injury risk. The need for several different herbicides and additives increases chances for mixing and application errors resulting in crop injury. The simplicity of the Roundup Ready soybean system reduces these application errors.

Table 7: Herbicide Active Ingredients Applied to Soybean Acres
(Represents 10 major soybean production states - 1996.)

No. Active Ingredients	Percent of Acres
1	12
2	35
3	28

4	22

Source: USDA Economic Research Service (U.S. Department of Agricultural, 1997).

Traditional soybean herbicides usually are safe to the crop, but can cause injury under some conditions. Selectivity is based on rate applied. If excessive rates are applied, as often happens in portions of fields where spray boom overlaps occur, injury to the crop can occur. Similarly, stressful weather conditions can increase herbicide uptake or reduce the soybean's ability to metabolize herbicides. Symptoms caused by herbicides under these conditions may not reduce yields, but can slow soybean growth, making the crop less competitive with weeds. Because Roundup Ready soybeans are genetically engineered to tolerate Roundup herbicide, little to no symptoms or stunting occurs due to the herbicide, even under stress conditions or with herbicide overlaps. Lack of herbicide-induced crop stress is one of the reasons for the rapid adoption of Roundup Ready soybeans (Marketing Horizons, 1996).

If residues of herbicides persist in soil following harvest of the treated crop, rotational crops may be injured. Many popular soybean herbicides are highly active on some sensitive rotational crops, meaning that residues must decline to very low levels before sensitive crops can be planted safely. For example, the Pursuit®[8] label (imazethapyr active ingredient) prohibits planting treated fields to sweet corn, oats, cotton, lettuce, popcorn, safflower, sorghum and sunflower for 18 months after treatment, and potatoes for 20 months after treatment. All crops not specifically listed on the label

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[8] Pursuit is the registered trademark of American Cyanamid Company.

cannot be planted for 40 months. In addition, a successful field bioassay must be completed before any non-listed crop can be planted. The Classic®[9] (chlorimuorn-ethyl active ingredient) label prohibits planting alfalfa, sorghum, or tobacco for 15 months, and requires conducting a field bioassay before planting any unlisted crops. Roundup does not have any of these limitations.

Soil pH can also influence the persistence of some soybean herbicides. For example, due to increased persistence of the active ingredient chlorimuron-ethyl, the herbicide Canopy®[10] must not be applied to soils with a pH above 6.8 unless the following rotational crop is soybeans or a resistant corn variety. Roundup herbicide lacks any residual activity thus eliminating any problems with injury to rotational crops, even when the crop is planted during the same season as application.

In summary, the broad spectrum weed control provided by the Roundup Ready soybean system solves many weed problems faced by soybean growers and adds an additional herbicide mode of action to be used in management of herbicide-resistant weeds. Risk of soybean injury is lower with the Roundup Ready soybean system than with most other seed/herbicide systems. Application timing of Roundup herbicide is more flexible than with most other herbicides, reducing pressure to spray when weather conditions favor drift. Lack of residual activity with Roundup herbicide eliminates any possibility of injury to rotational crops. Thus, besides reducing off-site environmental

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[9] Classic is the registered trademark of E.I. DuPont de Nemours and Company.

[10] Canopy is the registered trademark of E.I. DuPont de Nemours and Company.

problems such as water contamination, the use of the Roundup Ready soybean system also reduces herbicide-associated problems in crop production.

The Production Economics of Soybeans By Tillage Type

There are a number of purely economic advantages to the Roundup Ready soybean system that are further enhanced when used in no-till. Mitchell (1997) estimated dry land and irrigated soybean production costs for Kansas, Minnesota, Missouri, North and South Dakota, Nebraska and four regions of Iowa. The principal conclusion of these data is that, for most of the areas examined, no-till offers cost advantages over conventional till, on both dry land and irrigated fields. Average total savings for cost of production per acre were $15.00 per acre ($37.00 per hectare) in favor of no-till (Table 8). For labor and fuel, data from Mitchell (1997) also showed an economic advantage to no-till practices. Average savings for total labor costs per hour were $2.25 per acre ($5.56 per hectare) on no-till fields compared with conventional-till fields. CTIC (1997d) estimated the resulting time savings compared with conventional tillage for a typical 1,000 acre farm (405 hectares). CTIC found a reduction in time on the order of 450 hours a year. The decrease in machinery wear and tear was estimated at $5.00 per acre ($12.35 per hectare) per year resulting in savings of $5,000 per year. Average savings for total fuel costs ranged from $1.70 to $1.81 per acre ($4.20 to $4.47 per hectare) per year on no-till fields versus conventional-till fields (Mitchell 1996) (Table 9), while CTIC (1995) noted a savings of 3.5 gallons diesel fuel equivalent (DFE) per acre (32.7 liters per hectare) per year.

No-till soybean advantages also were reported in a 1990-1995 study, the Indiana Farming for MAXimum Efficiency, or Max program, which broke out herbicide costs (Hill, 1996, p. 1). Measuring average costs for herbicides and field operations prior to the introduction of Roundup

Ready soybeans, the study found that total costs for no-till were the lowest of any form of conservation tillage, and in total averaged $8.66 less per acre ($21.40 per hectare) than conventional tillage. (See Table 10). The Indiana data showed that no-till increased herbicide costs relative to conventional-till plowing, but that reduced costs for field operations more than offset these increases. The evidence shows the cost advantages of no-till versus conventional-till practices.

Another important benefit of no-till soybeans that rarely is quantified is the *opportunity cost* of adopting this type of tillage. The value of time saved is one of the single greatest driving force in no-till adoption (CTIC 1997a, Bradley 1996). When farmers adopts no-till, they have excess equipment capacity and need less time to manage existing acres. The farmer can then manage more acres or spend more time on non-farming activities. As a result, there is an added value to time saved that can be quantified by determining the revenue from extra acres minus the variable costs.

Altogether, there are reductions in total production costs when no-till soybeans are adopted and thus increased profits for farmers. Table 11 shows a summary of total production cost differences comparing no-till and conventional-till, together with labor, fuel and herbicide costs. The table demonstrates that total production costs and costs for labor and fuel average lower overall for no-till versus conventional till. While herbicide costs are higher on no-till acres due to the pre-plant burndown herbicide treatment, the reduction in field operations costs typically offsets it as seen in Table 10.

In conclusion, Mitchell's (1997) research shows that no-till soybeans (in a corn/soybean rotation) have measurable cost advantages over conventional-till soybeans on both dryland and irrigated acres. These cost advantages also are reflected in labor and fuel subaccounts. These results are reinforced by production cost data from Hill (1996) and the Indiana MAX program for 1990-1995, which also shows how no-till offsets herbicide costs.

Table 8: Estimated Costs of Production for Soybeans following Corn by Tillage Type

Kansas, Minnesota, Missouri, North and South Dakota, Nebraska and Four Regions of Iowa[11]
($ per Acre) Source: P. D. Mitchell, June, 1997.

State or Area	No-Till	Conventional-Till	Savings (cost) with No-Till
Kansas			
Dry land	108.97	126.15	17.18
Irrigated	182.42	199.60	17.18
Minnesota			
Dry land	108.78	106.49	(2.29)
Irrigated	265.91	257.53	(8.38)
Missouri			
Dry land	107.83	139.68	31.85
Irrigated	150.89	182.78	31.89
North Dakota			
Dry land	105.34	127.90	22.56
Irrigated	181.46	204.03	22.57
South Dakota			
Dry land	103.21	83.94	(19.27)
Irrigated	184.28	162.45	(21.83)
Nebraska			
Dry land	110.38	122.20	11.82
Irrigated	191.23	201.00	9.77
Iowa - Central			
Dry land	114.53	156.18	41.65
Irrigated	157.12	198.80	41.68
Iowa - Northeastern			
Dry land	126.07	141.82	15.75
Irrigated	---	---	---
Iowa - Southern			
Dry land	122.80	138.56	15.76
Irrigated	---	---	---
Iowa - Western			
Dry land	125.98	141.74	15.76
Irrigated	168.53	184.29	15.76
Avg. Dry land	113.39	128.37	14.98
Avg. Irrigated	185.23	200.60	15.37

Table 9: Estimated Labor and Fuel Machinery Costs for Soybeans following Corn by Tillage

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[11] Budgets are based on data from the U.S. Department of Agriculture (USDA) Cropping Practices Survey and the USDA Cost of Production, as well as other National Agricultural Statistics Society (NASS) databases and the Census of Agriculture. The most frequent tillage and pesticide systems for each region were identified from these data. Tractor and equipment sizes were subjectively chosen for each Agricultural Sector Model region as part of the 1997 USDA Resource Conservation Assessment (RCA) using data on farm size from the Census of Agriculture. Fertilizer application rates were derived from the Cropping Practices Survey and nitrogen application rates were based on a function fit to crop yield and nitrogen application data. The final result is a unique budget for each crop, tillage system, and dryland-irrigation combination in every region.

In Kansas, Minnesota, Missouri, North and South Dakota, Nebraska and Four Regions of Iowa ($ per Acre) Source: P. D. Mitchell, 1997.

State or Area	Labor Costs			Fuel Costs		
	No-Till	Conventional-Till	Savings (cost) with No-Till	No-Till	Conventional -Till	Savings (cost) with No-Till
Kansas						
Dryland	7.68	9.68	2.00	9.32	11.65	2.33
Irrigated	7.88	9.88	2.00	9.77	12.10	2.33
Minnesota						
Dryland	5.57	9.09	3.52	6.25	9.39	3.14
Irrigated	6.34	9.86	3.52	7.46	10.60	3.14
Missouri						
Dryland	7.51	13.37	5.86	8.27	11.45	3.18
Irrigated	7.71	13.57	5.86	8.42	11.60	3.18
North Dakota						
Dryland	7.68	10.14	2.46	8.64	11.95	3.31
Irrigated	7.88	10.34	2.46	9.10	12.40	3.30
South Dakota						
Dryland	5.10	3.52	(1.58)	5.11	3.08	(2.03)
Irrigated	5.30	3.72	(1.58)	5.56	3.53	(2.03)
Nebraska						
Dryland	9.23	10.25	1.02	11.40	11.38	(0.02)
Irrigated	9.94	10.60	0.66	12.35	11.98	(0.37)
Iowa - Central						
Dryland	11.14	13.48	2.34	11.07	13.12	2.05
Irrigated	11.34	13.68	2.34	11.22	13.27	2.05
Iowa -						
Northeastern	11.14	13.48	2.34	11.07	13.12	2.05
Dryland	---	---	---	---	---	---
Irrigated						
Iowa - Southern	11.14	13.48	2.34	11.07	13.12	2.05
Dryland	---	---	---	---	---	---
Irrigated						
Iowa - Western	11.14	13.48	2.34	11.07	13.12	2.05
Dryland	11.34	13.68	2.34	11.22	13.27	2.05
Irrigated						
AVG. TOTAL						
Dryland	8.73	11.00	2.27	9.33	11.14	1.81
Irrigated	8.47	10.67	2.20	9.39	11.09	1.70

Table 10: Six-Year Average Costs for Pesticide and Field Operations by Tillage System Soybeans 1990-1995 - (Farming for MAXimum Efficiency, Indiana MAX program)

Tillage System	Herbicides	Field Operations	Total
	--------------- $ per Acre (Hectare) ----------------		
No tillage	33.41 (82.55)	43.44 (107.34)	76.85 (189.89)
Ridge tillage	22.98 (56.78)	55.12 (136.20)	78.10 (192.98)
Reduced tillage	27.76 (68.59)	55.18 (136.35)	82.94 (204.94)
Conventional tillage (plow)	24.53 (60.61)	60.98 (150.68)	85.51 (211.29)

Source: P. R. Hill, 1996, p. 1.

Table 11: Summary of Average Total Soybean Production Costs, Labor Costs, Fuel Costs and Herbicide Costs by Tillage Type

$ per acre (hectare)		**Conventional-till**	**No-till**	**Savings (Cost)**	**% savings**
Estimated total costs of production*	*Dryland*	128.37 (317.20)	113.39 (280.18)	14.98 (37.02)	12
	Irrigated	200.60 (495.68)	185.23 (457.70)	15.37 (37.98)	8
Labor Costs 1996*	*Dryland*	11.00 (27.18)	8.73 (21.57)	2.27 (5.61)	21
	Irrigated	10.67 (26.37)	8.47 (20.93)	2.20 (5.44)	21
Fuel Cost 1996*	*Dryland*	11.14 (27.53)	9.33 (23.05)	1.81 (4.47)	16
	Irrigated	11.09 (27.40)	9.39 (23.20)	1.70 (4.20)	15
Average Herbicide Costs 1990-1995**		24.53 (60.61)	33.41 (82.55)	-8.88 (-21.94)	-36
Average Field Operations Costs**		60.98 (150.68)	43.44 (107.34)	17.54 (43.34)	29
Average Total Production Costs**		85.51 (211.29)	76.85 (189.89)	8.66 (21.40)	10

*Mitchell 1997. Seven state average: Kansas, Minnesota, Missouri, North Dakota, South Dakota, Nebraska and four regions of Iowa.
**Hill 1996. Farming for MAXimum Efficiency, Indiana MAX program data, for 1990-95. Source: P. R. Hill, 1996, p. 1.

The Production Economics of the Roundup Ready Soybean System

The cost of production estimates considered thus far have shown the advantages of no-till soybeans. This evidence is further enhanced by studies conducted by academics, Monsanto Company and seed companies (85 seed company partners contribute to the pool of information) to determine the economic advantages of the Roundup Ready soybean system

Academic Trials

In 1994 and 1995 academic field experiments conducted in Tennessee, the Roundup Ready soybean system achieved the highest returns to land, management and risk as compared to four other herbicide systems (McKinley 1996). The Roundup Ready soybean system achieved these higher returns as a result of higher yields and lower costs. Costs were lower because Roundup herbicide controlled both grasses and broadleaf weeds effectively, reducing both material and application costs.

Other academic trials are reported by the North Central Weed Science Society (NCWSS) – the regional weed science society covering 15 north central states and four Canadian provinces for 54 years. Fawcett (1997) reviewed the results from the 1997 NCWSS Research Report. His study criteria included measuring yield and evaluating weed control, such that Roundup herbicide had to be included on at least 10 percent, but no more than 90 percent of treatments. His treatment criteria included requirements of activity on both grass and broadleaf weeds, rates and timings had to be within current label ranges and all active ingredients had to be currently registered for use.

Of the nine studies in the 1997 NCWSS Research Report, seven states were included: Illinois (3 studies), Iowa (1 study), Kansas (1 study), Michigan (1 study), Minnesota (1 study), North Dakota (1 study) and Wisconsin (1 study). Average yield differences between Roundup herbicide-alone treatments and alternative herbicide treatments ranged from -0.3 to +12.5 bushels per acre (-20.1 to 839.8 kilograms per hectare) and averaged +5.3 bushels per acre (356.1 kilograms per hectare). (See Table 12). The yield advantage was attributed to the combination of improved weed control and decreased crop injury (Fawcett 1997).

Table 12: North Central Weed Science Society 1997 Research Report
Roundup Ready® soybean average yields with and without Roundup® herbicide treatments.

		Regular Herbicide		Roundup Herbicide Alone		
1997 Studies	State	# treatments	Yield (Bu/Ac)	# treatments	Yield (Bu/Ac)	Difference
Weber et al.	IL	9	40	2	46	6
Owen et al.	IA	4	40.3	1	47	6.7
Nelson et al.	MI	8	53.4	4	58.3	4.9
Kapusta et al.	IL	4	57.8	4	57.5	-0.3
Peterson et al.	KS	6	41	5	48.4	7.4
Zollinger et al.	ND	3	23	6	24.2	1.2
Corrigan et al.	WI	9	53.1	12	61.8	8.7
Kapusta et al.	IL	2	35	12	47.5	12.5
Hoverstad	MN	1	48	4	48.8	0.8
Average		*5.1*	*43.5*	*5.6*	*48.8*	*5.3*

Source: Fawcett 1997

In another nine trials conducted by academics and consultants in the Midwest, the Roundup Ready soybean system yielded 1.4 bushels per acre (94 kilograms per hectare) more than a competitive herbicide system and 27.3 bushels per acre (1,834 kilograms per hectare) more than soybeans with no weed control (Monsanto 1997b). These were controlled sites with small plot comparisons. Field variability was not accounted for in the trials.

Babcock (1997a) simulated yield losses as a function of weed pressure using an Iowa case study involving nine common weed types and the yield loss model of Cousens (1985). Estimates of herbicide effectiveness developed by Iowa State University (1996) were quantified, and the Roundup Ready soybean system was compared with a traditional seed/herbicide combination.[12] Babcock assumed that Roundup would control weeds at a 99 percent level, compared with 95

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[12] Conventional herbicide treatment was assumed to be a combination of Pursuit® and Prowl®, two conventional treatments in Iowa.

percent for a conventional herbicide treatments, under medium weed pressure. This assumption was validated in discussions with soybean breeders and agronomists (Orf, 1997). Using a weed-free yield of 50 bushels per acre (3,360 kilograms per hectare), Babcock simulated the yield advantage to the Roundup Ready soybean system, which allowed the soybeans to reach maximum yield potential. These yield simulations are reported in Table 13.

Table 13: Simulated Alternative Weed Control Systems – Average Iowa Soybean Yields
Yields per acre and hectare under medium weed pressure assuming weed-free yield equals 50 bushels per acre (3,360 kilograms per hectare).

	Soybean Weed-Control System		
Yield	Roundup + Roundup Ready Soybeans	Prowl + Pursuit + Regular Soybeans	Difference in Yield
Bushels per Acre	44.20	42.40	1.80
Metric tons per Hectare	1.20	1.15	0.05

Source: Babcock, 1997a, p. 36.

The academic trials generated positive evidence that yields are optimized by the Roundup Ready soybean system. Inclusion of the Roundup Ready gene has not reduced the yield potential of soybean varieties (Delanney et al. 1985) and in most trials has contributed to yield advantage over other herbicide-treatment systems.

Monsanto and Seed Company Trials

In 77 side-by-side on-farm comparisons conducted by Monsanto and seed companies in 1996 (Monsanto 1997a), the average yield advantage for the Roundup Ready soybean system (Roundup Ready soybean seed with Roundup herbicide) was two bushels per acre (134.8 kilograms per hectare) greater than the same seed with regular herbicide treatment. In 1997, 330 field trials reported a 2.2 bushel per acre (147.8 kilograms per hectare) advantage to the Roundup Ready soybean system. This increased growers' revenue by $15.40 per acre ($38.03 per hectare) at $7.00 per bushel. These studies accounted for a wide geography of sites and took into account field variability. Early weed presence had no impact on soybean yield when farmers began with a "clean start" – Roundup herbicide burndown treatment or clean tillage prior to planting.

A 1997 study by six Asgrow Concept Farms conducted nine trials evaluating the production economics of the Roundup Ready soybean system at different rates and timing applications based on weed heights, versus two conventional soybean herbicide programs[13]. Table 14 shows results of the trials, which were conducted in six locations: Atlantic, Iowa; Williams, Iowa; Tuscola, Illinois; Mapleton, Minnesota; York, Nebraska; and Eustar, Ohio. Regardless of the rate and/or split application for Roundup Ultra, net income was greater for the Roundup Ready soybean system than for the conventional treatments. As compared with the Prowl/Pursuit treatment, the Roundup Ready soybean system yielded an average of 4.4 more bushels per acre, and 3.5 more bushels per acre than the Galaxy/Poast Plus treatment. The most economical applications within the Roundup Ready soybean system occurred at 3-6" weed heights (Asgrow, 1997). These results are shown in the bar chart of Figure 8.

Table 14: Eight Herbicide Programs the Roundup Ready Soybean System
Yield of Roundup Ready soybean varieties treated with eight herbicide programs; two using conventional soybean herbicide programs and six using the Roundup Ready see/herbicide system

Herbicide	***Weed Ht. at application***	***Yield bu/acre (kg/ha)***	***Net Income $/acre ($/ha)***	***Herbicide $/acre ($/ha)***

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[13] Incremental cash flow was calculated by multiplying yield by $6.75, then subtracting herbicide cost and $4.00 per post herbicide application, as well as a $6.00 technology fee (based on a planting rate of 1.2 bags per acre) for Roundup Ready soybean seed.

Prowl 40 fl.oz. Pursuit 4 fl.oz.	Pre 1 - 2” (2.5 - 5 cm)	48.3 (54.1)	286 (706.70)	36 (88.95)
Galaxy 32 fl.oz. Poast Plus 24 fl.oz.	1-2” + 7 days	49.2 (55.1)	297 (733.88)	27 (66.72)
Avg. Other Herbicides		***48.75 (54.6)***	***291.50 (720.29)***	***31.50 (77.84)***
Roundup Ultra 32 fl.oz.	3” (7.6 cm)	52.8 (59.1)	332 (820.36)	14 (34.59)
Roundup Ultra 32 fl.oz.	**6” (15.2 cm)**	**53.3 (59.7)**	**335 (827.77)**	**14 (34.59)**
Roundup Ultra 32 fl.oz.	9” (22.9 cm)	52.5 (58.8)	330 (815.42)	14 (34.59_)
Roundup Ultra 32 fl.oz.	12” (30.5 cm)	52.2 (58.5)	328 (810.48)	14 (34.59)
Roundup Ultra 32 fl.oz. Roundup Ultra 24 fl.oz.*	3” 3”	52.4 (58.7)	312 (770.94)	28 (69.19)
Roundup Ultra 32 fl.oz. Roundup Ultra 24 fl.oz.*	6” 3”	53 (59.4)	320 (790.71)	24 (59.30)
Avg. Roundup Alone		***52.7 (59)***	***326 (805.53)***	***18 (44.48)***

Yield LSD (.10) = 1.1

* Two locations did not apply sequential herbicide treatments due to lack of weed pressure.
Source: Asgrow Seed Company. Asgrow Seed Technology Site. http://www.asgrow.com/AsgrowFarms/CFR97BnRR1.html. 1997.

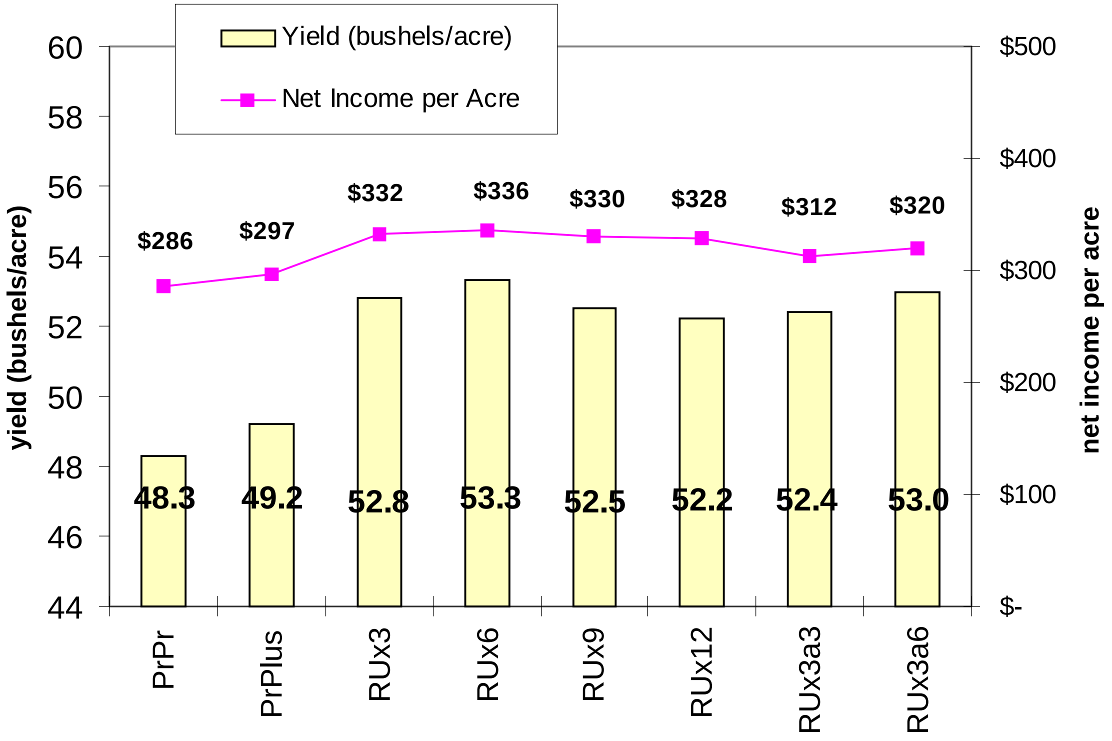

Figure 8: Yield and Net Income per acre
Bar chart showing yields in bushels per acre and a line graph of the net income per acre for each herbicide program.
Source: Asgrow Seed Company. Asgrow Seed Technology Site. http://www.asgrow.com/AsgrowFarms/CFR97BnRR1.html. 1997.

In conclusion, the Roundup Ready soybean system did not show a yield disadvantage. Rather, it demonstrated a yield advantage (Asgrow, 1997; Monsanto, 1997; Babcock, 1997a).

Farmer Perceptions of the Roundup Ready Soybean System and Adoption Rates

If the agronomic and economic advantages of an integrated Roundup Ready soybean system noted previously are accurate, then it is expected that farmers will adopt such systems rapidly and with enthusiasm. Evidence of this reaction is offered by surveys undertaken in 1996 and 1997.

A preharvest market survey of 1,066 growers indicated that 97 percent were satisfied with the overall results (Marketing Horizons, 1996). Nine out of ten indicated an intention to plant Roundup Ready soybeans in 1997, and the same proportion indicated that the seed technology met or exceeded their expectations, primarily because of weed control performance, good yields and crop safety. More than 80 percent of growers in the Midwest indicated a need for only one in-crop application of Roundup herbicide to get full-season weed control.

The September 1997 follow-up survey included more than 900 interviews with growers in the North Central United States. It was concluded that given average yields, Roundup Ready soybeans would capture about 39 percent of soybean acres nationally in 1998, and 38 percent of North Central acres, assuming seed availability (Marketing Horizons, 1997a). A more detailed assessment, released in August of 1997, also focuses on the characteristics of those farmers who planted Roundup Ready soybeans and their tillage practices. In the North Central region, 1997 seeding rates for Roundup Ready soybean seed were almost the same as for regular soybean seed – 70.0 pounds per acre versus 70.4 pounds per acre (78.4 kilograms per hectare vs. 78.8 kilograms per hectare). In the same region, 56 percent of those planting Roundup Ready soybeans used no-till, while 36 percent used conventional till (Marketing Horizons, 1997b, pp. 11; 17).

In the post-harvest survey (Marketing Horizons 1997c), 89 percent of users indicated that they were much/somewhat more satisfied with the Roundup Ready soybean system than traditional seed/herbicide programs. In addition, 89 percent of growers had an overall level of satisfaction, 76 percent found the crop to be of very good/good value, and 87 percent indicated their intentions to plant Roundup Ready soybeans in 1998, which will result in a 38 percent increase in acres planted among 1997 users. Overall 63 percent of all soybean growers plan to plant at least some Roundup Ready soybeans in 1998.

In summary, early results indicate strong grower response to, and acceptance of, the Roundup Ready soybean system. The advantages of the system are likely to be realized especially in relation to no-till. Data from Mitchell (1997) and Hill (1996) support these economic conclusions. Asgrow (1997) confirms the specific economic advantages of the Roundup Ready soybean system. It and other studies also indicate some yield advantages to the system. While this confirms both the agronomics and production economics of the technology, it has larger implications for a variety of environmental and conservation benefits.

Chapter III: Environmental Benefits

The economic advantages of the Roundup Ready soybean system also promote environmental benefits, especially if reduced inputs impose less wear and tear on natural ecosystems and if conservation tillage methods are used. The Roundup Ready soybean system's direct environmental benefits are related to the use of Roundup herbicide, which has a favorable environmental profile. However, when the Roundup Ready soybean system is grown with conservation tillage methods, especially no-till, a more extensive suite of environmental benefits are realized. These environmental benefits are a direct result of the tillage practice and not the Roundup Ready soybean system. However, the Roundup Ready soybean system has been shown to encourage the adoption of no-till because of its excellent weed control and crop safety. In the following sections, five environmental benefits are examined. When possible, the Roundup Ready soybean system is compared in both conventional- and no-till.

Benefit 1: Soil Quality: Erosion and Productivity

Maintaining and improving soils by reducing erosion and increasing soil quality involves multiple characteristics of land and soils and their relationship to agricultural activity. In the area of soil quantity, water and wind erosion are the major factors, while soil quality focuses primarily on tilth, organic matter, nutrient content and soil moisture capacity. Both conventional and conservation tillage systems were examined for environmental benefits related to soil quantity and quality.

Erosion involves the physical movement of soil particles from cropping areas to other areas or watercourses where its productive use is altered, reduced or lost. The rate of erosion is a function of both the physical character of fields and watersheds (e.g., slope, rainfall patterns) and management choices (e.g., cropping mix, contouring).

While conventional tillage operations typically negatively impact soil quantity by encouraging erosion, employing the Roundup Ready soybean system potentially reduces the number of trips across the field for cultivation. This reduction in the trips across the field occurs because herbicides are substituted for mechanical cultivation. This change in farm process reduces the number of trips across the field and soil disturbance, which eliminates an opportunity for soil erosion.

The greatest benefits related to soil erosion occur when Roundup Ready soybeans are planted in a no-till system. Impacts in specific watersheds and on particular fields will vary (USDA, ARS, 1997). However, G. R. Foster and S. Dabney (1995, p. 43), of the National Sedimentation Laboratory of the USDA, noted that increased crop residues left on field surfaces greatly reduce erosion, and that significant decreases in runoff mean that control of ephemeral gully erosion is much easier.

The CTIC suggests that no-till generally results in more than 90 percent reductions in erosion (Hebblethwaite, 1995). This assertion is supported by three rainfall studies showing that in comparison to conventional moldboard plows over the years 1973-1987, erosion was reduced by an average of 93 percent in no-till over conventional-till (Baker, 1990; Baker, et al., 1978; and Baker and Laflen, 1979).

Calculations by Babcock (1997b) are consistent with these estimates. Annual water erosion rates in Iowa with no-till were estimated to be 14 percent of those on conventionally-tilled fields on highly sloped land with gradients of 8 percent or greater. On land sloped at 4-6 percent, water erosion rates with no-till were estimated at 17 percent of those on conventionally-tilled fields, and on essentially flat fields with slopes of less than 2 percent, water erosion rates with no-till were estimated at 14 percent of those with conventional tillage. In Babcock's model, no-till saved an estimated 18 tons of soil per acre (40 metric tons per hectare) per year on 8 percent slopes, 5.4 tons per acre (12.1 metric tons per hectare)per year on 4-6 percent slopes, and 1.33 tons per acre (3 tons per hectare) per year on fields with slopes of 2 percent or less (Babcock, 1997b) (Figure 9).

In the case of wind erosion, Fryrear (1995, p. 44) indicated that conservation tillage, especially no-till, provided a definite advantage over conventional tillage in reducing the loss of top soil. Babcock’s (1997b) evidence confirms this view for Iowa. No-till wind erosion levels were estimated at 15 percent of those with conventional till on land sloped at 8 percent or greater, resulting in savings of 1.66 tons of soil per acre (3.7 metric tons per hectare) per year. On lands with 4-6 percent slope, no-till wind erosion was estimated at 9 percent of conventional till, with savings of 2.26 tons of soil (5.1 metric tons per hectare) per acre per year. On flat lands with 2 percent slope or less, no-till wind erosion rates were estimated at 4 percent of those of conventional-till, saving 2.76 tons of soil per acre (6.2 metric tons per hectare) per year.

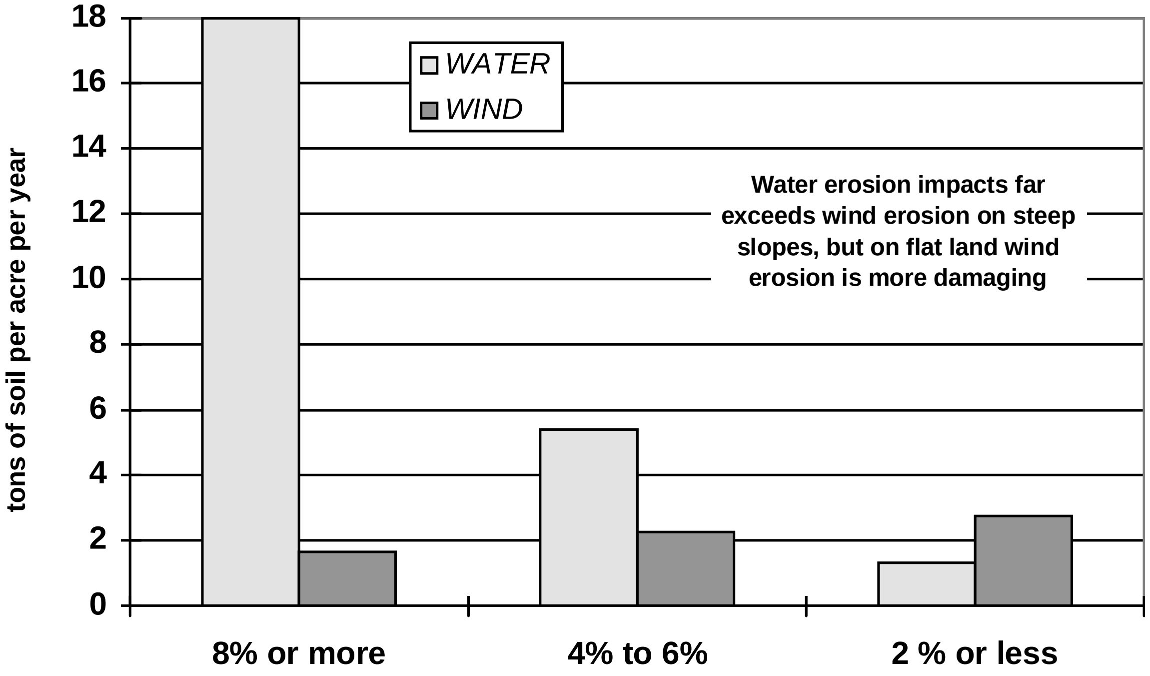

Figure 9: Water and Wind Erosion Rates by Slope: Soil Saved by Conversion to No-Till from Conventional Tillage
Source: Babcock, 1997b.

While erosion is essentially a quantitative issue, soil quality has numerous dimensions. These include the capacity of the soil to function, which depends on properties such as texture and structure, and the fitness of soil for use, sometimes referred to as soil health or condition (see Karlen, et al., 1997). Current research focuses on how physical, chemical and biological properties determine soil quality. Physical properties, for example, include soil tilth (aggregate size) and porosity, while chemical properties include acidity and nutrient levels. Biological properties include microbial activity and organic matter (see USDA, July 1997, pp. 41-49; Hudson, 1995). This study focuses on four main aspects of soil quality: soil structure measured by tilth, soil organic matter, soil compaction and soil fertility.

Soil structure measured by tilth[14] refers to the tendency of soil particles to aggregate into larger particles, the resulting way in which plants and soil organisms grow in this soil, and the effect of these characteristics on the flow of water. These characteristics all help to define soil structure. With conventional tillage, the vertical structure of the soil profile is drastically altered (Zaborski and Stinner 1995). A significant impact of cultivation and tillage practices on the soil community is the burial and accelerated decomposition of surface plant residues. As a result, the soil surface is exposed and subjected to greater fluctuation in temperature and moisture, and the timing of decomposition is altered. This disruption to the physical and chemical gradients of the soil causes a loss in the variety of environments and food sources within the soil structure. The overall abundance and diversity of soil organisms then tends to decline.

The Roundup Ready soybean system mitigates some of the reduction in soil quality characteristic of regular soybean tillage operations by decreasing the number of trips across the field for mechanical weed control. This reduction in compaction benefits soil structure and thus quality.

A no-till system further supports soil quality by promoting a more stratified soil structure, which supports a greater abundance and diversity of soil organisms. No-till benefits soil structure by allowing increases in earthworm populations of two to three times (CTIC, 1997d). While earthworms are not the only organisms that affect soil structure, they have important impacts on

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[14] "Soil tilth" is a traditional term referring to the structural tendency of a soil to fracture. Soil structure can be more technically defined in terms of form, stability and resilience. Form refers to the architecture of the soil, including the arrangement of solid and void space, affected by climate, tillage, biological processes and management. Soil stability refers to the capacity of a soil to retain its form when exposed to stresses such as tillage, rain and root growth. Soil resiliency refers to the soil's ability to recover a structural form when these stresses are removed (Kay, 1995, p. 7).

water infiltration and crop rooting, primarily by creating channels that allow water movement and crop rooting to occur. Conventional tillage reduces earthworm populations by drying soils, disrupting earthworm burrows and burying plant material used as food. Earthworm populations can be reduced by as much as 90 percent by deep and frequent tillage operations (Zaborski and Stinner 1995). Mechanical damage is an important mortality factor for the large invertebrates as is compaction of earthworm burrows. No-till, by contrast, does not discourage earthworm populations and allows better water infiltration and crop rooting.

Earthworms also create pores in the soil that aid tilth. Other evidence suggests that the pores left in no-till fields extend to greater depths and are more effective in transporting water and preventing surface evaporation than under conventional tillage (Kay, 1995). Studies of no-tilled fields by Lee (1985) found two- to 10-fold increases in water infiltration rates on no-till fields compared to conventional tillage. Kladivko, et al. (1986) found 15-fold increases in steady state infiltration rates due to earthworms.

A second aspect of soil quality affected by conservation tillage, especially no-till, is soil organic matter. Soil organic matter is defined as the organic constituent or fraction in the soil, including raw plant residues and microorganisms, active organic material that binds soil particles, and a resistent or stable fraction that gives soil its nutrient holding capacity (Manitoba Institute of Agrologists, 1997). Organic matter can be lost over time with tillage because oxygen introduced into the soil by plowing speeds microbial decomposition. However, in no-till, gains in soil organic matter result from increases in the balance of inputs of carbon due to photosynthesis, relative to losses of carbon due to decomposition and plant respiration. Agricultural production depletes organic matter because part of the plant is generally harvested, because crop species have less carbon-fixing capacity than native grasses, and because tillage, especially conventional tillage, accelerates organic matter decomposition (see Reicosky, 1994).

When inputs exceed losses, organic matter builds in soils. Reductions in tillage result in increased organic matter, which, depending on crop rotations, stabilize at higher levels, raising soil productivity (Campbell and Janzen, 1995, p. 10). Reicosky et al. (1995) summarized a number of studies investigating long-term changes in soil organic matter with different tillage and crop production systems. Considering 20 long-term studies using the moldboard plow, organic matter was reduced by an average 256 pounds per acre (286.7 kilograms per hectare) per year. In 10 long-term no-till studies, organic matter increased in all, with an average increase of 953 pounds per acre (1,067 kilograms per hectare) per year. Increases as high as 2,000 pounds per acre (2,240 kilograms per hectare) per year occurred in some studies, translating into an increase of about 0.1% soil organic matter per year.

A third element of no-till soil quality, related to organic matter, is soil compaction. A reduction in porous space in the soil occurs when soil is compacted by heavy farm machinery. In particular, the main cause of compaction is wheel traffic from farm implements. The effect of compaction is to limit root growth, reduce water infiltration, reduce microorganism and earthworm activity and nutrient uptake, and increase erosion and runoff. Soils high in organic matter resist compaction. When conservation tillage, especially no-till, is undertaken, increases in organic matter combined with fewer passes over fields by heavy machinery generally raise porosity after a transition period of several years. This pattern is shown in Figure 10, which indicates porosity changes over time in an Ohio study. In the period of transition, soybeans planted in no-till fields are recommended as a "repair crop" (Kinsella, 1995), making the Roundup Ready soybean system a good choice.

A fourth element of no-till soil quality is soil fertility, which determines capacity to supply the nutrients essential for plant growth.[15] Agricultural activity depletes some of these nutrients, which must be replenished by application of soil supplements including lime, manure and fertilizer. No-till improves the retention of many of these nutrients. Concerns over the maldistribution of nutrients under no-till (e.g., stratification of P and K on surface layers) have been laid to rest with soil testing. New application equipment also is being employed to ensure that stratification does not occur (see Blevins, et al., 1983 and Karlen and Sharpley, 1994). Soil fertility is further enhanced by the increase in soil porosity encouraged by no-till. Specifically, greater porosity allows plant roots to reach nutrients more easily, offsetting stratification (Karlen, 1995).

In summary, the Roundup Ready soybean system does impart some benefit to soil quality regardless of tillage system due to the potential for reduced passes across the field for cultivation. However, the primary benefits for the in terms of soil quantity and quality occur when Roundup Ready soybeans are grown in conservation tillage, especially no-till. Erosion, caused by both water and wind, is reduced on no-till fields by 90 percent or more compared with conventional moldboard tillage. Soil quality is enhanced by the impact of reduced tillage on soil structure, improving tilth. Soil organic matter also increases, raising soil productivity and moisture retention. This increase in organic matter, combined with fewer passes across fields, reduces soil compaction. Finally, soil fertility is enhanced by the capacity of no-till fields to retain plant nutrients in the soil.

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[15] The main plant nutrients are N (nitrogen), P (phosphorus), K (potassium), Ca (calcium), Mg (magnesium), S (sulfur), B (boron), Cu (copper), Fe (iron), Mn (manganese), Mo (molybdenum) and Zn (zinc).

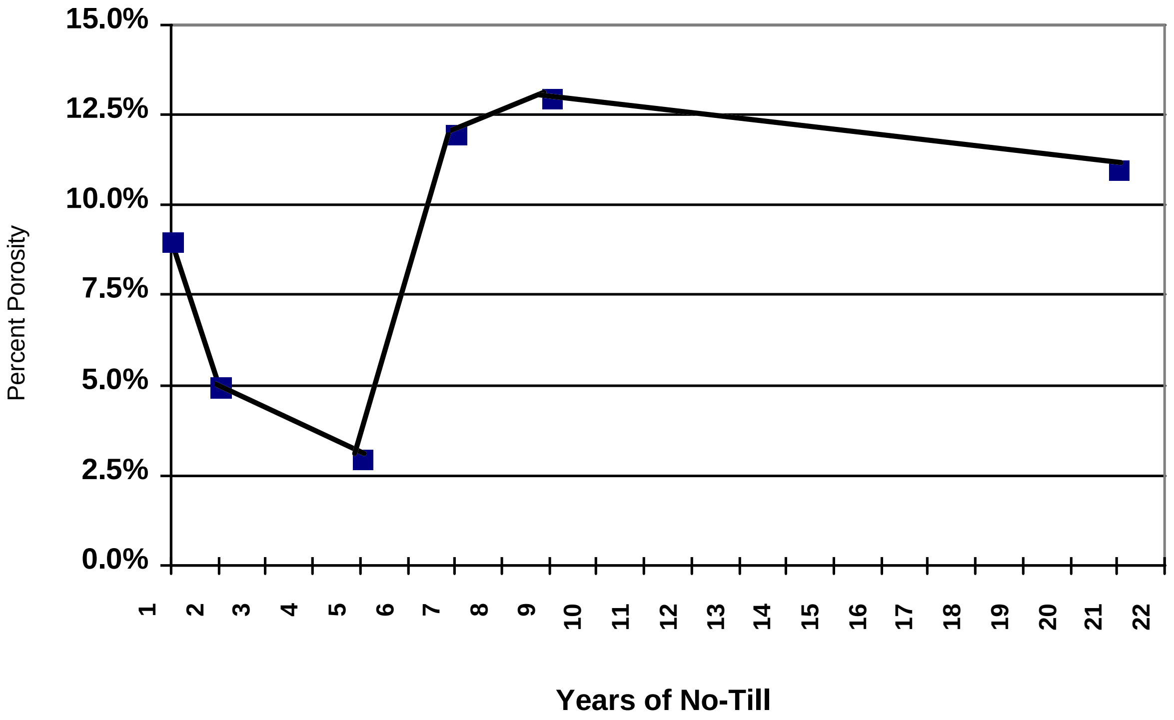

Figure 10: Changes in Porosity Larger than 0.5 mm Diameter in the Surface Soil from Coshocton, Ohio, After Beginning No-Till Management
Source: Kinsella, 1995, p. 16.

Benefit 2: Water Quality and Quantity: Surface and Groundwater

Closely related to soil erosion is water quality and quantity. Degraded water quality is regarded as the most serious environmental impact of agricultural production in the United States (Runge, 1996; OTA, 1995). Water quality and quantity benefits are related predominantly to the choice of tillage system although choice of herbicide can also impact water quality, thus making the Roundup Ready soybean system an appropriate choice when considering water quality.

The effect of conservation tillage on sedimentation depends on all of the factors determining erosion potential. This in turn affects the volume of soil particles entering streams and other water bodies. Estimates of the damage from erosion are much greater off-site than on-site, as soil particles enter rivers and streams, degrading water quality and increasing costs for water treatment, dredging and other activities (Crosson, 1995). Tillage systems that affect how much sediment leaves the field thus can play a key role in reducing such damages over time. The 1992 U.S. EPA National Water Quality Inventory ranked sediment as the most important cause of river and stream impairment, (impairing 45 percent of assessed miles). Sediment was followed by fertilizer and other nutrients (impairing 37 percent of assessed miles), and pesticides (impairing 26 percent of miles) (U.S. EPA, 1994).

A second factor determining water quality benefits, involving both tillage and the specific characteristics of the Roundup Ready soybean system, is runoff and leaching into groundwater of nutrients, herbicides and other pesticides. Studies of runoff due to natural rainfall events indicate a clear difference between no-till and conventional tillage, with no-till reducing pesticide runoff by an average of 70 percent[16] (Fawcett et al. 1994). Soil erosion, water runoff and pesticide runoff on no-till fields in an Iowa watershed were generally less than under conventional moldboard plow tillage. In the specific case of water runoff, three year averages on no-till fields were 32,766 gallons per acre (306,362 liters per hectare) compared to an average of 46,233 gallons per acre (432,279 liters per hectare) on conventional moldboard plow fields (Baker and Johnson, 1979) – a 30 percent reduction.

The increase in water infiltration on no-till fields has led to questions over whether pesticides and nutrients such as nitrogen (N) might leach through soils and into groundwater, especially when soybeans are grown in rotation with corn. This is of particular concern on sandy soils that are low in organic matter, but also on no-till soils due to increased porosity. However, research by Gish, et al. (1989) and others suggests that leaching of nutrients or pesticides under no-till is largely restricted to shallow soil depths, after which they are no more subject to preferential flow than under conventionally tilled fields (Fawcett, 1995, p. 49).

Kanwar, et al. (1997) compared nitrate leaching over three years from four tillage systems with 12-year tillage histories. They found that average nitrate concentrations (in tile effluent) were much higher under conventional moldboard plow tillage than any other system, while no-till plots had the lowest nitrate concentrations. Even so, because the amount of water that infiltrated into the soil was substantially higher under no-till, the quantity of nitrate leached was similar among no-till and the other tillage systems (Kanwar, et al., 1997; Fawcett, 1995). In an earlier study Kanwar (1990) found that nitrate loading in a corn/soybean rotation was 32.5 pounds per

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[16] Simulated rainfall events are also used to study runoff and leaching and tend to show less pronounced benefits from no-till, largely because they simulate extreme cases such as one in 50 year rainfalls, allowing less infiltration than under more normal events (Fawcett, 1995, p. 49).

acre (36.40 kilograms per hectare) under no-till, compared with 33.9 pounds per acre (37.97 kilograms per hectare) with moldboard plowing and 46.7 pounds per acre (52.35 kilograms per hectare) with chisel plowing.

In general, the choice of growing soybeans also impacts nutrient runoff because soybeans are nitrogen fixing and reduce the amount of nitrogen fertilizer applications needed for the subsequent rotational crop (e.g., corn). In a study of the impact of tillage on nitrogen fixation on soybean fields, Wheatley, et al. (1995) found that nitrogen fixation was increased by high amounts of crop residues and by not tilling soils prior to planting. The effect was to increase nitrogen fixation to more than 85 percent on conservation till, compared with less than 75 percent on conventionally-tilled fields. As they concluded:

> Increasing the percentage of N in the grain derived from N_2 fixation by conservation tillage practices has the potential to increase the residual N benefit of soybeans to a subsequent crop. Increasing the residual N of a legume crop by modifying tillage practices may help in ameliorating the decline in soil N in cropping soils of summer rainfall cropping regions (Wheatley, et al., 1995, p. 574).

In short, while total quantities of nitrate leaching with no-till appear to be similar to those occurring under conventional tillage systems, concentrations are reduced.

A final issue concerns water quantity and overall water conservation, sometimes referred to as water-use efficiency. This factor is primarily affected by changes in tillage system. Infiltration increases in reduced tillage lessens runoff and increases available moisture for plant growth occur as a result of reduced tillage. The capacity of soils to efficiently store water is positively related to residues left on soil surfaces under no-till and increases in infiltration (Unger, 1995). Related to infiltration is the rate at which water evaporates from soils. Figure 11 shows calculations of evaporation rates by Reicosky, et al. (1994). Five hours after tillage for a variety of tillage methods. The cumulative evaporation rate under no till (0.05 inches) is less than half that under conventional moldboard plow tillage.

In a comparison of soil moisture losses from fields with no-till versus conventional moldboard plow tillage, Reicosky, et al. (1994) found that cumulative water losses for the first five hours after tillage were 0.113 inches (0.287 cm)with conventional tillage versus 0.052 inches (0.132 cm) with no-till, or less than half. The residue left on field surfaces with no-till thus plays a key role in trapping sediment and preventing it from being carried off by water. It is far more effective to trap sediment at the source than further down watercourses, where expensive dredging and other measures must be undertaken (Foster and Dabney, 1995).

In conclusion, there are a numerous benefits related to water quality and quantity for conservation tillage, especially no-till. No-till reduces erosion, and thus sedimentation, resulting in fewer soil particles entering rivers, streams and lakes. No-till also reduces runoff of nutrients such as fertilizer and pesticides. The lower mobility of Roundup herbicide is also an advantage. Reduced leaching of nutrients into groundwater result in reduced concentrations of nitrates. Soybeans also act to increase the nitrogen "credit," reducing the need for supplemental applications to crops grown in rotation and future runoff of nutrients from those crops. Finally, conservation tillage increases water infiltration, conserving water quantity while improving water quality.

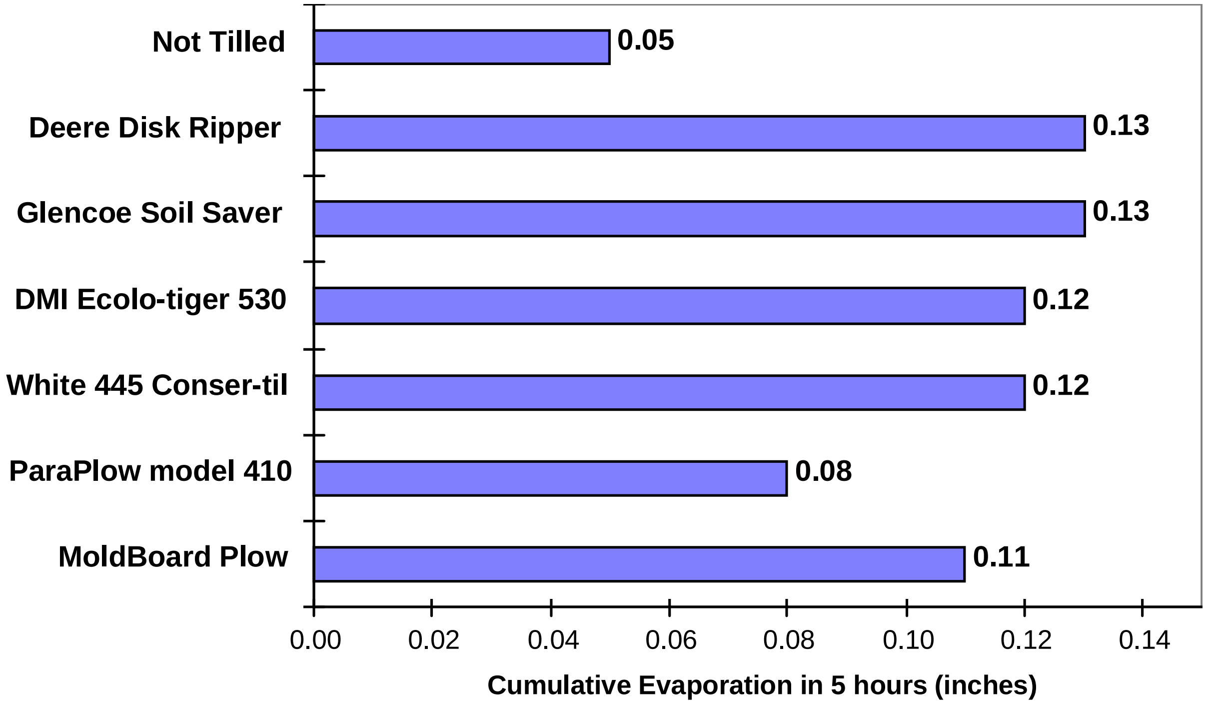

Figure 11: Cumulative Evaporation Five Hours After Tillage. Conservation Tillage Tool Demonstration August 24, 1994
Source: Reicosky, et al., 1994.

Benefit 3: Wildlife Habitat

Biological activity is affected not only by the choice of tillage practice, but also the type of crop and herbicides used. Although most benefits for wildlife are attributable to tillage practices, they are reinforced by the soybeans and the use of Roundup herbicide for two key reasons. First, soybeans provide superior food and cover, especially in closed canopy, to bird species. Second, the non-persistence and low mobility of Roundup herbicide make it of particular value from the point of view of biological activity.

Biological activity includes microscopic soil organisms, beneficial insects, soil-dwelling earthworms and other simple organisms, setting the stage for additional wildlife benefits on the surface of soybean fields. These wildlife benefits mean improved habitat for avian species, including waterfowl and quail. In addition, small mammals benefit from more abundant food sources and protected habitat. Finally, no-till improves stream and surface water quality and aquatic species ranging from invertebrates to fish.

Microbial populations are key to the health of the soil and the decomposition process. Evidence on the reaction of microbial biomass to glyphosate applications (Biederbeck et al.1997) supports the wildlife-related benefits of Roundup herbicide. Biederbeck et al. (1997) indicated that microorganisms effectively metabolized glyphosate, and that the numbers of propagules of all microbial groups in the soil increased following a glyphosate treatment (Grossbard 1985). This implies that the microflora are utilizing either the glyphosate itself or its degradation products. Other studies also provide evidence that microorganisms may be taking advantage of glyphosate (Roslycky 1982, Wardle and Parkinson 1990). Wardle and Parkinson (1990) found that glyphosate applications increased respiration and bacterial numbers as well as three fungal species.

They noted that microbial biomass was enhanced by no-till practices and diminished by conventional tillage. Overall, Biederbeck et al.'s (1997) 21-year study showed that glyphosate, when used to control weeds in a no-till fallow-wheat system, did not result in a deleterious effect on microbial populations. Furthermore, there was no negative effect on carbon or nitrogen mineralization with microorganisms appearing to respond positively to glyphosate.

Another wildlife category that is expected to benefit from no-till is invertebrates, including earthworms and insects. Warburton and Klimstra (1984, p. 328) reported statistically significant increases in invertebrates in no-till corn fields compared with conventional tillage. These were attributable to crop residues and vegetation, which provided over-wintering habitat. In an Indiana study, Griffith, et al. (1986) found 230,000 earthworms per acre (568,322 earthworms per hectare) on contiguous soybean fields under conventional tillage, compared with 500,000 earthworms per acre (1.235 million earthworms per hectare) under no-till (Scardena, 1996, p. 20). Warburton and Klimstra (1984) noted greater diversity of insect species, including a higher proportion of predators and fewer herbivores, in the no-till versus the conventional fields. This evidence suggests greater niche variety and the potential for greater biological control of plant-eating insects. Steffey (1995) also noted that reducing the disturbance of residue and the top few inches of the soil profile favors the survival and development of ants, ground beetles, rove beetles and spiders. These arthropod groups contain a number of generalist predators that feed on other insects.

In direct relation to invertebrate populations are the bird species living in or near agricultural land require nesting, food sources and brood habitat. The habitat provided by crop residue in no-till soybean stands with closed-canopies correlate to higher densities of bird species (Castrale, 1985). A large variety of bird species use these fields during the breeding season and feed there during spring and fall migrations (Best, 1995). Studies in Iowa (Basore, et al., 1986), Illinois (Warburton and Klimstra, 1984) and Indiana (Castrale, 1985) support these findings. For example, Warburton and Klimstra (1984) observed 14 avian species (in 265 observations) on no-till fields in southern Illinois, that included red-winged blackbirds, mourning doves, field sparrows, indigo buntings, bobwhite quail, common grackle and killdeer, among others. In comparison, conventionally-tilled fields produced fewer species in 93 observations.

Recent analyses of quail habitat, in particular, indicated that no-till soybeans offer quail chicks the most efficient feeding opportunities for insects. Table 15 shows the amount of time 10- to 13- day old quail chicks required to satisfy a daily insect requirement. No-till soybeans satisfy this requirement in 4.2 hours, essentially equal to fallow fields, and superior to field edges, corn, or cotton (Anderson, 1997). In an analysis of no-till soybeans on quail habitat, ecologists and biologists have concluded that herbicide treatments on no-till do not appear to generate reproductive impairment, and that no-till soybeans provide ideal cover and feeding for young quail (Kidwell, 1996, p. 36).

Commonly studied avian species related to tillage practices are ducks. Cowan (1982), in an early analysis of no-till impacts on waterfowl, found that ducks nest readily in fields with stubble remaining, whereas tillage operations severely limits their production. Table 16 shows duck nests in croplands and native cover under zero and conventional tillage in the “prairie pothole region” of Manitoba. Although the study considers no-till wheat, its findings relate to soybeans as well. The table shows that densities of nests on zero tillage areas was 1.5 to 1.4 times greater than on conventionally-tilled areas in 1977 and 1978, respectively. Subsequent analysis of no-till nesting habitat supports this research (Duebbert and Kantrud, 1987; Fisher, 1993).

Table 15: Amount of Time Quail Chicks Need to Satisfy Daily Insect Requirement

Field or Field Border	**Hours Required***
No-till Soybeans	4.2
Fallow Fields	4.3
Soybean Field Edge	9.3
No-till Corn	11.1
Corn Field Edge	15.2
Conventional Cotton Field	18.1
Conventional Soybean Field	22.2
Conventional Corn Field	25.1

*for 10- to 13-day-old chicks.

Source: Anderson, 1997.

Table 16: Duck Nests per Hectare in Croplands and Native Cover of Farms Under Zero Tillage and Conventional Management
(total hectares studied in parentheses)

	Zero Tillage*			Conventional Tillage		
Year	Field Cover	Native Cover	Total	Field Cover	Native Cover	Total
1977	0.12 (103)	0.25 (36)	0.15 (139)	0.0 (98)	0.38 (34)	0.10 (132)
1978	0.25 (32)	1.88 (8.5)	0.59 (40.5)	0.04 (45)	1.77 (13)	0.43 (58)
Avg.	0.15	0.56	0.25	0.01	0.77	0.20

Source: Cowan, 1982, p. 306. *Zero tillage is another term for no-till often used in Canada.

A second category of wildlife benefits relates to small mammals. Conservation tillage, especially no-till, tends to diversify populations of these mammalian communities, rather than increasing total populations (Young, 1984). This is relevant to concerns over possible rodent damage to newly planted crops. Clark and Young (1986) found that such damage on fields is usually localized and generally insignificant (Best, 1995, p. 54).

In addition to terrestrial invertebrates, tillage practices can have profound impacts on stream- and lake-dwelling insects. Reduced erosion and runoff from no-till fields has an important impact on sediment and nutrients flowing into water bodies. Perhaps more significant, soils under conservation tillage retain and biodegrade pesticides, offsetting the greater reliance on herbicides for weed control, especially under no-till (Fawcett, et al., 1994; Struger, et al., 1989; Helling, et al., 1998). In a recent analysis of these effects, Barton and Farmer (1997) concluded that across a wide variety of soils, slopes and cultivation practices, responses of water-dwelling invertebrates to tillage practices were very consistent. Streams draining land under "conservation tillage supported more diverse assemblages of invertebrates, including larger numbers of less tolerant species, which more closely resembled communities in relatively undisturbed reference streams, than did matched streams draining conventionally tilled fields" (Barton and Farmer, 1997, p. 214). The result of increased invertebrates in streams and lakes is increased food availability for fish, amphibians and birds. Species such as trout benefit particularly from reduced sediment, runoff of pesticides, and increased insect populations (see Roley, 1994).

In summary, evidence supports subsequent improvements in wildlife habitat and biodiversity in conjunction with conservation-till, soybeans and Roundup herbicide. This increase extends across a wide range of species from earthworms and other soil-dwelling creatures, to avian species such as quail and ducks, to small mammals, to terrestrial and aquatic invertebrates and fish. These impacts are reinforced by the Roundup Ready soybean system because soybeans provide excellent food sources and cover, and Roundup has low toxicity along with non-persistence and low mobility.

Benefit 4: Carbon Sequestration

Soils function as either a source of, or sink for, atmospheric carbon (C) (Johnson and Kerns 1991) and may play an important role sequestering carbon. Sequestration is the process by which CO_2 is removed from the atmosphere by plants and returned to the soil by the plant decomposition process. The soil binds the carbon and prevents future oxidation and formation of CO_2. Soil organic matter, considered to be the largest global terrestrial carbon pool (Post et al. 1990), influences atmospheric content of CO_2, CH_4, and other greenhouse gases (Bouwman 1989). It is also important for plant nutrition (Stevenson 1982), soil structure, soil compactibility (Soane 1990), and moisture content of the soil (DeJohg et al. 1983).

Conventional tillage does not encourage carbon sequestration and often accelerates the release of carbon into the air as CO_2; however, conservation tillage, especially no-till, increases the soil's potential for holding carbon (Kerns and Johnson 1993). It builds organic matter and prevents the oxidation of carbon and subsequent release into the air as CO_2. Conversely, intensive conventional tillage leads to losses of soil carbon (C) estimated at 30 to 50 percent (Schlesinger, 1985). These effects are closely related. Over time, agricultural expansion under conventional tillage has reduced the capacity of soils to absorb carbon and sped the release of CO_2 from the soil. It also has enhanced the oxidation process of organic matter, thus increasing CO_2 emissions from soil, which contributes to rising atmospheric CO_2 levels (Post, et al., 1990).

In a series of papers, Reicosky, et al (1995), reviewed field data showing that conventional tillage, especially moldboard plowing, decreased soil carbon levels. Reicosky (1995, p. 52) noted that moldboard plowing fractures and opens the soil, allowing rapid CO_2 exchange. By incorporating residue into the soil, conventional tillage also feeds a microbial "population explosion" as rates of decomposition increase, further reducing carbon stores. With no-till practices, by contrast, crop residues left on the surface decompose much more slowly, so that carbon is sequestered in the soil. In a detailed quantitative assessment of these effects, Reicosky found that CO_2 flux from soils is associated directly with tillage methods that limit soil disturbance. Those that minimize depth and extent of soil disturbances will have the lowest levels of flux, supporting the use of no-till from the perspective of improving CO_2 sequestration.

Figure 12 shows fall tillage methods in 1991 as analyzed by Reicosky and Lindstrom (1995, p. 185), comparing moldboard plow (MP), moldboard plow plus disk twice (MP+D), disk harrow once (DH) and chisel plow once (CH), all of which are compared in turn to no-till. As the graph shows, no-till has the lowest level of CO_2 flux of any tillage method, at any of the time-frames analyzed.

Kern and Johnson (1993, p. 208) estimated changes in soil organic carbon (SOC) with conservation tillage versus conventional tillage at three levels of conservation tillage to the year 2020. With 57 percent conservation tillage on all U.S. field crops by 2020, net gains of 80 to 129 Trillion grams (Tg) (Tg = 10^{12}g = 1 million metric tons = 1.102 million tons) of soil organic carbon were estimated. If conservation tillage rose to 76 percent by 2020, net gains of 123.4 million tons (112 million metric tons) to 203 million tons (184 million metric tons) of carbon were estimated. If full conversion to no-till occurred on the same 76 percent of acres by 2020, net gains of 315 million tons (286 million metric tons) to 516 million tons (468 million metric tons) of carbon in soil would result. Therefore the 21.6 million acres (8.74 million hectares) of soybeans would sequester 37.1 Tg Carbon, which is 40 million tons (37.1 million metric tons) by the year 2020 . If no-till soybean acreage increases, as expected, that amount also would increase. The role of the Roundup Ready soybean system in encouraging the conversion to conservation tillage thus has important implications for carbon sequestration.

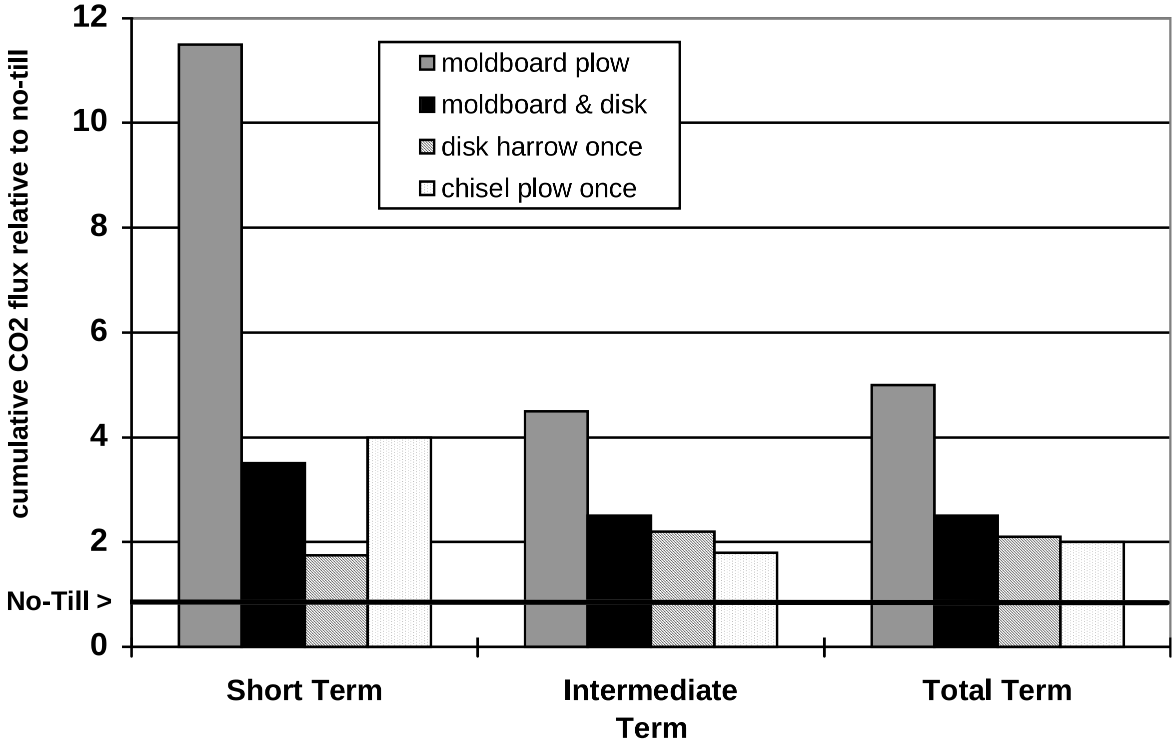

Figure 12 : Cumulative CO_2 Flux from Tillage Treatments Relative to No-Till for Three Different Periods
Source: Reicosky and Lindstrom, 1995, p. 185.

In summary, one of the important contributions of the growing use of no-till will be the sequestration of carbon and the reduction in cumulative loadings of atmospheric CO_2. As soil organic matter increases in no-till fields, these fields will serve as a sink rather than a source of CO_2. Soybeans accounted for 71 million acres (28.7 million hectares) in 1997 in the United States alone. The Roundup Ready soybean system's encouragement of the adoption of no-till represents a significant contribution to reducing these risks (Kern and Johnson, 1993; Alesii, 1997).

Benefit 5: Reduced Fuel Use and Carbon Dioxide (CO_2) Emissions

Reduced fuel use and a corresponding reduction in fuel emissions are associated with no-till and the Roundup Ready soybean system, regardless of tillage system. Both conserve fuel by reducing trips across the field as compared to traditional seed/herbicide combinations and conventional tillage.

Agriculture in the United States uses only about three percent of the total U.S. energy budget, of which tillage accounts for 8.3 percent, or about two-tenths of one percent of the total (Frye, 1995, p. 32). Even so, experts agree that conservation tillage uses less tractor fuel than conventional plowing, thus reducing fossil fuel use and emissions. Using Frye's (1984,1995) estimates (Table 17), a farmer uses approximately 5.44 gallons diesel fuel equivalents (DFE) per acre in a conventional tillage system. This estimate covers all tillage (plowing, disking, cultivating), planting, and herbicide and fertilizer applications. In comparison, the Roundup Ready soybean system in conventional tillage requires no cultivation but increased herbicide applications. However, the total fuel expended per acre is 3.95 gallons DFE per acre (36.9 liters per hectare). A benefit on fuel use is thus evident in the Roundup Ready soybean system.

No-till provides even further fuel savings over conventional tillage, which when coupled with the Roundup Ready soybean system are even larger. In no-till, herbicide applications replace tillage and cultivation. Using an estimate of three herbicide application per acre for pre-plant and in-crop applications, the total fuel use in no-till is approximately 1.92 gallons DFE per acre (17.95 liters per hectare), which is 3.5 gallons (13.23 liters) less than conventional tillage with traditional seed.

Table 17: Estimated Average Energy Requirements for Selected Tillage Operations and Production Inputs for the Roundup Ready Soybean System
(based on corn figures)

In gallons DFE per acre*	Traditional Seed in Conventional-till	Roundup Ready Soybean System in Conventional-till	Roundup Ready Soybean System in No-till
Moldboard Plowing	1.82	1.82	0

Disking	0.62	0.62	0
Field Cultivation	0.64	0	0
Planting	0.43	0.43	0.43
Weed control**	0.75	.33***	.33***
2nd Field Cultivation	0.43	0	0
Fertilizer	0.75	0.75	1.18
Approximate Total	5.44	0.75	1.18

**Diesel Fuel Equivalent (gallon DFE = 155 MJ energy)*
*** For weed control, 0.75 gallons DFE per acre is used for spraying or soil incorporating herbicides and 0.11 gallons DFE per acre is used for spray herbicides without incorporation. The Roundup Ready soybean system does not use soil-incorporated herbicides.*
**** Assumes at least three passes for herbicide treatments.*

Source: Based on Frye, 1984, 1995.

Frye's numbers are consistent with CTIC estimates. CTIC states that because only one trip across the field is needed in addition to planting no-till acres, compared with two to three tillage trips (as well as a planting trip) for conventional tillage, fuel use is reduced by 3.5 gallons of diesel fuel per acre (32.74 liters per hectare) per year under no-till (CTIC, 1997d).

A study of fuel use in different tillage systems by Slemens, et al. (1986)[17], found that while fuel use is sensitive to soil type and conditions, tractor fuel efficiency, implement type and operator skills, no-till field operations required 1.65 gallons DFE per acre (15.4 liters per hectare) compared with 6.60 gallons DFE per acre (61.74 liters per hectare) for moldboard plow

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[17] All of the reported studies are for corn. Because of corn's high nitrogen needs, total energy savings for no-till systems are highly sensitive to the form and rate of nitrogen fertilizer application. Nitrogen fertilizer inputs represent the largest energy input in a typical corn-soybean rotation, because natural gas is the raw material used to manufacture it. When total energy inputs for two Iowa fields were totaled over a five year period, fertilizer accounted for 75 percent of energy consumed, machinery for 14 percent, grain drying for 6 percent, and chemicals including herbicides for 5 percent (Karlen, et al., 1995).

conventional-tillage, a difference of 4.95 gallons DFE per acre (46.30 liters per hectare). However, herbicide requirements for no-till were equivalent to 2.88 gallons per pound (26.94 liters per kilogram) compared with 1.75 gallons per pound (16.37 liters per kilogram) for conventional till. Again, these estimates are consistent with those of the CTIC and Frye.

A decrease in fossil fuel emissions corresponds directly with a decrease in fuel use. Kern and Johnson (1993) estimated the impact on fossil fuel emissions due to conversions from conventional tillage to no-till. Their estimates, based on those of Frye (1984), indicate that such conversions will prevent 21.24 pounds per acre (23.8 kilograms per hectare) per year of carbon from being released into the atmosphere each year (as CO_2) from fossil fuel used in various tillage operations, equivalent to 5.7 gallons of number two diesel fuel per acre (53.3 liters per hectare) (Kern and Johnson, 1993, p. 208). Multiplied times the 21.6 million no-till soybean acres in 1997, the implication is that current conversion to minimum-till practices on soybeans prevent 417,000 tons (378,219 metric tons) of carbon from entering the atmosphere, equivalent to 80.8 million gallons (305 million liters) of number two diesel fuel.

In summary, both no-till and the Roundup Ready soybean system appear to offer fuel and emission savings per acre over conventional tillage and regular seed/herbicide systems, respectively. The greatest gains occur in the no-till system.

Summary and Conclusions

This study synthesized findings from diverse fields, offering an evaluation of the agronomic, economic and environmental effects of the Roundup Ready soybean system and no-till. It is important to emphasize that the findings of this study primarily reflect developments in a specific growing region – the North-Central United States. This region is generally representative of soybean-growing areas in the world, thus it is reasonable to suggest that many of the effects considered here are likely to occur wherever soybeans are grown, especially in combination with conservation tillage. Much additional analysis and research is required to fully grasp the implications of the Roundup Ready soybean system for sustainable agriculture. The study needs to be expanded to all United States and worldwide areas to continue to judge the sustainable impacts of the Roundup Ready soybean system.

The key findings of the study are as follows:

1. The Roundup Ready soybean system has proven its agronomic and economic advantages in the short time since its introduction. These advantages have led to rapid rates of adoption by U.S. farmers, who produce and export more soybeans than any other producers in the world. Of the 1997 growers surveyed, nine out of 10 growers were satisfied with Roundup Ready soybeans, and 87 percent said they gave much better or somewhat better value than traditional herbicide programs.

2. The specific advantages leading to rapid adoption of the Roundup Ready soybean system involve the improved capacity for weed control and maximized yields relative to regular seed /herbicide systems. In addition to the agronomic advantages of Roundup herbicide, yield studies from 1996 and 1997 indicate advantages of approximately two bushels per acre (0.124 metric ton per hectare) more than with regular seed/herbicide combinations, with no evidence of yield disadvantages.

3. The Roundup Ready soybean system is highly compatible with conservation tillage, especially no-till, and will make adoption of the system even more attractive. No-till confers cost advantages overall in the range of 10 to 20 percent, despite additional herbicide costs. Roundup herbicide can be used more flexibly and efficiently than many other herbicides,

especially as part of the Roundup Ready soybean system. Hence, adoption of conservation tillage will be assisted by the weed controlling capacity of the Roundup Ready soybeans system. This system in combination with no-till practices requires no plowing, fewer trips across the field for cultivation (mechanical weeding), and saves on fuel, time and machinery expenses. Fuel savings were estimated at 3.5 gallons of diesel fuel per acre (32.7 liters per hectare) per year, and labor/time savings at 450 hours per year. Machinery wear was reduced by an estimated $5.00 per acre ($12.35 per hectare) per year. Many of the environmental benefits of the Roundup Ready soybean system will occur in tandem with no tillage.

4. The Roundup Ready soybean system in 1996 and 1997 resulted in reduced in-crop requirements for pounds of active ingredient herbicide. Pounds of in-crop active ingredient used in the Roundup Ready soybean system fell by 22 to 26 percent in the total study area.

5. Conservation tillage reduced erosion due to wind and water by 90 percent or more compared with conventional tillage. Water erosion levels were simulated on no-till fields at 14 to17 percent of those on conventionally tilled fields, resulting in soil savings from 1.33 tons per acre (2.9 metric tons per hectare) to 18 tons per acre (40 metric tons per hectare) per year. Wind erosion levels were simulated at 4 to 15 percent of those conventionally tilled fields, equal to 1.66 tons per acre (3.7 metric tons per hectare) to 2.76 tons per acre (6.2 metric tons per hectare) per year.

6. Soil quality also is enhanced by conservation tillage, especially no-till. Soil organic matter increases, raising soil productivity, reducing compaction and increasing the ability of the soil to retain plant nutrients. Earthworm populations increased by two to three times, from 230,000 to 500,000 earthworms per acre (568,322 to 1.2 million per hectare). Water infiltration increased from two- to 15- fold. Soil organic matter increased dramatically, by as much as 0.1 percent per year. Soil compaction reduces and soil porosity increases, together with soil fertility.

7. Conservation tillage positively affects both water quality and quantity. Surface water quality is affected primarily by reduced sedimentation and runoff of water from fields. Water runoff was reduced by 30 percent in one study from 46,233 gallons per acre (432,278 liters per hectare) to 32,766 gallons per acre (306,362 liters per hectare). A larger natural rainfall study estimated reductions in pesticides runoff of 70 percent and water runoff of 69 percent. Since Roundup herbicide binds tightly to soil particles, its mobility is largely determined by soil movement itself. Reduced concentrations of nitrogen leaching through soils benefit groundwater. Soybean nitrogen fixation reduces the need for additional nitrogen fertilizer on crops grown in rotation. Conservation tillage increases nitrogen fixation to 85 percent compared with 75 percent on conventionally tilled fields in one study. Water quantity also is improved by increased infiltration and reduced runoff and evaporation, increasing soil moisture. Cumulative evaporation rates under no-till were less than half those under conventional tillage five hours after tillage in a Minnesota study.

8. Conservation tillage increases wildlife habitat in fields and water bodies drained by them, thus impacting biodiversity. These benefits range from micro-organisms to soil-dwelling

earthworms to quail, ducks and other birds, small mammals, insects and fish. In a study of 14 avian species, no-till fields resulted in 265 bird observations compared with 93 observations on conventional tilled fields. Quail chicks can satisfy insect requirements on no-till soybeans in 4.2 hours, compared with 22.2 hours on conventional soybean fields. Duck nesting habitat on no-till fields averaged 1.5 times greater than on conventional tillage in one study. The environmental profile of Roundup makes it of particular value from the point of view of wildlife conservation.

9. By leaving crop residues on the surface, conservation tillage reduces the release of CO_2 into the atmosphere. This allows no-till fields to function as a carbon sink, with implications for global climate change. Carbon sequestration measured by CO_2 flux from soils is lower on no-till than any other tillage system. Estimates of soil organic carbon saved by soybeans already in no-till to the year 2020 equal 40 million tons (37.1 million metric tons), and will increase as no-till is more widely adopted under the Roundup Ready soybean system.

10. The Roundup Ready soybean system and no-till save on fuel due to fewer passes across the field. This further reduces the consumption of fossil fuels and volume of CO_2 emissions. No-till was estimated to use 9.8 percent less fuel than conventional tillage, averaging 4.3 gallons per acre (40.2 liters per hectare). More recent studies estimate total fuel saved as equivalent to 3.5 gallons per acre (32.7 liters per hectare). Various other estimates are consistent, indicating savings from no-till in the range of 3.5 to 4.2 gallons per acre (32.7 to 39.3 liters per hectare).

11. In the final analysis, the benefits of coupling the Roundup Ready soybean system with conservation tillage are both private and public. Private gains accrue to producers due to the agronomic and economic advantages of the biotechnology. Public gains result from the advances in environmental sustainability, including soil conservation, water quality improvements, wildlife habitat benefits, carbon sequestration and reduced fossil fuel consumption.

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