Herbicide development and marketing of weed control in the United States of America

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Summary

The discovery of the phenoxyacetic acid herbicides initiated the "chemical era" of weed control. At this time, United States agriculture was expanding greatly because of the large demands for food. In 1945, 2,4-D was first marketed in the United States. The enthusiasm for, and success of, 2,4-D fuelled the search for other synthetic herbicides. By 1980, 90 – 95% of the cropland planted to major crops was treated with herbicides. Corn (*Zea mays* L.) and soybeans (*Glycine max* (L.) Merr.) account for 80% of the herbicide market for major crops in the United States. The amide and triazine herbicide classes have dominated the herbicide market since 1976, but, newer, more active herbicides are becoming popular. Herbicides have proven themselves to be economically beneficial and critical for high production agriculture. Selling herbicides has become very sophisticated and competitive with market maturation.

Market segmentation created additional opportunities for the industry to develop new products. Increasing costs and lack of discoveries forced numerous companies out of the business. Regulatory and environmental pressures are causing the agrichemical industry to develop a new marketing strategy.

The evolution of regulatory legislation in the United States which lead to the creation of the Environment Protection Agency (EPA) in 1970 and the passage of the Federal Environmental Pesticide Control Act (FEPCA) in 1972, is discussed. FEPCA and its amendments have been very costly to the agri-chemical industry. Registration costs and development time have soared. Fewer products are being discovered, and then only for major crops. Regulations, however, have not decreased the use of herbicides.

Pesticide regulations are very capable of protecting human health and the environment in the United States. However, major improvements are necessary in the registration process, in order to avert serious damage to the agricultural industry.

Introduction

"I will go root away the noisome weeds, that without profit suck the soil's fertility from wholesome flowers." – Shakespeare, Richard II, Act iii. sc. 4.

Weeds and their control are as old as history. They were there in the Garden of Eden and they are in my garden in Greensboro, North Carolina today.

Shakespeare mentioned weeds disparagingly in at least six of his plays written between 1592 and 1599, one being Richard II. Centuries passed and weeds remained; the general philosophy appeared to be that weeds were a curse that had to be endured, and about which little could be done. Weeds remained an obstacle to agricultural production into the early part of this century. Table 1 depicts the chronological progress of weed control as compiled by Timmons (12). It can be seen that during the period 1941 – 1968, 0.35% of the 7,970 years since stabilized agriculture began, the greatest advances in weed control were made. It was during this period that weed control became a science. The phenoxyacetic herbicides were discovered and the potential for chemical weed control was realized. The "chemical era" of weed control began.

This paper reviews the history of herbicide development over several decades, with particular emphasis on issues affecting consumer acceptance, such as marketing techniques, regulations, public perception, and legislation. Trends and recommendations for the future will be discussed.

Discovery and growth

The world was at war in the early 1940s. A major reason for the significant growth of United States agriculture was the need created by the devastation of food production in areas of the world ravaged by war. Ironically, the discovery of the herbicidal properties of 2,4-D was linked to the government's interest in developing tools for chemical warfare (11). Scientists researching 2,4-D and related plant growth hormones were convinced that these chemicals had great possibilities in agriculture.

Several chemical companies were interested in marketing 2,4-D in 1944. The American Chemical Paint Company marketed the first selective herbicide produced on a commercial scale, under the brand name "Weedone", in 1945. The enthusiasm for this new chemical weed killer was demonstrated by the production statistics from 1945 to 1964, when the consumption of 2,4-D rose from 417,000 to 24.1 million kilograms

The growing interest in chemical weed control stimulated industry to research and develop better herbicides. In return, these products fuelled a significant increase in herbicide use. In 1964, 32.3 million kilograms of herbicide active ingredients were consumed; this represented 31% of the total amount of pesticides used. Insecticides were the biggest component of pesticides used in 1964, at 52%. Within the next seven years, herbicide usage surpassed insecticides and reached 82% of total pesticide usage in 1982 (10).

Only about 10% of the cropland in the United States planted to the major crops – corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), soybeans (*Glycine max* (L.) Merr.) and wheat (*Triticum aestivum* L.) – was treated with herbicides in 1952, but the share jumped to 90 – 95% by 1980 (10). The trend in herbicide use in crop production is illustrated in Figure 1 (1,2,10). In 1964, corn and wheat accounted for the majority of crop herbicide use. By 1971, soybeans became the second largest market for herbicides. Today, more than 80% of the herbicide market for crops is in corn and soybeans. No doubt 2,4-D set the stage for chemical weed control; newer classes of herbicides were subsequently discovered that popularized the use of chemical weed control. Herbicide application became a part of the farmer's cultural program. The estimated total amount of herbicide used in food crops in the United States has decreased based on 1990 surveys conducted by the United States Department of Agriculture (USDA) (1,10). There are probably three reasons for this trend; (1) total hectares planted to the major crops, corn and soybeans, is lower, (2) growers are using lower rates, and (3) new herbicides are more active.

By 1966, the post-emergence herbicides started to lose their dominance to pre-emergence herbicides like the amides, carbamates and triazines (Table 2) (1,10). These three classes shared 75% of the market in 1982. In 1990, the triazines (atrazine) and amides (alachlor, metolachlor) remained as the dominant classes of herbicides (13). Newer classes of chemicals have recently appeared and have become very important. In the 1990 consumption data (Table 2) two important new classes, imidazolinones and sulfonylureas do not appear – their proportion of the herbicide consumption being less than 1%. However, the sulfonylureas and imidazolinones respectively treated 24% and 27% of the soybean crop in 1990, versus 23% treated with amides, but it required significantly less to do so; 80 times less material in the case of the sulfonylureas (Table 3) (1).

In 1971, the nitrophenols were a growing class of herbicides, but by 1990, this class disappeared primarily because the EPA had banned their use. These two events, the discovery of highly active herbicides and the impact of EPA regulations, are having a significant impact on herbicide development

Herbicide benefits[1]

There has been considerable research conducted and papers published on the benefits of pesticides, and herbicides in particular, to the agricultural revolution in the United States. The efficiency and productivity of the American farmer would not be possible without these modern tools. The great demands to increase food production, which began in the 1940s, required farmers to become more efficient. The farm population in 1940 was 30 million and declining sharply; by 1985, it had dropped to less than 3 million. This meant fewer farmers were available to produce a greater quantity of food. Higher inputs in the form of

[1] Personal communication with Mr. Arnold Vogt, Ciba-Geigy, Greensboro, NC.]

agricultural machinery and chemicals, and less labour, were necessary to increase productivity. The United States Office of Technology estimates that by the year 2000 as few as 50,000 farms may account for as much as 75% of the United States agricultural production – illustrating the tremendous efficiency of our farmers. A summary of economic statistics that have been influenced by the availability of effective agricultural chemicals is presented in Table 4 (3,4,5,10). Herbicides have played an instrumental role in improving crop productivity at minimal expense.

The land area devoted to the major crops – corn, cotton and wheat – has not increased; the one exception is soybeans. Though farm legislation has an influence on the area under tillage, farmers can grow more on less land. Compare the yields for corn, cotton, soybeans and wheat in 1952 versus 1990 (Table 4.1). Certainly, improved crop varieties, fertilizers, insecticides and fungicides play important roles, but also note that herbicides were used on 95% of the hectares for each crop, except wheat, in 1990.

In the period 1947 to 1986, farmers used 73% less labour while increasing their investment in agricultural chemicals appreciably. The herbicide proportion of the latter input would be small, since the total pesticide share of operating expenses was 5.5% in 1987. During this same period, agricultural productivity grew by 230% (10).

During the recent twenty-year period (1968-1988) pesticide costs have decreased significantly when measured against other input costs or crop production (Table 4.2). In 1977 dollars, the index of pesticide costs to labour costs decreased by 55%. Similarly, the indices of pesticide costs to machinery and fuel costs decreased by 58% and 48% respectively. Notably, pesticide costs as measured against declining crop prices also decreased by 20%, further illustrating the economic benefit of pesticides in crop production (Table 4.3).

Several studies have shown pesticides to be efficient production inputs. One in particular estimated an average return of $3.30 to $4.90 per herbicide dollar in corn production compared with not using herbicides, but increasing cultivation (9). There is no doubt in my mind that wise selection and use of herbicides is economically beneficial. The farmer should be the judge of the best weed management program for each situation, without being unduly impeded by environmentalists, regulators and legislators.

Marketing weed control[1]

Truly competitive marketing of herbicides did not begin until the late 1960s. Prior to this, marketing principally consisted of "taking orders". Distribution was mainly through fertilizer dealers, and crop protection products were secondary.

As new herbicide active ingredients were being introduced after 2,4-D, marketing strategies started to develop. During this period, marketing was mainly selling the concept of chemical weed control and not product against product. Crop protection chemicals became routine rather than "as needed". With this came the emergence of pesticide specific distributors. Late in the decade selling products, like atrazine, became extremely price competitive among dealers, especially distributors. Sales programs generally offered early-order and early-take to get the best price. Large-scale advertising started to develop, especially in the print media.

The next ten years, beginning in 1970, was the "golden era" of herbicides for chemical companies. From 1966 to 1971, the consumption of herbicides went from 45 million kilograms to over 90 million kilograms and by 1976, had doubled again (Figure 1). Approximately 35 basic manufacturers were competing against one another for a share of the booming marketplace (6). Competition became more intensive. The market was starting to be divided into segments, like pre- versus post-emergence, broad-leaved weeds versus grasses, and various types of formulations. Pre-packaged herbicide mixtures, such as atrazine and alachlor, were being introduced to farmers. Large sums of money were now being spent on advertising on television. Crop yield was a key issue in herbicide promotions.

The number of competitors started to decrease because of less success in finding innovative products. Companies were being bought outright or merged with one another to become more competitive. This was to become more common in the next decade. Annual sales climbed over $100 million per year for the bigger companies.

[1] Personal communication with Mr. Bruce Yergler, Ciba-Geigy, Greensboro, NC.)

It seemed as if a company would just start to realize success with a unique proprietary product when the product would become a commodity due to patent expiration. Atrazine was the first major herbicide to go 'off patent' in 1976. Companies had to start planning in advance patent expiration strategies to protect their big investments. At the time of the atrazine patent expiration, Ciba-Geigy sold over $100 million worth of it in the United States; it was Ciba-Geigy's major product. A modern and highly efficient atrazine production facility had been constructed for $52 million and could produce 50 million kilograms of active ingredient per year. New formulations of atrazine were introduced. A pre-pack (pre-packaged mixture) with metolachlor came on the market in later years. Emphasis was placed on product quality and customer service. All these efforts helped to alleviate large in-roads by other atrazine competitors, especially foreign sources.

The herbicide market growth slowed down in the mid-1980s; the major markets became saturated, 90 – 95% of the area was treated. Emphasis turned to stronger market segmentation, like conservation tillage, control of specific weed species and double-cropping. Pre-packs were prevalent, and were used in market strategy. Consolidation of the chemical industry continued as research expenditures increased significantly, due principally to extreme regulatory requirements for EPA approval. Pioneers in the early development of herbicides, like Stauffer (thiocarbamates) and AmChem (2,4-D and chloramben), disappeared after being purchased by other giants. Advertising was now being directed to growers by the use of direct-mail techniques; direction was stronger to the large, professional farmer who was a much better business person than in earlier days. The use of television for product advertising started to decrease in the late 1980s. Herbicides started to be sold in bulk containers rather than in packages. EPA regulations started to have a major impact on herbicide marketing in the later part of the 1980s. Some of the areas that were affected were: products disappeared (nitrophenols), crop uses were reduced, formulations started shifting from liquid to dry, efforts to reduce soil mobility were increased, and restrictions on soil textures and methods of application became necessary. Manufacturers started to become more visibly and publicly concerned about environmental impact. They used it in advertising, product promotions, and customer services to improve their images.

By 1990, the total amount of herbicides consumed in the United States for crop production had dropped from a high of 216 million kilograms in 1988 to approximately 173 million in 1990 (Figure 1) (2,8,10). Some of the volume decrease is due to the introduction of new active ingredients. The value of this market, however, is $2.5 billion and still remains attractive to the fewer companies left (8). The number of basic manufacturers has dropped from 35 to 17 in 1991 (6).

Competition among the remaining companies has become very intense, as they vie for a larger share of mature markets. Most companies have introduced marketing programs which encourage sales by offering financial incentives to distributors who exceed specified volume levels; some have programs that offer bonuses based on the market share of their product line.

Some projections of what the marketplace will be like in the next decade are as follows:

1. Farms will continue to grow in scale.
2. Farmers will continue to become more educated and business oriented; they will be more environmentally conscientious.
3. Sales personnel will need to have more technical training as new products and markets become more complex.
4. Dealers will be 'mega-dealers' and have large investments in environmental stewardship.
5. There will be fewer basic manufacturers.
6. Manufacturers will have to continue to provide and increase environmental education and services to farmers and dealers.
7. "Relationship Marketing" will take on more importance and replace the mass media approaches, especially the use of television.
8. Advertising and product promotion will be more educationally oriented.

Of course, some of these projections have been under way for a few years, but caused by public pressure and competition.

Regulatory impact[1]

Until the mid-1960s, the primary purpose of regulatory policy in the United States was to protect consumers from ineffective and acutely toxic products. In the early twentieth century, agricultural chemicals consisted mainly of insecticides and fungicides. The regulation of such pesticides started with the Insecticides Act of 1910 (7). This statute was essentially a labeling one; it did not require registration nor establish significant safety standards for pesticides. The use of pesticides remained low, so there was little pressure to regulate them; the Insecticide Act remained intact for 37 years.

By World War II, synthetic organic pesticides had emerged, demonstrated great effectiveness, and received rapid market acceptance. In 1947, Congress replaced the Insecticide Act with the more comprehensive Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). This law required that pesticides be registered by the USDA before their sale or distribution in interstate or foreign commerce. Also, products were required to have warnings on highly toxic pesticide containers, and instructions for their safe use.

Numerous changes have occurred in pesticide regulatory law since the FIFRA of 1947. Since the 1960s, the American public has expressed concerns about the potential health, safety, and environmental effects of pesticide use. Important issues have included residues in food, farm worker safety, cancer risks, birth defects, impact on wildlife and endangered species, and groundwater contamination. Agricultural chemicals have been, and continue to be, a target for environmentalists attempting to raise the awareness of the public and legislators about real or perceived effects of pesticides. As a result, 10 federal statutes have been passed to regulate pesticides. A chronology of the regulatory legislation and intent is presented in Table 5. Highlights of regulatory history have been the creation of the EPA and the passage of FEPCA in 1972 which overhauled FIFRA and initiated the re-registration process.

FEPCA and its subsequent amendments are having a major impact on the pesticide industry. There has been a downward trend in the number of new pesticides approved since 1975 (6). The impact has been greater on insecticides than herbicides. The industry is intensively involved in re-registering the commercial products that have been on the market for ten or more years. The cost and resources involved in this process have diverted some of the research and development (R&D) efforts of the industry away from new products. Based on a National Agricultural Chemicals Association survey, basic pesticide manufacturers spent 28% of their total R&D expenditures on product defense and re-registration in 1990 (personal communication, Mr. Lawrence Norton, National Agricultural Chemicals Association, Washington, DC).

Development cost for a new product today is in the range of $15 million from discovery to EPA approval. In the 1960s, the cost was approximately $5.5 million. The prohibitively high costs are forcing companies to seek registration in only the most lucrative markets. The number of basic manufacturers has dropped drastically because of exorbitant research and development expenses. From 1972 to 1990, there were a total of 61 companies that were granted registrations by the EPA for new active ingredients to be used in agriculture (6). Over 50% of these registrants are no longer in the business, either having given up totally on the pesticide business or having merged or been absorbed by another company. Such pioneering names as AmChem, Chipman, PPG, Shell (in the U.S.A.), Stauffer, and Union Carbide have disappeared from the agrichemical marketplace.

The dramatic change in the emphasis of the pesticide policy has actually had little effect to date on the percentage of crop area receiving herbicides. The quantity of herbicides used has decreased principally because the newer herbicides have lower use rates (Figure 1). Regulatory policy has certainly had an impact on the type of herbicides being researched over the last decade. The maturity of the herbicide market has also had an influence on the number of companies interested in making further costly commitments to pesticide research.

The pesticide regulations in the United States have been very effective from the perspective of protecting human health and the environment. This is especially true from the

[1] Personal communication with R. L. Feulner, Ciba-Geigy Corporation, Greensboro.

standpoint of the new herbicides receiving approval, the re-registration of older products, and the research into alternative pest controls. There are those who would certainly not agree with this viewpoint, but I speak with experience from trying to satisfy EPA requirements. The regulatory process is a disaster. It lacks the credibility necessary to deter spurious claims made by activists against pesticides – products that in reality have benefits which clearly outweigh any potential risks to humans or the environment. The EPA is overburdened with work and lacks the strong leadership needed to rise above the political pressure and unfounded criticism. Regulatory decision-making is too slow and lacks adequate scientific foundation. Decisions are influenced as much or more by politics than science.

Industry and the public both would benefit from a regulatory process grounded in fact, science and objectivity. In such a process, regulatory changes would be made only when justified by science. The regulatory climate would be more stable and regulators better able to function properly and efficiently.

Unless we see improvements in the regulatory process, the outlook for our industry is rather bleak. Development costs will continue to increase and there will be fewer new products, fewer product registrants and fewer basic manufactures. Also, there will be more potential for pest resistance, crop loss and loss of profit for American agriculture. We know that more than 25% of the pesticides registered today will not be available to growers in 1997 – the year the EPA re-registration program is to be completed.

In the United States, unless rational leadership comes forth and more judicious decisions made, the long-term effects of the regulatory process could be devastating to agriculture.

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Table 1 *Chronological perspective of progress in the art and science of weed control.*

Period of Years	Percent of Time	Percent of Progress*	Significant events
B.C. to 1800 A.D.	97.9	1	Hand implements, wood, later with metal points or blades. Cattle drawn implements, wood and metal plows, wheel hoe. Early publications on nature of weeds and problems and damages caused.
1801 to 1900	1.25	4	Improved plows, wheel cultivators, mowers, disks, drags of "horse-power era" Early hand and horse drawn sprayers. Early seed and weed laws. Early use of and research with inorganic herbicides. Increase in publications on nature and distribution of weeds, problems caused and methods of control. Weed control proved chief advantage of cultivating row crops.
1901 to 1940	0.50	15	Transition from horse drawn to gasoline tractor-power implements. Improved blade, shovel and rod weeders and tractor-mounted sprayers. Gasoline powered aquatic weed crusher and saw-boats, chains, and drags. Increased research with inorganic herbicides and cultivation methods. First full- time extension and research weed workers. Fifteen herbicides available for public use.
1941 to 1968	0.35	80	Discovery of phenoxyacetic herbicides. Beginning of "chemical era" of weed control. Number of herbicides available for public use increased from 15 to 100 with emphasis on selective weed control in crops. Rapid increase in research and extension man-power. Organization of state and regional weed conferences and of Weed Society of America. Weed control officially named a science.

*Timmons' estimates of relative amounts of total progress.

Table 2 *Proportions of herbicide classes used on major crops in the United States of America from 1964-1990.*[1]

Year	1964	1966	1971	1976	1982	1990
Class						
Phenoxys	46	38	16	11	5	4
Amides	6	5	22	30	31	33
Triazines	15	21	28	31	27	28
Nitrophenols	1	2	21	8	8	0
Carbamates	7	7	5	10	17	15
Anilines	1	4	6	8	8	12
Other[2]	24	23	2	2	4	8

[1] Proportions based on percentage of total active ingredient applied to major crops to include cotton, corn, soybeans, sorghum, rice, tobacco, peanuts, wheat, alfalfa, other hay crops, and pasture (10). Survey data in 1990 included on cotton, corn, potatoes, soybeans, rice and wheat (1).

[2] The "other" classification was not broken down in the 1964 – 1982 surveys and included numerous classes of less than 24. In 1990 some of the herbicide classes and estimated % are: benzoic acid, 1.8%, glyphosate, 1.3%, ureas, 1.4%, imidazolinones, 0.5%, and sulfonylureas, 0.3%.

Table 3 *The quantity of three different herbicide classes required to treat a given area of soybeans in 1990.*

Herbicide class	% of Hectares treated	Total kg applied x 1000
Amides[1]	23	11,172
sulfonylureas[2]	24	139
Imidazolinones[3]	27	638

[1] Alachlor, metolachlor
[2] Chlorimuron-ethyl, thifensulfuron
[3] Imazaquin, imazethapyr

Table 4 *A summary of economic statistics influenced by the availability of agricultural chemicals in the United States. of America*

	ha (million) 1952	ha (million) 1990	% treated herbicides 1952	% treated herbicides 1990	Yield, kg ha^{-1} 1952	Yield, kg ha^{-1} 1990
4.1 Crop productivity:						
Corn	33	30	10	95	2,628	7,450
Cotton	11	5	5	95	314	719
Soybeans	7	23	0	95	1,394	2,290
Wheat	32	31	12	51	1,240	2,661
4.2 Index of pesticide costs to other inputs[1]	1968		1988		%Change	
Labour	165		75		-55	
Machinery	175		74		-58	
Fuel	155		80		-48	
4.3 Index of pesticide costs to crop prices[1]	156		125		-20	

[1] Index shows relative cost of pesticides to other inputs listed and to crop prices computed on the basis of 1977 ratio = 100.

Table 5 *Federal pesticide legislation in the United States of America, 1990-1990*

Year	Legislation	Intent
1910	Insecticide Act	The first legislation to protect consumers from fraudulent goods; a labeling statute .
1947	Federal Insecticide, Fungicide andRodenticide Act (FIFRA) .	Emphasizes labeling of contents: USDA administers the act.
1954	Miller Amendment to Federal Food, Drug and Cosmetics Act (FFDCA) .	Requires a maximum acceptable level (tolerance) be established for pesticideresidues in foods and animal feed. (Administered by Food and Drug Administration.)
1958	Delaney Amendment to FFDCA.	Regulates pesticide residues in processed food. (Administered by Food and Drug Administration.)
1964	FIFRA amended.	More attention is given to health and the environment. The USDA is authorized to deny, suspend or cancel a registration immediately, if necessary, to prevent an imminent hazard to the public.
1970	President Nixon's Reorganization Plan No. 3.	Creation of the EPA to assume the pesticide regulatory functions of USDA and FDA.
1972	Federal Environmental Pesticide Control Act (FEPCA), amended . FIFRA	Completely overhauled FIFRA and significantly increased the authority of EPA. This is the backbone of current regulation. Set new health and environmental standards. Started the "re-registration" of pesticides registered pre-1972.
1975-1990	FIFRA Amendments.	Amendments in 1975, 1978, 1980, 1988 and 1990 to fine tune FEPCA of 1972.

Figure 1 *Growth of herbicide use in the major crops of the United States, 1964-1990.*