HERBICIDE APPLICATION TECHNOLOGY IN THE UNITED STATES: PAST, PRESENT AND FUTURE

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1. INTRODUCTION

Among the many changes that have occurred in agriculture, few have impacted food production efficiency than those concerning the use of fertilizer and pesticides. At present, approximately 25,000 formulated pesticide products are registered for use in the United States. There are fewer than 750 active ingredients currently in production, with 200 leading active ingredients. The total U.S. annual production is estimated at 1.2 bilion kg of active ingredients. Of this amount, 0.7 bilion kg represents wood preservatives, disinfectants, and sulfur. The remaining 0.5 bilion kg of "convencional pesticides" (herbicides, inseticides, and fungicides) were sold to users at a cost of $7.4 bilion in 1988.

In the convencional pesticide market, agriculture accounts for over two-thirds of pesticide user expenditures and about three-quarters of the volume used annually; the remainder of the market comprises industry, government, and home and uses. Herbicides are the leading type of convencional pesticide, with over 50% of both domestic sales and volume used. EPA estimates that total U.S. farm expenditures on pesticides, $5.1 bilion in 1988, represents approximately 4 percent of total farm production expenditures ($132 billion in 1989).

Proper application of agricultural chemicals is a key factor in the ecological and economical use of these products for production of food and fiber. Significant changes in techniques and practices for applying agricultural chemicals have occurred during my 30 year career in this area. The purpose of this paper is to document some of the major developments, discuss state-of-the-art technology, and look at future needs for new and improved application technology. The major emphasis will be on herbicide application rather than other pesticides because of the vast amounts of herbicides that are applied to several hundred million hectares each year.

2. BACKGROUND AND HISTORY

Sprayers and granular applicators have been used for many wears to apply pesticides in horticultural and row crops. In the mid 1800's plants were washed or wiped with cloths or brushes containing some form of pesticide. The invention of the compressed air sprayer in the early 1900's provided a much improved method of applying chemicals. Traction powered sprayers and dusters enjoyed a brief period of popularity during the early 1900's just prior to the development of small gasoline engines.

Since the development of modern synthetic pesticides in 1939, the need for rapid, precise, and uniform application of these products has created an arsenal of devices available for economical application of pesticides. This equipment has evolved first, from the basic

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necessity of atomizing of liquids and transporting and depositing the basic liquid or dry chemicals on soil or plants. Second, machines were required to do this rapidly and effectively; and third, application equipment had to be designed with the knowledge, materials, and most reliable sources that were available at the time. From very simple beginnings, a wide variety of highly efficient equipment for application of agricultural chemicals has been developed.

Following the introduction of 2,4-D in the mid 1940'S, many small companies introduced sprayers into the US machinery market. Prior to that time, most spraying was confined to horticulture crops where high pressures were used to apply fungicides and insecticides at very higt spray volumes. The new row crop sprayers were designed for applying volumes of 200 to 500 L/ha. The spray tank often consisted of a pair of standard 210-L oil drums. Little attention was given to the application process in the design of these row crop sprayers. There was much concern about pumps, pressure regulators, screens, hoses, and boom arrangements. In fact, there was such a supply of relatively inexpensive sprayers on the market that many major machinery manufacturers did not offer sprayers in their product line. Many small manufactures simply assembled sprayers from readily available off-the-shelf components.

Part of the lack of design specificity of application equipment can be attributed to large margins of selectivity for the early pesticides. Pesticides were relatively inexpensive and were effective when applied over a wide range of rates. However, in the late 1950's people other than those tradicionally in agriculture became concerned about the extensive use of pesticides. By the mid 1960's, pesticide development costs began to increase while specificity also increased. Thus, margins of selectivity decreased and many more people expressed concern about pesticide use. Then in the late 1970's research with low-volume application equipment led to the use of rotary atomizers and electrostatic sprayers. The use of low and ultra-low volumes, coupled with more herbicides designed for the postemergence application market, heightened interest in application processes. Today's new products are formulated for application at very low application rates and requeri precise application.

There has been a renewed interest in improving the accuracy of applying chemicals in recent years. This is due to, not only the development of more selective compounds that are applied at low, but also to increased cost of chemicals, applicator and field-worker exposure concerns, food safety issues, and environmental concerns regarding water quality and spray drift. Despite all the available educacional materials, the large number of training meetings and spray clinics held, the accuracy of applying pesticides has not kept pace with the development of new chemicals. New highly selective pesticides are efficaciours at rates less than one hundred grams per hectare and must be applied with increased precision. Some chemical companies now state that the factor limiting the effectiveness of their products is the accuracy by which they are being applied.

Although a considerable amount of new application technology has been introduced during the past 20 years (ULV, CDA, Electrostatic), the basic method of applying chemicals using hydraulic nozzles has not changed significantly over the past 40 years. This is partially due to the fact that the new technology has not been proven to be consistently efficient in applying the vast array of pesticide compounds available , and it is also due partly to the fact the operators are not using conventional equipment to its maximum efficiency. Before an applicator invests thousands of dollars in new application technology, considerable effort can be made, to improve the application accuracy with existing equipment.

Custom application had it's beginnings with application of dry fertilizers. Trucks and pull-type trailers with either single or twin centrifugal spinners came into use around 1950. Advances were made in metering and spinner design so that by 1960, the spinner spreader was the most popular machine for broadcast application of dry bulk blended fertilizers. Liquid products expanded the market to include sprayers and with the development of "weed and feed" techniques in the 1960's, custom application has been a major factor in applying farm chemicals. High flotation equipment, including self-propelled units, were introduced in the mid 1960's and quickly achieved a dominant position in the custom application market. Commercial application has increased rapidly and presently over one-half of all herbicides are applied by custom applicators.

3. MODERN DAY DEVELOPMENTS

About 15 years ago there was considerable interest in using **rotary atomizers** as a replacement for hydraulic nozzles on sprayers. These rotary atomizers allowed pesticides to be applied in much lower volumes of diluent than was commonly used with hydraulic nozzles, with spray application rates of 50 L/ha as opposed to the 200 L/ha with conventional nozzles, While rotary atomizers failed to replace hydraulic nozzles, the trend to use lower sprayer application rates has continued.

Electrostatic spray techniques have been under development for many years. While this technology is very successful for the commercial painting industry, it has yet to demonstrate a significant, consistent improvement for applying pesticides in agriculture. The greatest potential for this technology is for the application of inseticides and fundicides on plant foliage for control where coverage is very important.

Many devices for **selective application** of pesticides have become avaiable during the past 15 years. These devices include directed nozzles, shielded nozzles, and recirculating sprayers. Wicks, rollers and other wiping devices have been widely used for topical application of herbicides to plants. Interest in selective application was revived and expanded by the development of the herbicide glyphosate.

The driving force behind many of the modern application technologies is the development of sensors and advancement of **electronic controllers**. Spray controllers are integrated into the spray monitor that has been widely used for years. Controllers not only monitor the application process but also compensate for any changers in application. Controllers are designed to automatically compensate for changes in speed and application rates on-the-go. Some are computer driven which works well with many new application techniques. Computers and controllers work together to place fertilizer and herbicide inputs in the precise position at the prescribed amount.

Direct injection may be the technology that potentially could have the greatest impact on the application industry. With direct injection, spray tanks contain only water or carrier, and pure chemical or special blended materials are injected directly into the spray lines that are appying the carrier. The two systems currently on the market use either a piston pump to inject the chemical into the carrier where it is then combined in an in-line mixer prior to spraying or a series of peristaltic pumps to meter a specific amount of chemical and inject it into the carrier on the inlet side of the carrier pump.

Direct injection systems normally can be set up to accommodate from one to four chemicals at a time. Rates can be accurately controlled by computers to take advantage of site-specific needs requiring precise application. On line printers are available to produce a permanent record of chemical use and job location.

Direct injection eliminates the need to mix chemicals, thus pesticide compatibility problems are also eliminated. Cleanup of equipment is minimal and with no leftover solutions, proper disposal is not a major concern. Since the chemicals are in returnable containers and are handled in a closed system, the risk of operator exposure is greatly reduced. Because of the added precision and the ability to spot spray only where the pesticides are needed with the direct injection process, a substancial savings to the producer and the environment is also realized.

Another technology that has gained widespread acceptance is **on-board, on-the-go impregnation** of fertilizer and herbicide products. Impregnation, originally accomplished in the fertilizer plant, is now done with air-flow applicators. Units are designed to place herbicide on the fertilizer carrier at the time of the fertilizer application in the field.

Several developments have improved on-the-go impregnation. With the availability of new granular herbicide formulations, application units have been designed to apply fertilizer and granular herbicides at the same time. Co-application has become a popular alternative to the original liquid impregnation process. Several granule herbicide products now on the market are capable of being bulk handled in closed systems and can be either co-applied or applied separately.

The most recent developments with liquid impregnation and co-application involve the concept of prescription application. In response so the need to reduce chemical imputs, equipment manufacturers have developed computer guited systems to place the fertilizer and pesticides produtcts in the exact location and at the precise level needed. This technology is commonly referred to as "variable rate technology (VRT)". Traditional approaches to farming a large field as one unit is becoming obsolete. Since most fields contain different soils and different production capabilities, it is reasonable to add the imputs based on the variable needs within the field. The term site-specific farming is often used to describe this practice.

Currently, two major systems are being used to apply variable rates of fertilizer and herbicides. For one system, the key to applying the fertilizer and pesticide imputs at variable rates is the development for extensive field maps based on soil tests. Grid maps for each field are developed with specific soil information provided to help imput level needed. When soil map information is incorporated with on-board computer application equipment, precise timing, placement and rate of fertilizer and herbicide inputs are possible.

A second system uses a soil probe mounted on the from of the applicator unit to analyze the soil organic matter on-the-go. Information from the sensor is analyzed by a computer and fertilizer rates are adjusted immediately to meet field needs.

One new and promising technique to increase spray penetration and coverage on plants while reducing spray drift is to use air to help transport the spray to the target. There are two types of air-assistance systems: **air-assist sprayers and air-assist nozzles**. Air-assist sprayers use air to transport the droplets after they are atomized while air-assist nozzles also use air to help atomize the liquid as well as transport it to the target.

Air-assist sprayers are built like regular sprayers with hydraulic nozzles except that a sleeve with openings is mounted on the boom. High velocity air is emitted from the openings and is accompanied with liquid spray from standard hydraulic nozzles. Although more popular in Europe, air-assist sprayers are being introduced in the US.

Air-assist nozzles, also called twin-fluid nozzles, work very differently from air-assist sprayers, The spray-liquid is atomized by the air inside these nozzles. A conventional sprayer with a standard spray boom is used, but air lines and a compressor are added. Results indicate that air-assist nozzles have the potencial to replace some of the required spray volume with air to help atomize the liquid and help transport it to the target plant. With these nozzles it is possible to reduce normal spray volumes, and by selection of the correct operational parameters, it is possible to change the droplet size spectrum and obtain good results with minimum drift potential.

Several innovations have been made in the design of **commercial application equipment**. During the last 10 years equipment manufacturers have developed machines that apply dry fertilizers similar to liquid sprayers. Commonly referred to as boomed dry spreaders, these applicators have pneumatic or auger-type distribution systems. The auger systems have a metering screw which meters the fertilizer through orifices spaced along the boom. The pneumatic systems meter the material into a manifold that divides and feeds the material into lateral tubes. The tubes are supplied with high speed air from a hudraulically driven blower. The nozzles consist of deflector shields to distribute the product in a uniform pattern. Automatic rate controllers are commonly used on most modern dry spreaders.

Liquid units are available that can vary product rates and treat over one hectare per minute. Boom movement is hydraulically dampened to permit application at high speed. Positive nozzle shut-offs, boom height sensors and reliable marking systems have greatly improved the application efficiency. Custom machines are generally equipped with electronic monitors and controls which automatically adjust to compensate for speed changes.

A major emphasis by chemical companies and equipment manufacturers in recent years has been to find new and innovative ways to make the handling of chemicals more convenient and to reduce exposure for the people who use pesticide products. **Bulk and minibulk liquid handling systems** are good examples of this. Bulk tanks are available to store, transport, and handle liquid and granular pesticides. Commercial and private applicators can now purchase and use pesticide products with reduced exposure and the returnable containers eliminate excessive use of and the disposal problems associated with smaller nonreturnable containers.

4. FUTURE DEVELOPMENTS

Wise use of inputs has always been the goal of production agriculture. Farmers and chemical dealers are becoming more sophisticated, with attitudes that reflect an environmentally conscious mindset. With public scrutiny of chemical use and legislators passing regulation after regulation limiting the use of chemicals in agriculture, it becomes essential that technological developments are forthcoming to safeguard environmental concerns. New technology is becoming available for chemical application that not only will increase application efficiency but will also protect the environment.

Prescription farming is the "hot-topic" regarding new technology for application in the future. Although units are currently in commercial use, more developments will greatly refine the techniques. Major developments in field mapping and computer application controls will be refined. The availability of global positioning system (GPS) technology has helped site-specific farming come together without a lot of hand labor and measuring. "Realtime vield monitors are the final link for prescription farming. Several monitors are coming on the market that have increased accuracy at an economical cost. Another challenge for this technology is to make the entire system compatible. In the near future, researchers expect a small electronic card that can be used to transfer data from the combine to in-home computers.

As scientists continue to narrow in on precise production inputs, the equipment industry will work to improve and develop the equipment needed to achieve a sustainable agriculture. Minutely accurate field positioning and extensive field mapping for chemical needs will provide a very precise system for meeting the application needs of the twenty-first century.