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Variable Rate Herbicide Application Using GPS and Generating a Digital Management Map

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1. Introduction

This chapter covers developing a precision method of variable rate application (VRA) for application of cyanazine pre-emergence herbicide which eventuates to save considerable pre-emergence herbicide, reduces its adverse effects on the environment and agricultural products, and increases crop yield. For this purpose a digital management map is generated using the global positioning system (GPS). A field of about 6500 m² is selected for the grid soil sampling. After that local and Universal Transverse Mercator (UTM) coordinates of the field are determined using total station surveying equipments and four static GPS receivers. Data processing is then accomplished using a personal computer equipped with surveying software. Some soil characteristics such as soil texture and soil organic matter content are also determined by soil sampling and analyzing the soil samples. Five interpolation methods are then used to determine the make-up at other points of the grid. By using Cross Validation method for evaluation of these interpolators and considering manufacture recommendations for cyanazine herbicide application based on soil texture and soil organic matter content, management zones with different herbicide application rates are determined and eventually a digital management map is generated. For implementation of the generated digital management map, a direct injection system is designed and constructed. This system is based on GPS data for positioning of sprayer, comparing the GPS data with digital management map data, measuring of speed, and finally injection of active ingredient inside carrier fluid using solenoid injectors proportionate to any management zone on the digital management map. Using the generated digital management map and equipments of VRA, optimized rate of required herbicide for the selected field is determined. Finally, total required herbicide with VRA is compared with uniform rate application for the entire selected field.

2. What is cyanazine?

Cyanazine is a synthetic chemical that is widely used as a pre-emergence herbicide to control broad-leaf weeds and grasses in agricultural crops. This chemical is in the s-triazine family of herbicides. Some common trade names for cyanazine include Bladex and Fortrol. Cyanazine is also available commercially premixed with another s-triazine, atrazine.

3. The history of cyanazine

Cyanazine was first registered for use as an herbicide by Shell Chemical Company in 1971. In the U.S., over 90% of its use in agriculture is to control weeds in corn fields. Its highest use is in corn-growing states of the Midwest. It is used primarily as a pre-emergent herbicide on corn. It is usually applied once during the growing season to control weeds before the corn-seedlings emerge from the soil. It is also used to control weeds in sorghum, cotton, barley, wheat, oil rape seed, sugar cane, potatoes, and in forestry.

4. The usage of cyanazine

Cyanazine ranked as the 5th most used herbicide in U.S. agriculture in 1990-93, with an estimated 32 million pounds of active ingredient (AI) used per year. Cyanazine was third in herbicide usage in New York State (NYS), with 650 thousand pounds of AI used annually during the same time period.

5. The current regularity status of cyanazine

Cyanazine, along with the s-triazine herbicides atrazine and simazine, was placed under Special Review by the U.S. Environmental Protection Agency (EPA) in 1994. Cyanazine was placed under Special Review because of concerns raised about its cancer-causing potential in experimental animals and possible risks to humans exposed to this herbicide. On August 2, 1995, Du Pont Chemical Co., then the primary manufacturer and registrant, voluntarily proposed to phase out its production of cyanazine and to stop production for use in the U.S. by December 31, 1999. Sale and use of existing stocks of cyanazine will be prohibited after September 30, 2002. The EPA sets the maximum levels of cyanazine allowed in public drinking water supplies. The maximum contaminant level (MCL) for cyanazine has been set at no more than 1 microgram per liter of drinking water (one microgram is one-millionth of a gram). The EPA also sets the limits on the maximum levels of cyanazine residues allowed in food for human consumption, and in animal feed. These maximum levels are called tolerances. The Food and Drug Administration (FDA) and the U.S. Department of Agriculture (USDA) are the federal agencies responsible for monitoring the residues of cyanazine in domestic and imported foods. Foods that exceed the tolerances can be seized or destroyed by local or federal government officials.

6. Who might be exposed to cyanazine?

People possibly exposed to cyanazine include:
- Agricultural workers who have mixed, handled or applied cyanazine, or herbicide mixtures containing cyanazine
- Family members that had lived on farms that have used cyanazine
- People who have been involved in cyanazine manufacture, or in preparing commercial mixtures of herbicides that contain cyanazine
- People who have handled or laundered clothing contaminated with cyanazine
- People who have consumed cyanazine-contaminated water
- People who have consumed foods with residues of cyanazine and its breakdown products

7. How can save herbicides and reduce their adverse effects?

Sprayer controllers have been developed by agricultural equipment vendors to minimize variation of applied rates of chemicals within fields. The control systems that allow these devices to compensate for changes in vehicle speeds now also provide the potential to apply variable rates of herbicides according to preplanned maps. The types of sprayer systems and controllers capable of variable rate control are discussed here, along with their advantages and disadvantages. Communications between task computers used to store maps and these sprayer controllers are also discussed.

8. Variable rate technology equipments for weed control

Perhaps you apply pre-emergence herbicides for which recommended rates are based on soil texture and soil organic matter content. Furthermore you recognize large variability in soil texture and soil organic matter content within your field units. If so, variable rates may improve overall herbicide performance and reduce costs while reducing its adverse impacts on the environment and agricultural products. Perhaps your farming operation has grown to the point that you are no longer completely familiar with all of the fields and local weed pressure areas within them. Perhaps you have other operators for your application equipment who are even less familiar with those fields than you are. Any of these may be reasons to consider the application of chemicals from a map-based or real-time sprayer system.

Most of us have performed a form of variable rate application with a traditional sprayer. By traditional, we are referring to a system in which the chemical is tank-mixed with a carrier (generally water), and the nozzles and pressure regulating valve are calibrated to provide a desired volumetric application of chemical solution at a certain forward speed. Any change in the boom pressure or vehicle travel speed from that of the calibration results in an application rate different from the desired rates. We have all used this to our advantage at times. For example, when observing an area of heavy weed infestation you might manually increase the pressure or reduce speed, thereby applying a higher (and somewhat unknown) rate of herbicide. Some precision application technologies rely on the use of a map of planned application rates, coupled with a global positioning system (GPS) receiver, to determine the appropriate herbicide rate for a given area in the field. Moreover, you can apply sensor based (real-time) approach to reach this ideal.

If you have begun adopting some precision farming technologies, then you might have a yield monitor and a GPS receiver. Since the GPS receiver is necessary for map-based application of agricultural inputs you already may have one of the big items on hand. Two other components are required to conduct VRA of herbicides. First, some form of "Task Computer" will be required to provide a signal indicating the current target rate for the current location. Second, a system for physically changing the application rate to match the current target rate will be required. Let's examine the technologies available for this part of the overall system first.

There are a number of different types of control systems on the market today that are adaptable to precision application. For the purposes of this discussion we will lump them into three categories. The first is total flow-based control of a tank mixture. The second is chemical injection based control, and the third is chemical injection control with carrier control. Incidentally, all of these systems evolved out of the desire to automatically match

application rates to variations in ground speed. This eliminates much of the errors in application that could occur if ground speeds change from the calibrated setup. These systems are effective at reducing this error. With the application rate managed by an electronic system, the ability to apply variable rates is a logical next step. This requires that the target application rate, or set point, be changeable according to the rate established for that location.

8.1 Flow-based control system

The flow based control of a tank mixture is the simplest of the three types discussed here. These systems combine a flow meter, a ground speed sensor, and a controllable valve (servo valve or proportional solenoid valve), with an electronic controller to apply the desired rate of the tank mixture. A microprocessor in the console uses information regarding sprayer width and desired liters per hectare to calculate the appropriate flow rate for the current ground speed. The servo valve is then opened or closed until the flow meter measurement matches the calculated flow rate. If a communication link can be established between this controller and a "map system", a VRA can be made. An illustration of the components comprising such system is shown in Figure 1.
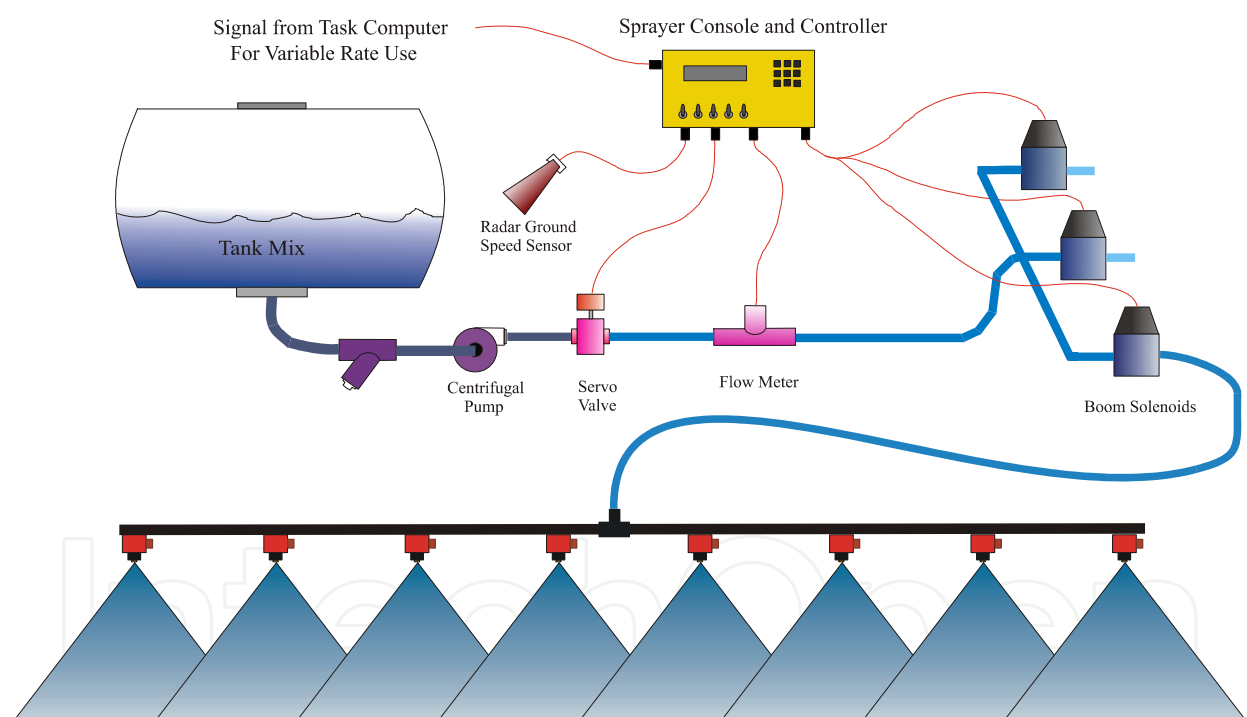

Fig. 1. A flow-based control system (adapted from Humburg [7]).

Common alternatives for varying the total flow are:
- Varying the system pressure through (a) direct pressure regulation, (b) by-pass pressure control, (c) eccentricity of the pump's rotor and (d) pulse width modulated nozzles
- Varying the nozzle diameter

The first approach and its technical solutions are limited by the square root relationship (Equation 1) between pressure P_i and flow through a nozzle orifice Q_d so that doubling the flow rate requires a four-fold increase in pressure. Therefore, the range of operating

pressures is relatively narrow. The coefficient k is an experimentally determined coefficient which depends on the type and size of the nozzle and liquid used.

$$Q_d = \frac{\sqrt{P_i}}{k} \qquad (1)$$

Another limiting factor is the pressure range over which conventional pressure nozzles will provide a defined spray quality and volume distribution pattern (turn-down ratio). This means that the range of application rates that can be applied with a given size of conventional nozzle by changing the liquid pressure is limited to ± 25% of the nominal output (1.25:1). As the pressure drops below a specified level, the spray pattern becomes distorted and application uniformity is sacrificed. When nozzles are operated above the recommended pressure range, too many small droplets are generated. Because of these two limitations of the application rate range, traditional sprayers are not suitable for site-specific control strategies.

The second approach to controlling the sprayer output with a wider range of dose rates consists of using a twin-fluid nozzle with a dose rate range of 3:1 or a variable flow (swirl-type) nozzle with a range of 4:1. Variable-duration, pulsed spray emission technology was developed for flow rate control with traditional spray nozzles. This is a relatively new variable rate application technology that is referred to as 'pulse width modulation' (PWM). It utilizes an electronically actuated solenoid valve coupled directly to the sprayer nozzle. An advantage of this technology over pressure-based systems is that the usable range of application rates available through one type of nozzle is greatly increased. Utilizing a duty cycle range (pulse width) of 10 to 100 % and the use of PWM nozzles would result in a flow control range of 10:1. To obtain this kind of flow control with a pressure-based system, the system pressure would have to vary 100:1. This is clearly out of the workable range for sprayer nozzles. Not only a wide range of flow control can be obtained using a pulse width modulated sprayer system, it can also be changed relatively quickly. The nozzle valves' capability of changing the flow 10:1 has been given as less than one second.

Another approach to achieving a high turn ratio with common sprayers has been developed recently. These systems involve the use of multiple nozzles in each nozzle location along a boom with the ability to pneumatically switch between output orifices and to adjust nozzle pressures. By using different combinations of orifice sizes and pressures it is possible to achieve a turn ratio of approximately 10:1. In this case the application rate ranges from 50 to 500 L ha^{-1}.

A further approach, i.e. a reflectance-based system uses nozzles fitted with solenoid valves that open briefly to apply spray when the nozzles pass over green vegetation. This system is commercially available along with another system, which is based on the same principle.

The following prototype is an example of a machine-vision system guided sprayer. This system was developed and tested by Tian et al. (1999). To create an intelligent sensing and spraying system, a real-time machine vision sensing system was integrated with an automatic herbicide sprayer (Figure 2). Multiple video images were used to cover the target area. For greater accuracy each individual spray nozzle was controlled separately. Instead of trying to identify each individual plant in the field, weed infestation zones were detected.

A "triple-tank" system for variable application of three different chemical solutions was also developed by the Institute of Agronomy in Bonn in cooperation with the Kverneland Group. This system was set up with three parallel nozzle supply lines; solenoid valves are used to
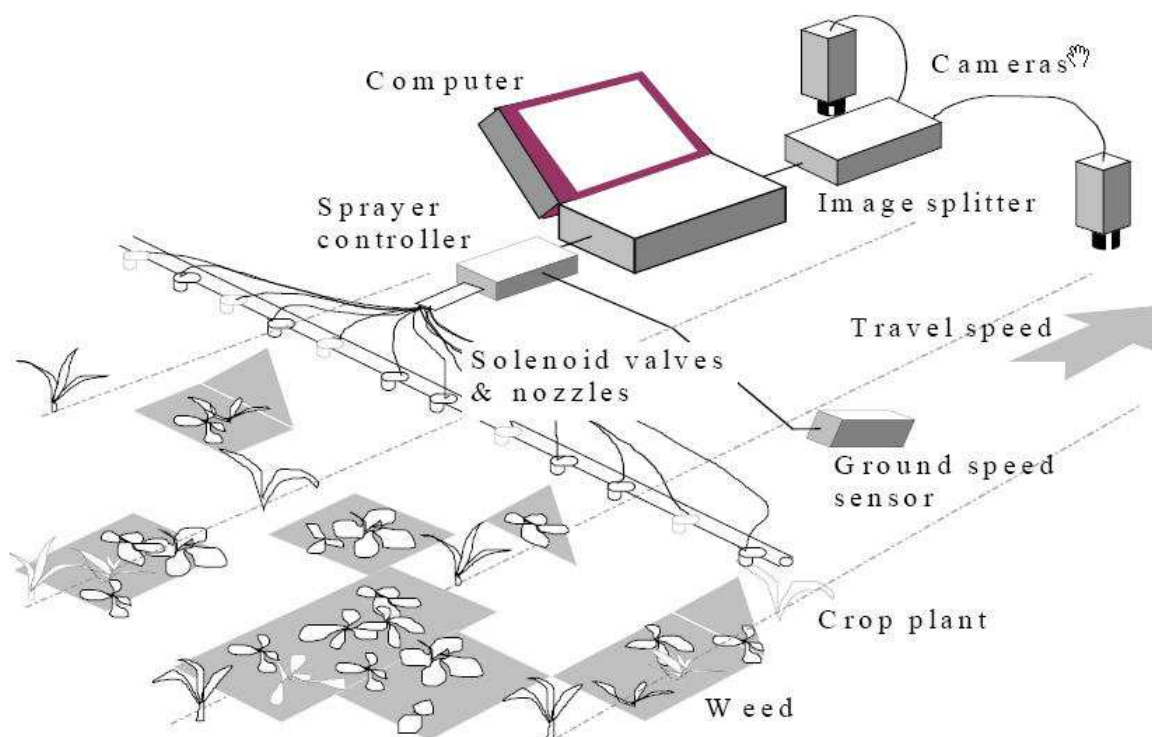
Fig. 2. A machine-vision system guided sprayer (adapted from Tian et al. [24]).

switch between boom sections as instructed by the sprayer's control unit. Each of the lines is connected to a tank with a spray mixture with an appropriate chemical concentration.

Examples of commercial systems with flow-based control capability include Micro-Trak's 9000 series controller, Mid-Tech's 6100 series, Raven Industries SCS 440 or higher, and Dickey John's Land Manager and PCS systems. These systems have the advantage of being reasonably simple. They are also able to make rate changes across the boom as quickly as the control system can respond to a new rate command, which is generally quite fast. As with any technology flow-based controllers also have limitations. The flow sensor and servo valve control the flow of tank mixture by allowing greater or lesser pressure to be delivered to the spray nozzles. This can result in large changes in droplet size in the spray, and potential problems with drift. Some systems will warn you when the commanded flow rate is outside the best operating range for your nozzles. You can adjust the vehicle speed to get the flow rate back into an acceptable range. Also, an operator may have to deal with leftover mixture and is exposed to the chemical during the mixing process. If you want a relatively simple system and can live with these limitations, this one should meet your needs while giving you the capability of VRA of herbicides.

8.2 Direct chemical injection system

An alternative approach to chemical application and control uses direct injection of the chemical into a carrier fluid such as water. These systems utilize the controller and a chemical metering pump to manage the rate of chemical injection rather than the flow rate of a tank mixture. The flow rate of the carrier (water) is usually constant (occasionally variable), and the injection rate is varied to accommodate changes in ground speed or changes in the commanded rate based on maps or sensors. Again, if the controller has been

designed, or modified, to accept an external command, the system can be used to do VRA. The components of a system are shown in Figure 3.
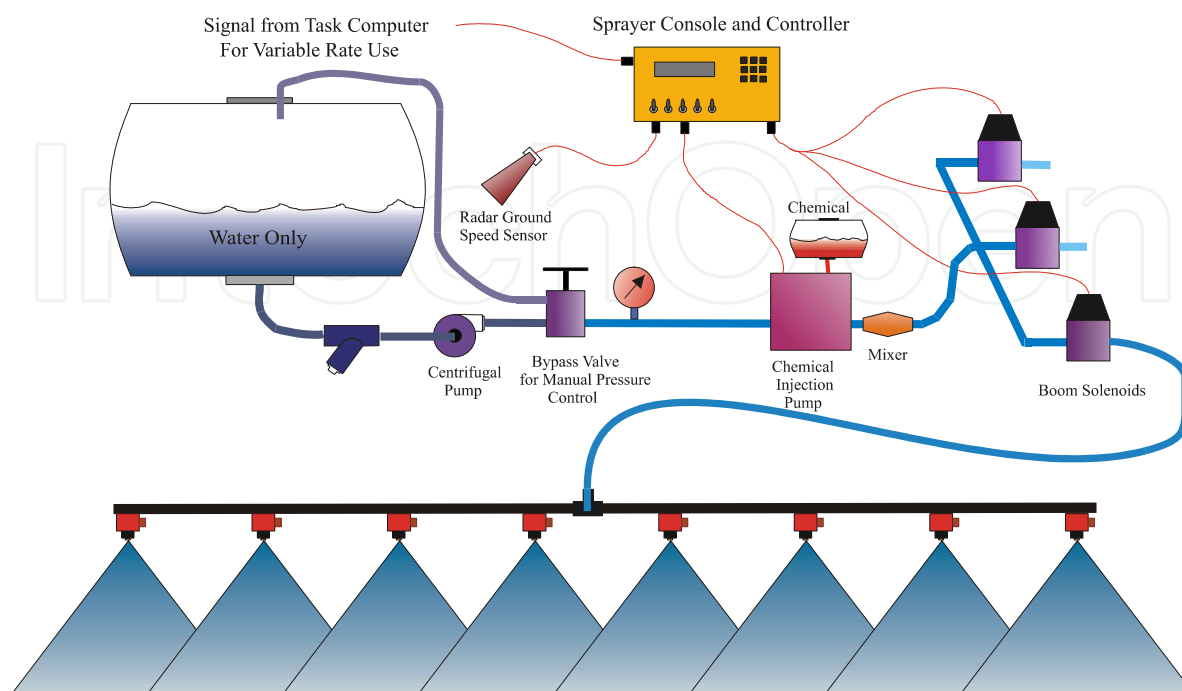

Fig. 3. A direct chemical injection system (adapted from Humburg [7]).

Chemical injection eliminates leftover tank mixture and reduces chemical exposure risk. An additional advantage of this system is that the constant flow of carrier can be adjusted to operate the boom nozzles to provide droplets with a desirable size and distribution. The principle disadvantage for variable rate control is the long transport delay between the chemical injection pump and the discharge nozzles at the ends of the boom. The volume of this plumbing must be applied before the new rate reaches the nozzles. This can cause large delays in the rate change and "Christmas Tree" patterns of application as the new concentration of chemical works its way out through the boom. For example, a simulation of a farmer-owned broadcast sprayer conducted at South Dakota State University indicated that nearly 30.5 m of forward travel would occur before a newly commanded rate would find its way to the end nozzles of that sprayer. These limitations have lead to systems that use both carrier and injection control. Raven Industries, Micro-Trak, and Dickey John all have injection pump systems. All would also recommend that for VRA they be used in conjunction with carrier control as described below.

8.3 Direct chemical injection system with carrier control

Chemical injection with carrier control requires that the control system change both the chemical injection rate and the water carrier rate to respond to speed or application rate changes. One control loop manages the injection pump while a second controller operates a servo valve to provide a matching flow of water. A perfect system of this type would deliver a mixture of constant concentration just as if it were coming from a premixed tank. The system can have many of the advantages of both of the earlier systems. Direct injection of chemical means that there is no leftover mixture to worry about, and the operator is not exposed to chemicals in the process of tank mixing. Changeover from one rate to another

occurs as quickly as both chemical and carrier controllers can make the change, which is generally very fast. The components comprising such system are shown in Figure 4. Disadvantages include a more complex system with higher initial cost, and the problem of pushing varying amounts of liquid through the spray nozzles as rates change, with the resulting changes in droplet and spray characteristics. Available systems that fit into this category include, but are not limited to, the Raven SCS 700 series, the Mid-Tech TASC 6300 system, or the Micro-Trak TNi1740. If you do a lot of spraying and wish to avoid the hazards of tank mixing, these systems will give you a great deal of control over your spraying operations and offer the capability of applying variable rates of herbicides from a pre-planned map. A few specific control systems have been mentioned here. However, this is an area of rapid change, and new models with advanced features debut regularly. It is suggested to search the World Wide Web using the manufacturer's name as a keyword as a means of locating product descriptions and specifications. Most systems will fit into one of the categories described here.
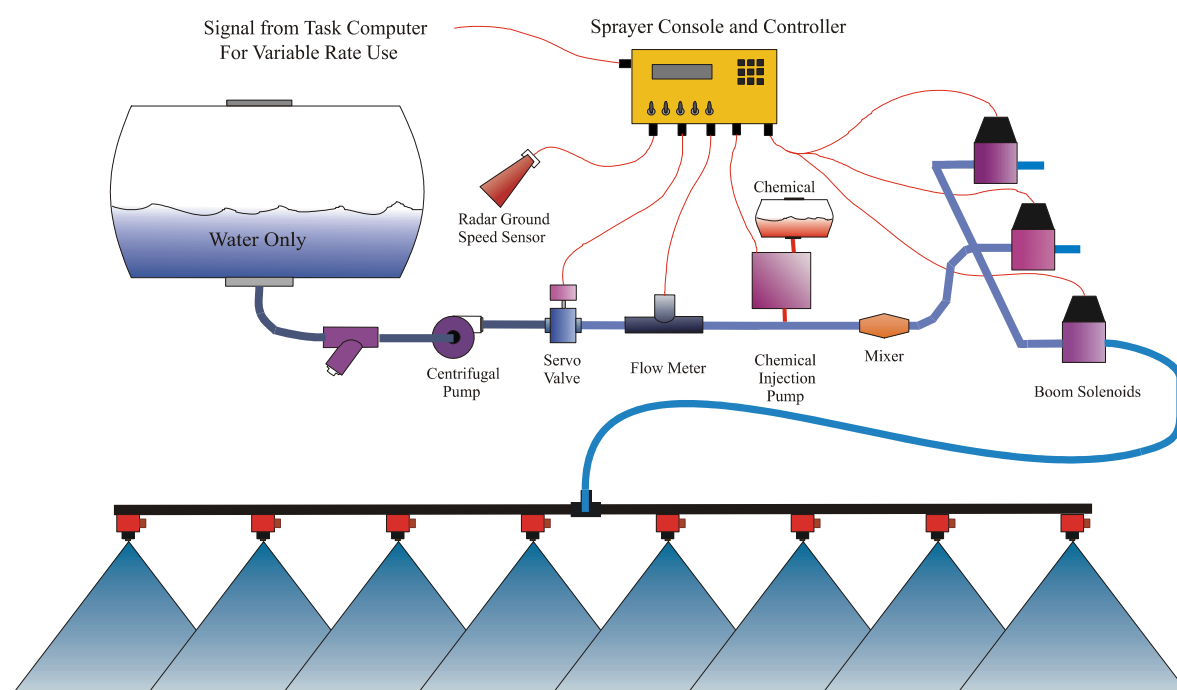

Fig. 4. A direct chemical injection system with carrier control (adapted from Humburg [7]).

There is a range of possible solutions for the technical realization of the direct injection method. In considering the suitability of these solutions, it is first necessary to determine the requirements. In an ideal case, sprayers with a direct injection system should cover the whole operating range of common field sprayers currently available on the market. The most important factors and requirements can be divided into two groups. The first includes requirements which are relevant to the on-line approach to site specific herbicide application. The second group includes requirements which are related to injection metering systems only. The basic requirements are all listed below.

• Requirements for on-line site-specific application:
1. Application rate of the carrier
2. Application rate of the chemical
3. Minimum total response time of the application system

4. Forward speed
5. Position of weed detection device (sensor)
6. High spatial resolution of sprayer
7. Uniformity of mixture concentration across a working width (lateral distribution)
8. Application of several different herbicide/additive products according to weed population

- Requirements for injection metering system:

1. Fast change of dose rates according to changes in operating parameters – minimum response time of injection system
2. Accurate metering of herbicides across the range of dose rates found in practice (flow rate of carrier/chemical)
3. Optimal number and position of injection points
4. Dimensioning of the injection system in accordance with the required nozzle/system pressure
5. Ability to deliver and inject a wide range of herbicides with varying physical properties
6. Good miscibility and solubility of herbicides with carrier (homogeneity of mixture)
7. No or, if applicable, few herbicide / spray residues
8. Easy rinsing of chemical supply lines
9. Easy and safe handling of concentrate tanks
10. Capability of being fitted to most existing sprayers
11. Robust construction of the system and use of durable materials

8.4 Putting it all together

The discussion so far has centered on how the different controller and plumbing systems achieve a given rate of application. The other part of implementing variable rate, or site-specific, weed control concerns how we store and communicate commanded rates to these sprayer systems. In simple terms, this requires a "task computer" and a communications link. The task computer holds the map of rates that you have planned. This map would most likely have been developed on your desktop computer with a mapping program. That program must save the application map in a form understandable to your task computer. Note that the task computer could actually be a conventional notebook computer running the desktop software, but the industry is moving towards more rugged devices with fewer moving parts. Examples of these include Raven's AMS198 and John Deere's Green Star system. The Ag Leader PF3000 system combines this task computer concept into the yield monitor console so that the unit can serve both purposes. Other systems are undoubtedly available, these are only examples. The map is typically loaded into the task computer on a PCMCIA card that uses no moving parts. Current practice also includes connecting the GPS receiver to the computer. The software running on the task computer then determines the current rate command based on the coordinates it receives from the GPS receiver and sends the rate for that management zone to the sprayer controller.

How the chemical rate information is passed from the task computer to the sprayer is another issue. Current practice in most cases is to use the RS 232 Serial Interface to connect the task computer to the sprayer controller. This standard interface is able to send strings of characters and numbers from a task computer that the receiving device can use if they are in exactly the right format. A properly formatted message might begin, for example, with a specific character to signify a chemical rate and be followed by a specific number of digits

that represent the actual rate to the controller. These messages are currently specific to each controller manufacturer. Raven, Micro-Trak, and Dickey John allow direct connection of an RS 232 cable for this purpose. Mid-Tech uses a Data Link communications managing module between the task computer and their sprayer controller. In each case it is necessary for your task computer software to be fully aware of the format of the rate message required by the device with which it is communicating. Companies generally make this format available to anyone who needs it, including mapping software developers. If your mapping program has "drivers" for your brand of sprayer system, communication between the software and sprayer should not be a problem. "Drivers" are small computer files or programs that tell your software the specific ways to deliver information to another specific device. If drivers are not available, it will require more work and some understanding of your software and serial communications to make the two devices function together. This communications link is usually used in both directions as the sprayer controller sends the current measured application rate back to the task computer which records this information as a part of a map record.

Whatever your level of technology usage today, it is valuable to stay informed with regard to the changes occurring in production agriculture. Not all new technologies offer clear and large economic benefits to all producers. However, being familiar with the technology will allow you to decide which pieces of the precision puzzle may be used to help you survive and thrive in a competitive world.

9. Generating a digital management map using GPS

9.1 Selected field
A field about 6500 m^2 at the Research Site of Qazvin Province Agricultural and Natural Resources Research Center in south-west of Qazvin province is selected to generate a digital management map.

9.2 Surveying
For surveying, four benchmarks are delineated on the selected field using the 30 × 20 × 20 cm concrete blocks. The settlement location of these blocks is arbitrary so that these blocks are used later as locations for settlement of total station surveying equipments and four static GPS receivers. Using total station surveying equipments, local coordinates of four benchmarks are determined so that coordinate (1000, 1000, 100) is allocated to B$_4$ benchmark and then relative coordinates of three other benchmarks, i.e. B$_1$, B$_2$ and B$_3$ are determined concern to benchmark B$_4$ (Figure 5).

The local coordinates and the contours of the selected field are obtained by settling total station surveying equipments on benchmark B$_4$ and settling reflector on various locations of the selected field. Then, the preliminary local map of the selected field is generated using the LAND software. By means of the LAND software a 42-cell grid is also created and laid out on the selected field (Figure 5). Each cell of the grid is 148 m^2. As the coordinates obtained by the total station surveying equipments are local and can not be used in the precision faming, these coordinates are converted to Universal Transverse Mercator (UTM) coordinates. For this purpose four static GPS receivers with 5 mm accuracy are used for positioning of the four benchmarks. A static GPS receiver used in this study is shown in Figure 6.
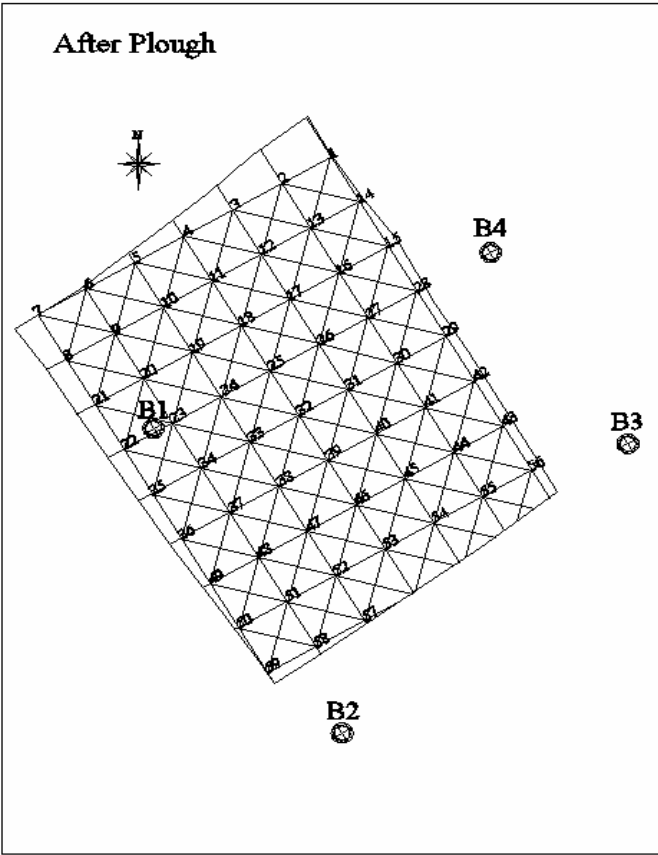
Fig. 5. Field grid and position of the four benchmarks.

Fig. 6. A static GPS receiver.

The static GPS receivers are installed on tripods and their heights are measured manually. Observation of satellites is last almost four hours so that more position data and consequently more accuracy are obtained. The number of data received by the static GPS receivers is 14676, 14934, 15024 and 2991 for the B_1, B_2, B_3 and B_4 benchmarks, respectively. The number of data received by the static GPS receiver installed on the B_4 benchmark is less than those of other benchmarks due to possibly less observation of the GPS satellites. For the purpose of processing, the GPS data are transferred to a personal computer using the HC LOADER software. Handling and processing of the GPS data is performed using the COMPASS software. First the height of antenna is defined for the software and this work is performed for the four antennas. Then, the software automatically processes the GPS data and data processing is performed in WGS84 coordinate system. After processing longitude, latitude and altitude of the four benchmarks are determined. Table 1 shows longitude, latitude and altitude (UTM coordinates) of the four benchmarks.

Benchmark	Longitude	Latitude	Altitude (m)
B_1	49:54:37.28 E	36:05:00.39 N	1292.329
B_2	49:54:39.26 E	36:14:57.56 N	1288.264
B_3	49:54:42.16 E	36:15:00.22 N	1287.967
B_4	49:54:40.79 E	36:16:02.14 N	1293.663

Table 1. Longitude, latitude and altitude (UTM coordinates) of the four benchmarks

The LAND software is used again to convert local coordinates to UTM coordinates. In this stage UTM coordinates of all grid points are obtained by defining UTM coordinates of the four benchmarks in the LAND software and obtaining vector of position transfer. The three-dimensional contour map generated for true perception of the selected field is shown in Figure 7.
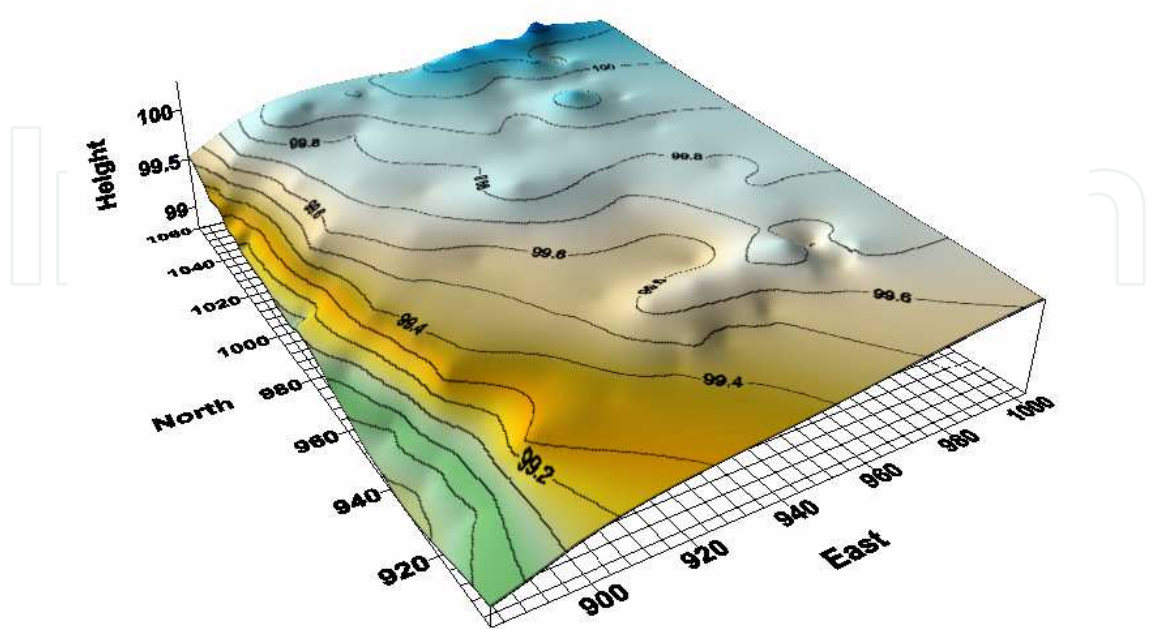

Fig. 7. Three-dimensional contour map of the selected field.

9.3 Soil sampling

In order to generate digital management map for VRA of cyanazine pre-emergence herbicide, soil texture and soil organic matter content are determined in the center of all cells of the grid which is laid out on the selected field. All soil samples are collected by bulking augured core (internal diameter 7.5 cm) from the 0-30 cm soil layer. Soil depth of 30 cm is the average depth for expansion of roots, i.e. active crop root zone. After collection, soil samples are placed in airtight polyethylene bags and transported back to the Soil and Water Laboratory. Finally, texture and organic matter content of all soil samples are determined as described by Soil Survey Manual. The laboratory test results indicate that the minimum, maximum and range of organic matter content of the soil samples are 0.43%, 1.25% and 0.82% (by weight), respectively. In addition, the mean and standard deviation of organic matter content of soil samples are 0.86% and 0.18%, respectively. Also, texture of soil samples vary between loam, sandy loam and loamy sand.

9.4 Conformity of UTM position layer with herbicide application rate layer

After obtaining test results of soil samples, soil texture and soil organic matter content in the center of each cell of the grid are assigned to UTM position of the center of each cell. In order to extend soil texture and soil organic matter content of center of each cell to other grid points, five interpolations methods, i.e. Inverse Distance to a Power, Kriging, Minimum Curvature, Moving Average and Radial Basis Function can be used. By using Cross Validation method for evaluation of interpolators, it is demonstrated that Minimum Curvature method is the best interpolation method for estimating grid points where sampling has not been done.

9.5 Digital management map

Digital management map for VRA of cyanazine pre-emergence herbicide can be generated based on the manufacture recommendations for application rate for different soil textures and soil organic matter contents (Table 2). It can be seen from Table 2 that application rate increases with increasing soil organic matter content and as soil texture varies from sand and sandy loam to clay loam and clay.

Considering manufacture recommendations (Table 2) and soil test results which indicate soil organic matter content ranges from 0.43% to 1.25%, and soil texture varies between loam, sandy loam and loamy sand, four management zones with four different herbicide application rates as 1.4, 1.7, 2.9 and 3.5 L ha^{-1} are determined, and eventually digital management map for VRA of cyanazine pre-emergence herbicide is generated as two-dimensional and three-dimensional maps indicating four distinct zones corresponding to the different soil conditions, and consequently different herbicide application rates (Figure 8).

10. Implementation of the digital management map

For implementation of the generated digital management map, a direct chemical injection system was designed and constructed. This system was based on GPS data for positioning of the sprayer, comparing the GPS data with digital management map data, measuring of velocity and finally injection of active ingredient inside carrier fluid using solenoid injectors proportionate to any management zone on the digital management map. The most important factor for evaluation of the developed direct chemical injection system was response (delay) time. This time was defined the period from the instant the injection begins

until the chemical concentration reaches 95 % of the equilibrium rate. The results showed that response time depends significantly on carrier fluid pressure and injection position of active ingredient inside carrier fluid. A schematic illustration of the developed system is shown in Figure 9.

Soil texture	Soil organic matter content (%)					
	< 1.0	1.0	2.0	3.0	4.0	≥ 5.0
Sand	0.60	0.75	1.25	1.50	1.75	2.00
Sandy Loam	0.75	1.25	1.50	1.75	2.00	2.25
Loam, Silty Loam, Silt	1.25	1.50	1.75	2.00	2.25	2.50
Sandy Clay Loam, Clay Loam, Silty Clay Loam	1.50	1.75	2.00	2.25	2.50	2.75
Sandy Clay, Silty Clay, Clay	1.75	2.00	2.25	2.50	2.75	3.00
Peat or muck	Not recommended					

Table 2. Recommended application rate (L ha^{-1}) of cyanazine pre-emergence herbicide based on soil texture and soil organic matter content range

(I)   (II)

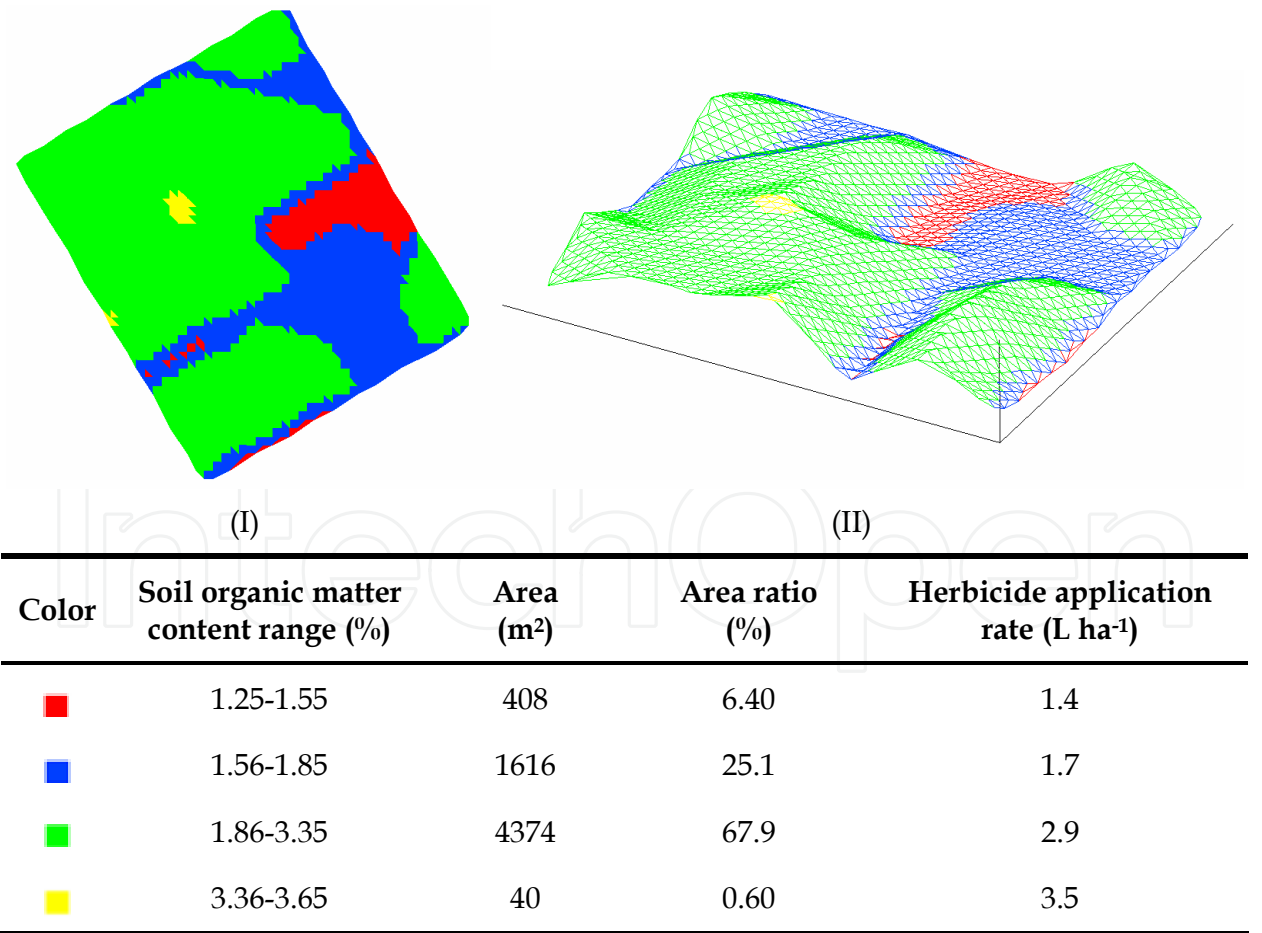| Color	Soil organic matter content range (%)	Area (m^2)	Area ratio (%)	Herbicide application rate (L ha^{-1})
🟥	1.25-1.55	408	6.40	1.4
🟦	1.56-1.85	1616	25.1	1.7
🟩	1.86-3.35	4374	67.9	2.9
🟨	3.36-3.65	40	0.60	3.5

Fig. 8. Two-dimensional (I) and three-dimensional (II) digital management map of the selected field for VRA of cyanazine pre-emergence herbicide

Fig. 9. Schematic illustration of the developed direct chemical injection system

11. Comparison between VRA and uniform rate application

As shown in two-dimensional and three-dimensional digital management maps (Figure 8) 6.4, 25.1, 67.9 and 0.6% of the selected field need application rates as 1.4, 1.7, 2.9 and 3.5 L ha^{-1}, respectively. Based on the generated digital management map for VRA, total required herbicide for the entire selected field is determined to be 1.6 L. If herbicide application is based on the digital management map and VRA instead of 2.9 L ha^{-1} which is the herbicide application rate for 67.9% of the selected field, herbicide application can be decreased up to 13%. Also, herbicide application can be done economically, and suppressing of weed growth in all management zones will be successful and without further adverse effects on the environment and agricultural crops.

If herbicide application rate of 1.4 and 1.7 L ha^{-1} is considered as herbicide application rate of the entire selected field, herbicide application can be decreased as 44.2% and 32.2%, respectively (Table 3). However, suppressing of weed growth in some management zones may be unsuccessful. Conversely, if herbicide application rate of 2.9 and 3.5 L ha^{-1} is considered as herbicide application rate of the entire selected field, herbicide application can be increased as 15.7% and 39.6%, respectively (Table 3). In this situation suppressing of weed growth in all management zones can be successful, but additional herbicide application will have adverse effects on the environment and agricultural crops.

At present, many farmers apply more herbicide than the manufacture recommendations for herbicide application rate in order to reach secure results for suppressing of weed growth. But using digital management map for VRA, herbicide application can be done economically, and suppressing of weed growth will be successful and without further adverse effects on the environment and agricultural crops.

Management zone No.	Area (ha)	Area ratio (%)	Herbicide application rate (L ha^{-1})	Needful herbicide (L)	A	B	C
1	0.0408	6.40	1.4	0.057	0.901	0.713	44.2 Decrease
2	0.1616	25.1	1.7	0.275	1.095	0.520	32.2 Decrease
3	0.4374	67.9	2.9	1.269	1.867	-0.253	15.7 Increase
4	0.0040	0.60	3.5	0.014	2.253	-0.639	39.6 Increase

A: Required herbicide for the entire selected field based on uniform rate application of each management zone (L)
B: Difference between column A and required herbicide for the entire selected field based on variable rate application i.e. 1.6 L (L)
C: Increase or decrease of required herbicide for the entire selected field based on column B and 1.6 L (%)

Table 3. Comparison between VRA and uniform rate application

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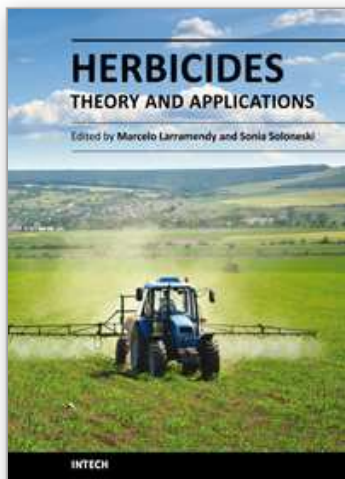[6] Corwin, D.L. and R.E. Plant, 2005. Applications of apparent soil electrical conductivity in precision agriculture. *Computers and Electronics in Agriculture*, 46: 1-10.
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Herbicides, Theory and Applications

Edited by Prof. Marcelo Larramendy

The content selected in Herbicides, Theory and Applications is intended to provide researchers, producers and consumers of herbicides an overview of the latest scientific achievements. Although we are dealing with many diverse and different topics, we have tried to compile this "raw material" into three major sections in search of clarity and order - Weed Control and Crop Management, Analytical Techniques of Herbicide Detection and Herbicide Toxicity and Further Applications. The editors hope that this book will continue to meet the expectations and needs of all interested in the methodology of use of herbicides, weed control as well as problems related to its use, abuse and misuse.

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