An ASAE Meeting Presentation

Paper Number: 051120

Evaluation of a Variable Rate Application System for Site-Specific Weed Management

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Written for presentation at the
2005 ASAE Annual International Meeting
Sponsored by ASAE
Tampa Convention Center
Tampa, Florida
17 - 20 July 2005

Abstract. *The objective of this study was to evaluate the ability of a conventional spray system adapted for VRA to successfully apply herbicides in a site-specific manner. A tractor mounted, VRA spraying system was constructed with commercially available equipment during the spring of 2003. The sprayer was equipped with 568 L tank and a 7.6 m boom with Spraying Systems Turbo TeeJet 11002, 11003, and 11004 nozzles mounted on 15, three-position nozzle bodies spaced 51 cm. The sprayer controller was a Raven SCS 440 with serial interface. To attain automatic product shutoff, the controller used a fast-close control valve placed on the 2.5 cm main product line located after the flow meter. A sprayer-mounted radar was used to monitor speed. A Trimble AgGPS 132 using Coast Guard differential correction communicated the sprayer's location to a Compaq™ Ipaq™ 3850 running Farmworks Farm Site Mate VRA software. Farm Site Mate VRA transmitted recommended rates from a prescription map to the sprayer controller and logged actual application data. Field studies were conducted during 2003 and 2004 on nine different fields throughout Kansas using a reduced rate preemergence and/or postemergence VRA with prescribed rates being applied by changing sprayer volume. Errors associated with the VRA were noted. The VRA sprayer was calibrated to center the 1.5 to 2.8 m transition zone between the 7.6 by 7.6 m grid cells. Usually the transition zone consisted of a smooth increase or decrease in herbicide rate, except a rate spike was noted in situations when the prescribed rate changed from off to on. Additionally, heavy residue and/or plant canopy interfered with the radar's ability to determine speed resulting in increased or decreased application rates. Even with these errors, research results demonstrated that weed patches could be managed using commercially available VRA technology.*

Keywords. Variable rate application, precision agriculture, spatial weed management

Introduction

An integrated weed management (IWM) strategy maximizes producers' profits and reduces weed control inputs (Thornton et al. 1990; Swanton and Weise 1991). An integral part of an IWM strategy is the development of economic thresholds, which is the weed density at which the predicted yield loss equals the cost of control. Economic threshold decisions are often made on a field-average-wide basis, except weeds are not typically spread evenly across a field but are distributed into patches (Dieleman and Mortensen 1999; Johnson et al. 1995; Wiles et al. 1992). An average weed population for a field may exceed an economic threshold on a field-wide-basis but may actually be below the economic threshold in areas and warrant no weed management (Cardina et al. 1995). With the introduction of commercially available variable rate application (VRA) technology, Mortensen et al. (1998) proposed that a producer could site-specifically apply a herbicide in areas of the field where weed density exceeds the economic threshold. As a result site-specific weed management (SSWM) becomes a key component to IWM by reducing herbicide inputs and maximizing profits (Vogel 2005).

Uniform rate application involves applying a herbicide at a constant rate across a field regardless of weed populations. Conversely, VRA technology is used to site-specifically target weed populations by spatially adjusting herbicide rates. One of the main components of a VRA is the Differential Global Positioning System (DGPS), which identifies the location of the sprayer to the on-board computer. The ability for the DGPS to receive an accurate position is essential for a precise VRA because if a variable rate sprayer cannot apply the correct amount of chemicals at the proper time and location then it is ineffective (Anglund and Ayers 2003). Using an airplane equipped with a SATLOC AirStar M3 DGPS and WAAS correction, Smith and Thomson (2003) found that real position of the airplane as compared to the DGPS location was positive when traveling in the North and South direction and negative in the East and West direction. Although the differences where notably small with the DGPS, the inaccuracy increased the total of errors associated with a VRA. The second component for a VRA is an on-board computer. The computer with appropriate software receives information from the DGPS, which is used to locate the sprayer within the application map and send the corresponding target application rate to the sprayer controller. The third component for VRA is a sprayer controller that automatically adjusts flow based on changes in speed or target application rate received from the on board computer (GopalaPillai et al. 1999).

Conventional sprayers have a limited range of herbicide rates due to the non-linear increase in pressure when flow is increased. At the present, SSWM application systems utilize expensive and experimental VRA spraying systems and SSWM would be more readily adapted if VRA systems could be constructed using available equipment to effectively manage patchy weed populations (Gerhards et al. 2002; Goudy et al. 2001; Williams et al 2001). The objective of this study was to evaluate the ability of a conventional spray system adapted for VRA to successfully apply herbicides in a site-specific manner.

Materials and Methods

To apply a SSWM application, a tractor mounted, variable rate sprayer was constructed with commercially available equipment in the department of Biological and Agricultural Engineering at Kansas State University during the spring of 2003 (Figure 1). The sprayer was equipped with a 570 L tank and a 7.6 m, three section boom with Spraying Systems Turbo Teejet® (TT) 11002, 11003, and 11004[i] nozzles mounted on 15, three-position nozzle bodies spaced at 51 cm. The sprayer controller was a Raven SCS 440 with serial interface[ii]. To attain automatic product shutoff, the controller used a fast-close ball control valve on the 2.5 cm main product line placed after the flow meter. A sprayer-mounted radar was used to measure speed. The variable rate sprayer was powered by a PTO-mounted Hypro belt driven centrifugal pump[iii]. A Trimble AgDGPS 132[iv] using Coast Guard differential correction with sub-meter accuracy, communicated the sprayer's location to a Compaq™ Ipaq[v] 3850 running Farmworks Farm Site Mate VRA[vi] V.8.22 in 2003 and V.9.22 in 2004. Farm Site Mate automatically transmitted recommended target herbicide rates from a prescription map to the sprayer controller and received back as-applied data, which was logged and geo-referenced.

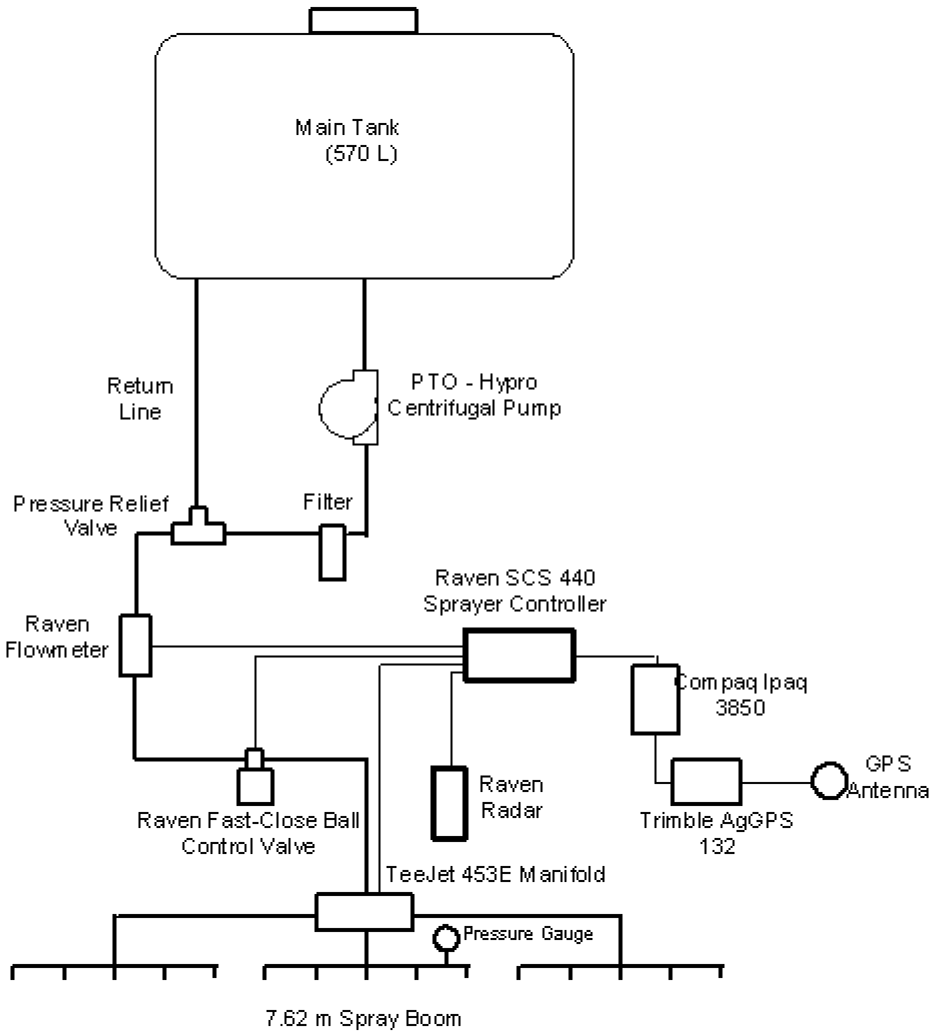

Figure 1. Schematic of the tractor-mounted variable rate sprayer

Field studies were conducted during 2003 and 2004 on nine different fields throughout Kansas using a reduced rate preemergence and/or postemergence VRA. After planting the crop, a PRE herbicide was applied at 0, 0.33, 0.67 and 1x of the recommended rate in 7.6 m-wide strips (ten 0.76 m rows) and was replicated through the field. Reduced rates of PRE herbicide were based on changes in application volume, that is, a constant herbicide dilution was maintained in the tank and changes in L ha^{-1} of solution applied increased or decreased the herbicide rate. For example, 0.33x was applied at 93 L ha^{-1} at 172 kPa using TT11002[1] nozzles traveling at 7.2 km hr^{-1}, the 0.67x was applied at 197 L ha^{-1} at 172 kPa using the TT11003[1] nozzles traveling at 7.2 km hr^{-1}. The 1x recommended rate was applied at 280 L ha^{-1} at 241 kPa using the TT11004[1] nozzles traveling at 5.6 km hr^{-1}. A 7.6 by 7.6 m grid was superimposed onto each field so that weed sampling points were located in the center of each grid cell. Approximately three days prior to the POST herbicide application, weeds species were identified, classified into size categories, and counted in a 1 m^2 quadrat at each weed sampling location. Weed density in the 1 m^2 quadrat was assumed to represent the population in the 7.6 by 7.6 m grid cell. An optimal rate was assigned to each grid cell based on weed species, density and size and the predicted yield loss (Rider 2004). Strips in each field were assigned a SSWM or a standard treatment and replicated. The optimal rate was applied to each grid cell in the SSWM strip, while a set of three grid cells (7.6 by 23 m) randomly received 0, 0.5, 0.75, or 1x the recommended rate of herbicide for the standard treatment. The POST application was then applied using the previously described equipment. Weed populations were assessed three weeks after treatment (3 WAT). Crop yield was recorded using a combine equipped with a global positioning system and a yield monitor.

Results and Discussion

Construction of the VRA Sprayer

A commercially available pressure-based spray system was assembled for this project. The system was a conventional tractor mounted 3-point sprayer that could be transferred quickly between tractors without modifications. A Raven SCS 440 sprayer controller, with radar, flowmeter, standard butterfly control valve, and boom control valves were installed to factory specifications.

After the construction of the conventional pressure based sprayer with the Raven SCS 440 sprayer controller was complete, the focus of assembly shifted to connecting the Compaq Ipaq 3850 with FarmWorks Farm Site Mate software and the Trimble AgGPS 132 DGPS receiver to the sprayer controller. The installation of the software and the DGPS receiver converted the conventional pressure-based sprayer into a spraying system able to apply map-based VRA. To achieve this objective, a PCMCIA IPAQ expansion pack along with a Socket™ serial I/O PC card[vii] was purchased to connect the Compaq Ipaq 3850 to the Raven SCS 440 sprayer controller (Port 5). Several calibration steps were needed before the Raven SCS 440 sprayer controller and Farm Site Mate could communicate correctly. First, the Raven SCS 440 spray controller 'target rate 1' was selected and the logging options were turned on with the appropriate logging interval set in either seconds or feet of travel (Raven SCS 440 manual). Second, on Farm Site Mate, the Raven controller was installed under the variable rate setup menu with the appropriate port, boom width, and distance between boom and DGPS antenna selected (Farm Site Mate manual). For the Ipaq to receive a DGPS signal, a universal autosync cable along with a null modem was used to connect the Trimble AgGPS 132 to the port at the base of the Ipaq (Port 1). After choosing the correct port and baud rate from the GPS settings menu (baud rate with the Trimble AgGPS 132 is usually 4800 or 9600), Farm Site Mate was ready to receive a DGPS signal from the Trimble AgGPS. With the creation and uploading of an appropriate variable rate map to Farm Site Mate, the commercially available conventional pressure-based sprayer was ready for a VRA.

Challenges with the VRA

Given that the herbicide rate changes were based on volume, and that nozzle orifice size could not be changed during the variable rate POST application, the relative maximum range of herbicide rate was limited by the non-linear increase in pressure when application rates were increased. Considering all constraints, including minimum and maximum carrier volume quantity and recommended operating pressures of the nozzles, relative maximum range of application rates were established. The equipment and the method of applying the variable rate herbicide application evolved throughout the study. For the 2003 growing season, the maximum range was changed from 0x and 0.4 to 1x by varying the carrier volume from 140 to 336 L ha^{-1} using the TT11004[1] nozzles. For the 2004 growing season, the herbicide range was established at 0x and 0.45 to 1x the recommended herbicide rate. The corresponding variable rate POST application volume and pressure ranged from 140 to 299 L ha^{-1} and 103 to 310 kPa, respectively. The TT11004[1] spraying nozzle was used and speed was kept constant at 6.4 km hr^{-1}. The large carrier volume was selected to keep recommended application volume, at any herbicide rate, above the minimum application volume on the herbicide label. In addition to following herbicide label directions, a large carrier volume made it easier for the sprayer controller to attain a particular target application rate. That is, the application error and corresponding error in herbicide rate applied associated with a low volume VRA would in effect, be greater at low than at high volumes. Thus, to achieve the most accurate herbicide application, a large application volume was selected while still following label directions.

Prior to the first VRA, it was necessary to assure that the sprayer changed the target rate at the appropriate time. To accomplish this the transition zone was centered between the 7.6 by 7.6 m grid cells. It was particularly important to ground truth the sprayer to insure the majority of each grid cell received the appropriate herbicide rate. By placing flags at 7.6 by 7.6 m grid cell intersections and by monitoring boom pressure, an appropriate feed delay was entered into the variable rate configuration in Farm Site Mate. The feed delay measurement was 1.3 seconds, which meant that Farm Site Mate sent the new target application rate to the Raven SCS 440 sprayer controller 1.3 seconds ahead of the 7.6 by 7.6 m grid cell intersection. The transition zone measured between 1.5 to 2.8 m depending on the difference between the old and new target application rates. The 1.5 to 2.8 m transition zone centered on the intersection of the 7.6 by 7.6 m grid cell assured the sprayer would apply the target rate at the center weed sampling point while traveling 6.4 km hr^{-1}.

In addition, the testing prior to the first variable rate herbicide application revealed that the application log data was not geo-referenced in the anticipated location. Initially the DGPS antenna was located at the highest point on the tractor cab, approximately 10 feet in front of the spraying boom. As previously mentioned, the Farm Site Mate software was configured to allow the distance between the DGPS antenna and the spraying boom to be adjusted so that the target application rate changed in the correct location. Unfortunately, this adjustment did not adjust the location of the application log data. The application log data was geo-referenced at the location of the DGPS antenna, not the location of the spraying boom. To assure that application data was geo-referenced in the right location, a metal base was constructed and placed above the spraying boom to mount the DGPS antenna.

Using the initial configuration of the conventional-pressure based sprayer with the standard butterfly control valve, automatic product shut-off could not be attained without manually using the master switch. The installation of a fast-close ball control valve after the first two VRA herbicide applications resolved the automatic product shut-off problem. However, the smoothness of transition of different application rates was affected. The standard butterfly valve resulted in smooth transitions between old and new target application rates (Figure 2). However, the conversion to the fast-close ball control valve resulted in rate spikes that reached as high as 450 L ha^{-1} between old and new target rates (Figure 3). The rate spike was worse in situations when the application rate changed from 0x to 0.5x than from 0x to 1x application rate. The result from the over application of herbicides was a 1 m wide application strip that caused crop injury and possible yield loss.

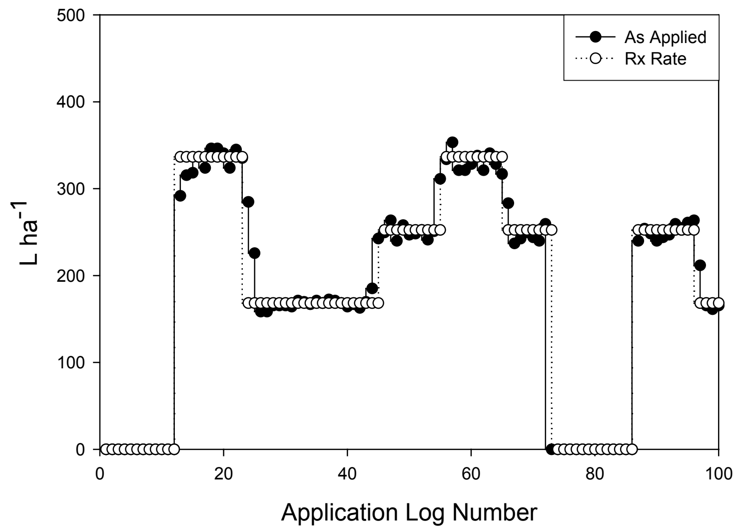

Figure 2. As applied and prescription (Rx) rate application log with standard butterfly control valve.

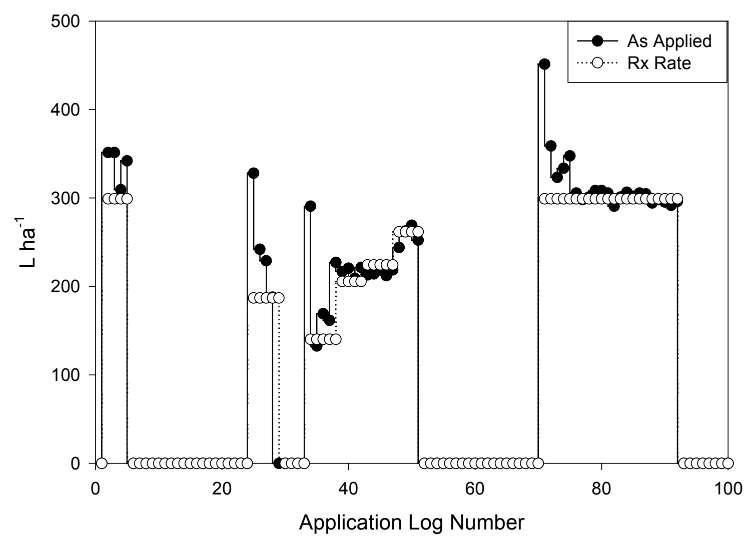

Figure 3. As applied and prescription (Rx) rate application log with fast-close ball control valve.

In certain application situations, the prescription rate change was not large enough to trigger the control valve to open or close. In these situations, the as applied rate remained the same even though the prescription rate changed. The dead-band digit control valve calibration number with the Raven SCS 440 sprayer allowed for a 3% difference between the target and actual application rate (Raven SCS 440 manual). The dead band digit smoothed the application so that the Raven SCS 440 spray controller was not constantly adjusting the actual application rate when it was not needed. Another inaccuracy in the VRA application came from heavy residue and/or plant canopy that interfered with the radar's ability to measure speed. The interference caused the measured speed to oscillate resulting in increases or decreases to the calculated application rate. Only in rare, late postemergence herbicide application did interference become a problem with the radar's ability to measure speed.

Site-Specific Weed Management

Field studies in 2003 and 2004 were conducted to develop, implement, and evaluate a SSWM system that utilizes a low or variable rate PRE herbicide followed by a planned POST site-specific herbicide application. These studies, designed to implement and evaluate SSWM in glyphosate-resistant corn and soybean SSWM using a planned two-pass herbicide application, were successfully implemented in corn and grain sorghum fields. POST SSWM herbicide usage was between 21 and 98% depending on weed infestation and PRE herbicide rate. Yield was influenced by dry environmental conditions. Yield was reduced with no PRE or POST herbicide and SSWM, which validated the need for a two-pass system. With glyphosate-tolerant crops, large weed infestations resulted in the lack of herbicide reduction in the corn fields and eliminated any advantage of SSWM. Weed control with SSWM was better than standard treatment herbicide rates (0, 0.5, 0.75 or 1x) and similar to a uniform 1x treatment and did not reduce yield in glyphosate-tolerant crops.

Conclusion

In the spring of 2003, a commercially available VRA sprayer with a Raven SCS 440 sprayer controller, Compaq Ipaq 3850 with Farmworks Farm Site Mate Software, and a Trimble AgGPS 132 using Coast Guard correction was constructed. Field studies took place during the 2003 and 2004 growing season and errors associated with the variable rate herbicide application were noted. Before the VRA, the maximum range of application volume was established considering all constraints, including minimum and maximum carrier volume quantity and recommended operating pressures of the nozzles. The variable rate sprayer was calibrated to center the 1.5 to 2.8 m transition zone between grid cells with different herbicide target rates. The transition zone with the standard butterfly control valve was smoother than with the fast-close ball control valve. The fast-close valve could reach as high as 450 L ha^{-1} over application. The dead-band digit calibration value allowed for small changes in the actual application rate as compared to the target application rate without correction. This allowed for small changes in the target application rate resulting in no action by the Raven SCS 440 sprayer controller. The field studies demonstrated that a commercially available pressure-based VRA sprayer could be used to successful implement SSWM.

Acknowledgements

The authors would like to that the Kansas State University Department of Biological and Agricultural Engineering and the Department of Agronomy. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, under Agreement No. 2003-34103-13192. Additionally we would like to thank our producer cooperators, Doug Keesling, John Oden, Harlan Ebright, Kenny Tucker, and Lee Scheufler, whom helped us implement SSWM across Kansas.

References

Anglund, E. A. and P. D. Ayers. 2003. Field evaluation of response times for a variable rate (pressure-based and injection) liquid chemical applicator. Appl. Eng. in Agric. 19:273-282.

Cardina, J., D. H. Sparrow, and D. L. McCoy. 1995. Analysis of spatial distribution of common lambsquarters (Chenopodium album) in no-till soybean (Glycine max). Weed Sci. 43:258-268.

Dieleman, J. A. and D. A. Mortensen. 1999. Characterizing the spatial pattern of Abutilon theophrasti seedling patches. Weed Sci. 39:455-467.

Gerhards, R., M. Sokefeld, C. Timmerman, and W. Kuhbauch. 2002. Site-specific weed control in maize, sugar beet, winter wheat, and winter barley. Prec. Agric. 3:25-35.

GopalaPillai S., L. Tian, and J. Zheng. 1999. Evaluation of a flow control system for site-specific herbicide applications. Transactions of the ASAE. 42:863-870.

Goudy, H. J., K. A. Bennett, R. B. Brown, and F. J. Tardif. 2001. Evaluation of site-specific weed management using a direct-injection sprayer. Weed Sci. 49:359-366.

Johnson, G. A., D. A. Mortensen, L. J. Young, and A. R. Martin. 1995. The stability of weed seedling population models and parameters in eastern Nebraska corn (Zea mays) and soybean (Glycine man) fields. Weed Sci. 43:604-611.

Mortensen, D. A., J. A. Dieleman, and G. A. Johnson. 1998. Weed spatial variation and weed management. p. 293-309. In: J.L. Hatfield, D. D. Buhler, and B. A. Stewart (eds.), *Integrated Weed and Soil Management*, Ann Arbor Press, Chelsea, MI.

Rider, T. W. 2004. An Economic evaluation of site-specific herbicide application. M. Sc. thesis. Kansas State University, Manhattan, Kansas. 90 p.

Smith L. A. and S. J. Thompson. 2003. DGPS position latency determination and ground speed calibration for the SATLOC Airstar M3. ASAE paper no. AA03-009. St. Joseph, Mich.

Swanton, C. J. and S. F. Weise. 1991. Integrated Weed Management: The rationale and approach. Weed Technol. 5:657:663.

Thornton, P. K., R. H. Fawcett, J. B. Dent, and T. J. Perkins. 1990. Spatial weed distribution and economic thresholds for weed control. Crop Protection. 9:337-342.

Vogel, J. W. 2005. Implementing site-specific weed management in Kansas row crops. M. Sc. thesis. Kansas State University, Manhattan, Kansas. 195 p.

Wiles, L. J., G. W. Oliver, A. C. York, H. J. Gold, and G. G. Wilkerson. 1992. Spatial distribution of Broadleaf weeds in North Carolina soybean (Glycine max) fields. Weed Sci. 40:554-557.

Williams II, W. M., R. Gerhards, and D. A. Mortensen. 2000. Two-year weed seedling population responses to a post-emergent method of site-specific weed management. Prec. Agric. 2:247-263.

Sources of Materials

[i] Turbo TeeJet 11002, 11003, 11003, nozzles, Spraying Systems Co., Wheaton, IL 60189.

[ii] SCS 440 Spray Controller, Raven Industries Inc., Sioux Falls, SD 57117.

[iii] 9400C belt driven centrifugal pump, Hypro Pumps, New Brighton, MN 55112.

[iv] AgGPS 132 DGPS Receiver, Trimble Navigation Limited, Sunnyvale, CA 94085.

[v] Compaq Ipaq 3850, Hewlett Packard Co., Palo Alto, CA 94304.

[vi] Farm Works Farm Site Mate, CTN Data Services Inc., Hamilton, IN 46742.

[vii] Socket serial I/O PC card,