PERFORMANCE EVALUATION OF A PROTOTYPE VARIABLE RATE SPRAYER FOR SPOT- APPLICATION OF AGROCHEMICALS IN WILD BLUEBERRY FIELDS

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ABSTRACT

Wild blueberry yields are highly dependent on agrochemicals for adequate weed control. The excessive use of agrochemicals with uniform application in significant bare spots and plant areas has resulted in increased cost of production. A cost-effective automated prototype variable rate (VR) sprayer was developed for spot-application (SA) of agrochemicals in a specific section of the sprayer boom where the weeds have been detected. The weed patches were mapped with an RTK-GPS receiver in test tracks before and after kaolin (colored dye additive) application in the spray liquid to evaluate the performance accuracy of the VR sprayer. The application rate was set up at 187.0 L/ha. The selected buffer (before and after) was 25.4 cm and average ground speed was 6 km/hr. These maps showed that chemical was sprayed on all targets (weed patches) precisely in selected tracks in both fields. The water spray was replicated three times with both SA and uniform application (UA) in selected tracks of a wild blueberry field to evaluate the repeatability of the sprayer and to quantify the chemical saving with SA. Results showed SA rates ranged from 45.5 to 53.0 L/ha (SE = 3.20) in track 1 and from 26.5 to 29.4 L/ha (SE = 0.88) in track 2. The UA rate varied from 160.70 to 161.70 L/ha (SE ranged from 0.16 to 0.37) in both tracks. The reason of variation in SA rates might be some weeds were damaged due to repeated passes of vehicle in the tracks and ultrasonics could not detect the shorter (damaged) weeds.

The chemical saved with SA was 69.22% with 22.67% weed cover and 82.50% with 18.13% weed cover in track 1 and in track 2, respectively. Based on these results, the VR sprayer could be used for in-season SA of agrochemicals in wild blueberry cropping systems to significantly reduce the amount of agrochemical usage and also reduce environmental pollution.

Keywords: sensors, controllers, DGPS, GIS, spot-application, wild blueberry, agrochemicals

INTRODUCTION

Wild blueberry is the most important horticultural crop produced in eastern Canada with over 52,000 ha under management producing 59 million kg of fruit valued at $160 million annually. Wild blueberry yields are highly dependent on herbicides for adequate weed control (Jensen and Yarborough 2004 ; McCully et al. 1991). Growers apply herbicides in the fall to control fescue grasses uniformly during the growing season. The repeated and excessive use of herbicides has resulted in increased cost of production. Chemically-polluted runoff from fields cause contaminated surface and ground waters (Comparetti and Orlando., 2001, Pimentel and Lehman, 1993; Tardiff, 1992). Estimates indicate that 10-30% of pesticide agent can be reduced by using variable rate sprayers in different cropping systems (Ganzelmeier, 2006). Carrara et al., (2004) saved 29 % herbicide with variable rate application as compared to conventional application in a wheat crop field. The targeting of herbicides to grass weed patches in cereal crops may lead to reductions in herbicide amounts of 40-60%, depending on the weed patch distribution within the field (Stafford and Miller, 1996). Similar or more agrochemical savings potentials are expected in the wild blueberry industry, given the high proportion of bare spots (30-50% bare spots in wild blueberry fields; Zaman et al., 2008) in typical wild blueberry fields. There is an urgent need to develop affordable, reliable VR sprayer, using inexpensive sensors and automated variable rate controller for real-time spot-specific application of agrochemicals in wild blueberry cropping system.

Many researchers have attempted to develop variable rate (VR) technologies for various crops (Rockwell and Ayers, 1994; Giles and Slaughter, 1997; Steward and Tian, 1999; Tian, L. 2002; Miller et al., 2003; Carrara et al., 2004; Schumann et al., 2006a, 2006b; Dummer et al., 2008) to date little attention has been paid to wild blueberry production systems. Michaud et al., (2008) developed a VR prototype sprayer to deliver pesticides based on prescription maps, developed in GIS software, using aerial spectral scans of wild blueberry fields. The system was sensitive to positional error caused by global positioning system (GPS) and obtaining up to-date aerial photography was expensive, the quality was quite variable, and data processing for weed detection was also intensive and difficult.

Several machine vision systems have been developed to detect weeds in different cropping systems (Sui, et al., 1989; Shearer and Holmes, 1990; Zhang and Chaisattapagon, 1995; Tian et al., 1997; Zhang et al., 2009), because real-time weed detection at the time of spot spraying could be very valuable for cutting chemical costs and reducing environmental contamination. However, these vision systems, based on morphological or textural weed detection methods, generally needed a relatively high image resolution, and the detection algorithms were quite complicated and computationally expensive (Meyer et al., 1998; Zhang et al., 2009). There is a need to develop spot-specific herbicide application technologies that will use local sensors to sense the weed in real-time and provide the weed detection information to fast VR controllers for spray at right targets.

Ultrasonic sensors are widely accepted for quantification of plant heights (Kataoka et al., 2002; Shrestha et al., 2002; Sui et 1989; Schumann and Zaman, 2005). Swain et al. (2009) developed and tested low-cost ultrasonic system for weeds (taller than plants) and bare spot mapping in real-time within wild blueberry fields during growing season. They reported that cost-effective ultrasonics performed well to detect tall weeds (taller than plants) and bare spots in wild blueberry fields.

Advances in sensing technology and VR control systems have offered new opportunities for detecting weeds and spot-application of agrochemicals in a specific section of the VR sprayer boom where the weeds have been detected. Many commercial controllers have been developed to deliver agrochemicals on site-specific basis using GPS guided prescription maps within field (DICKEY-john Land Manager II: DICKEY-john Corporation, Auburn, IL; MidTech Legacy 6000 controller: Midwest Technologies, Springfield, IL; Raven 660 controller: Raven Industries Inc. Sioux Falls, SD). Schumann and Hostler (2009) with the partnership of a machinery manufacturer (Chemical Containers, INC, Lake Wales, FL, USA) developed an 8-channel computerized VR controller consists of electronic hardware with internal firmware and matching Windows Mobile 6.0 software on a handheld pocket PC computer (PPC). The controller is linked with PPC using wireless Bluetooth®. Typically this controller does not use prescription maps, but relies on sensors to provide real-time weed information which is used to dispense the correct herbicide rate for the weed eradication within field. Therefore, cost-effective, reliable and fast ultrasonics and VR controllers could be used to develop VR rate sprayer for in-season, spot-application of agrochemicals in wild blueberry cropping system.

In this study, a cost-effective automated VR prototype sprayer consisting of ultrasonic sensors, 8-channel computerized VR controller, DICKEY-john Land Manager II, solenoid valves, PPC with operating software was developed and tested for in-season, real-time weed detection and spot spraying in weed blueberry fields.

METHODOLOGY

Development of Prototype Variable Rate Sprayer (VR Sprayer)

VR sprayer consisted of ultrasonics, computerized 8-channel VR controller (VRC), DICKEY-john Land Manager II (DJC), handheld Pocket PC (PPC) with operating software, DICKEY-john servo valve and flow meter, solenoid valves, nozzles and a tank capacity of 209 litres was developed. The VR sprayer was mounted on an all-terrain vehicle (ATV). The 6.1 m sprayer boom was divided into eight sections (76.2 cm each section) and mounted behind the ATV at 76.2 cm above the ground. The boom height was adjustable so that weed sensing area and spray could be fine-tuned to crop conditions. Eight solenoid valves and nozzles (one valve and one nozzle in each section) were mounted on the boom with a uniform (76.2 cm) interval between them. The nozzles were TeeJet TP8004 nozzles (Maritime Supplies Limited, Monton, NB, Canada) with a spray angle of 110 degrees. Using a series of T joints, the line connecting the distribution valve to each section was then connected to each solenoid valve to which a nozzle was fitted as closely as possible. The model 2201A solenoid valve (Delware Pump & Parts Limited, Delware, ON, Canada) was operated on 12-volts and consumed only 2 watts. Each valve has a maximum operating differential pressure of 861 kPa at a flow computed using the reported Cv value 0.45 of the valve. The feed line from the pump was going through a DJ flow valve and flow meter then was separated into two lines, each line (right and left) feeding four sections of the boom. The pump was operated by a Honda gas engine (Honda Inc., NS, Canada).

The wide angle beam, long range and fast measurement cycle Maxbotix LV-MaxSonar-EZ1 Sonar Module ultrasonic sensors, (Robotic INC, Boisbriand, QC, Canada) were incorporated vertically into individual boom section to detect weeds taller than blueberry plants in real-time within wild blueberry fields. The 6.1 m long sensor boom was mounted in front of the ATV at 1.1 m height above ground surface. The sensors were connected to VRC (Chemical Containers, INC, Lake Wales, FL, USA). The VRC consists of electronic hardware with internal firmware and matching Windows Mobile 6.0 software on a PPC. VRC was interfaced to a PPC and could be operated easily from a PPC using wireless Bluetooth® radio.). VRC received target detection signal from sensor and opened valve in specific section of boom where the target had been detected. The VRC was installed in the ATV cab and was connected to DJC (DICKEY-john Corporation, Auburn, IL., USA). After receiving target detection information from the sensor VRC automatically communicated with DJC. The DJC regulated discharge of the nozzles in specific sections of the boom where the target had been detected based on ground speed obtained from WAAS-enabled DGPS (Garmin International, Inc. Olathe, KS., USA) through a DJ servo valve and DJ flow meter (Figure 1).

Fig.1: An automated variable rate sprayer for spot- application of agrochemicals.

Laboratory Tests

Ultrasonic sensors were calibrated to measure the distance from the ultrasonic sensor to the target in the metal shop at Nova Scotia Agricultural College (NSAC), Truro, NS, Canada. The distances (from sensor to the target) were measured with a measuring tape three times at ~12.7 cm intervals up to 152.4 cm and voltages were recorded using a digital multimeter at the time of distance measurements for comparison. The multimeter was connected to sensor and a converter (converting 120V AC to 5V DC). The voltages were converted into bytes (converting analog to digital; 0-1024 bytes) to make compatible with the program software installed in PPC. The measured distances (from sensor to target) and bytes were compared by linear regression using SAS 9.1 software (SAS Institute, Cary, NC., USA) to examine the performance accuracy of ultrasonic distance measurements. The calibration equation was incorporated into program software installed in PPC.

An experiment was conducted in the metal shop at NSAC to calculate look-ahead delay time (i.e. lag time between sensor detection and discharge time) for VRC to open the valve at the right target after receiving target detection information from the sensor. An LED bulb was wired into switch #8 on VRC. A Canon FS100 digital camcorder (Canon Canada Inc., Mississauga, ON, Canada) was positioned in front of the spray nozzle (nozzle #8) to record the video. Bulb was placed within 5.8 cm of the camcorder lens so that it could be seen in the lower corner of the video frame. The video was recorded for one minute when the sensor detected the target and bulb was ON (controller opened the valve). Test was repeated five times and video images were analyzed with Cyberlink Power Direct software (CyberLink Corporation Fremont, CA., USA), allowing for a frame by frame analysis of lag time between sensor detection and discharge time.

VRC received target detection signal from sensor and simultaneously communicated with DJC. An experiment was conducted at NSAC to evaluate the performance accuracy of DJC for flow rate measurements from the nozzles mounted on the sprayer boom. The volume of water from each nozzle and then from different combinations of nozzles was recorded from the DJC and also measured manually with graduated cylinders at the same time for comparison. The experiment was repeated three times and volume measurement readings were averaged in Excel (Microsoft Office 2003). The differences between DJC volumes and manually measured volumes were used to characterize the performance of the DJC.

Real-Time Field Test

After calibration tests, two wild blueberry fields were selected in central Nova Scotia to test the performance accuracy of the VR sprayer for spot-application of agrochemicals in July, 2009. The selected fields were the Adams site (field 1; 45.441199° N, 63.541249° W) and the cattle market site (field 2; 45.45202° N, 63.449626° W). Both fields were in their sprout vegetative year of the biennial crop production cycle in 2009, having been in the crop year in 2008. The fields had been under commercial management over the past decade and received biennial pruning by mowing for the past several years along with conventional fertilizer, weed, and disease management practices. The main weed species, in competition with wild blueberry were goldenrod (*Solidago sp.*) in Londonderry field, and black bulrush (*Scirpus atrovirens Willd.),* dogbane (*Apocynum androsaemifolium L.*) and bracken fern (*Pteridium aquilinum L.*) were more in cattle market field. Meteorological conditions were considered as constant during the field experiments.

Two tracks (100 m x 6.1 m each) were selected in each field to test the accuracy of VR sprayer for detecting weeds and spraying at right targets (Figure 2 and 3). The boundaries of selected tracks were mapped with real time kinematics - global positioning system (RTK-GPS) (On GRADE Inc. Dartmouth NS, Canada) in both fields.

The weed patches were mapped with RTK-GPS in test tracks of both selected fields before and after kaolin (colored dye additive) application to evaluate the performance accuracy of the VR sprayer in two wild blueberry fields. The sprayed maps were superimposed on weed maps in Arcview 3.2 GIS software. The application rate was set up at 187.0 L/ha. The selected buffer (before and after target) was 255 cm and average ground speed was 6.0 km/hr. The water was sprayed and replicated three times with both SSA and uniform application in selected tracks of a wild blueberry field to evaluate the repeatability of the spray applications and to quantify the chemical saving with SSA. The total applied chemical for each track was obtained from DJ controller with both SA and uniform applications. The area of each track before and after application of chemical was measured with RTK-GPS. The mixed procedure (PROC MIXED) was used to analyze the data and means were compared using PDIFF option of LSMEANS statement with SAS 9.1 software. Matching means were separated by the t-test at 5% level of significance and variability in data was expressed with standard error (SE).

RESULTS AND DISCUSSION

The principle components of VR sprayer (sensors and controllers) were successfully calibrated and tested in the metal shop at NSAC for target sensing and spraying at right target in a specific section of the sprayer boom where the target has been detected. Ultrasonics were calibrated for distance measurement and linear calibration model showed that distance measured from sensor to target was correlated highly significantly with the bytes (R^2 = 0.999; $P< 0.001$). Ultrasonic sensor calibration equation for height measurement incorporated into software installed in PPC to permit the sensor of target detection accurately.

Results indicated that VRC was operated easily from PPC using wireless Bluetooth® radio with Windows Mobile® compatible software. VRC was faster and accurate enough to open the valve at right target with delay time 0.054 second (Table 1) after receiving the sensor target detection information. The VRC received target detection signal from sensor and automatically communicated with DJC at the same time. The DJC also performed reliably and rapidly to regulate flow rate in each nozzle through DJ servo valve and flow meter with 97.5 % accuracy during calibration test (Table 2). Therefore, principle components of VR sprayer (ultrasonics, VRC, DJC, DJ servo valve and DJ flow meter) could be used to develop VR sprayer to detect targets (weeds taller than plants) and spot-application of agrochemicals at right targets reliably to reduce cost of production and protect environment.

Table 1: Look-ahead time delay for 8-channel computerized variable rate controller to open valve in specific section of the boom where the target has been detected.

Trial	Camera start time	Nozzle open time	Difference	Average look-ahead delay time (sec.)
1	6.30	6.33	.033	
2	10.033	10.10	.067	
3	13.866	13.933	.067	0.054 sec.
4	17.33	17.366	.033	
5	20.466	20.533	.067	

Table 2: Comparison of DICKEY-john Land Manager II discharge measurement with manually measured discharge from the nozzles in different sections of sprayer boom.

	Number of Nozzles							
Volume (liters)	All 8	1	1,2	1,2,3	1,2,3,4	1,2,3,4,5	1,2,3,4,5,6	1,2,3,4,5,6,7
Manually measured	36.9	12.0	13.3	14.9	18.6	18.9	18.9	18.6
DJ Controller	37.4	11.7	13.3	15.2	19.0	19.4	19.6	19.0
Difference (%)	1.4	2.5	0	2.0	2.1	2.0	1.5	2.1

Real-Time Field Test

Tall weeds remain a serious threat for the growth of wild blueberry as well as for smooth mechanical harvesting causing fruit losses. Wiping and rolling methods can be used where weeds are taller than the blueberries. Cutting was not effective and wiping could result in injury to the blueberry plant, so other safer alternatives were needed (Yarborough, 2006). Results of this study indicated that automated identification of taller weeds in real-time and spot-application of herbicides using ultrasonic and fast VRC would help in monitoring their growth in wild blueberry fields (Figures 3 and 4). Visual observation also revealed that VR sprayer performed reliably during the field experiments, permitting real-time target (weed) sensing and spot-application at right targets in a specific section of sprayer boom where the weeds have been detected. Therefore, it is important to develop VR sprayer using ultrasonics and VRC for in-season spot-application of agrochemicals in wild blueberry fields in order to increase net economic returns.

The VRC was accurate and faster enough with 0.054 second look-ahead delay time to spray water on selected targets accurately during the experiments in selected fields (Table 1). The VRC automatically compensated changes in look-ahead delay time caused by variation in ground speed during operation for accurate applications. The timing calculation for the look-ahead delay time is dependent on the ground speed. The ground speed was obtained in real-time from a WASS-enabled DGPS to compensate changes in look-ahead delay time to spray at right targets. The ground speed during the field operations was 6 ± 0.2 km/hr. Threshold height from the sensor to weed canopy was set at 30.48 cm height to detect the weeds accurately in the selected fields. The buffer, before and after the target, was adjusted at 25.4 cm for precise overlapping of agrochemical applications on targets. The look-ahead delay time and other constant parameters, threshold height from the sensor to weed canopy and buffer before and after the target, were stored in non-volatile flash memory on the main microcontroller for accurate spray on right targets. The stored operating parameters could be easily retrieved and activated by linking the VRC with a PPC using wireless Bluetooth® radio and editing or selecting values on the setup screen with Windows Mobile® compatible software. Based upon the results, it is suggested that VRC interfaced with PPC should be incorporated into commercial sprayer for spot-specific application of agrochemicals reliably and accurately in wild blueberry fields to improve profitability and environmental protection.

Results of this study indicated that DJC regulated the flow accurately through DJ servo valve and flow meter in specific nozzle of the boom section where the weeds had been detected with SA (Figures 3 and 4). It is observed that DJC automatically compensated the changes in nozzle flow rate caused by variation in ground speed during operation. The ground speed was obtained in real- time from a WASS-enabled DGPS during operation for accurate applications.

The application rate was set up at 187.0 L/ha in DJC. On a conventional chemical broadcast application sprayer, the nozzle spacing and the boom height chosen mainly depend on the overall spray pattern uniformity requirement. For the new VRC, the sensing system spatial resolution was considered as the major factor in the nozzle spacing selection. For each individual nozzle to be controlled separately, the size of the section which one nozzle covered was equal to, or slightly larger than the detection zone of the sensing system. The weed maps and spray coverage maps showed that automated variable rate performed well for spot-application of agrochemicals accurately and efficiently (Figures 3 and 4). Due to space constraints, only the weed and spray coverage maps of field 1 are shown here

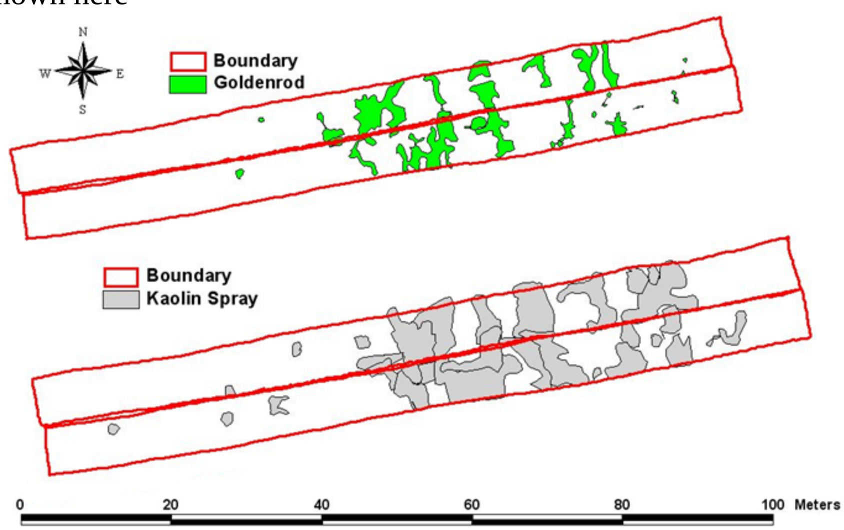

Fig. 3: Maps showing weed patches before spray (top) and after spray coverage (bottom) in field 1.

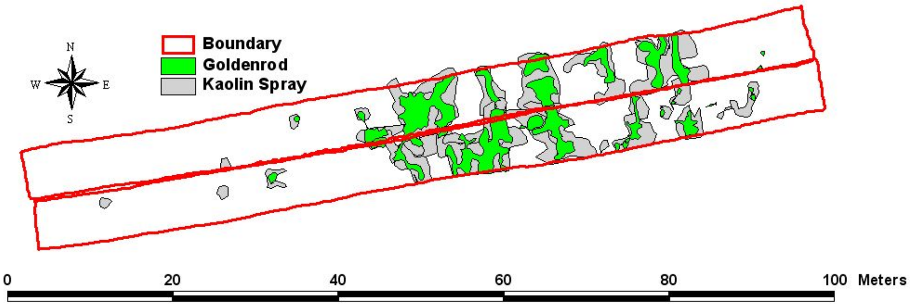

Fig. 4: Weed map overlaid on the map after spray coverage in field 1.

Results indicated SA rates ranged from 45.5 to 53.0 L/ha (SE = 3.20) in track 1 and from 26.5 to 29.4 L/ha (SE = 0.88) in track 2. The UA rate varied from 160.70 to 161.70 L/ha (SE ranged from 0.16 to 0.37) in both tracks (Figures 5 and 6). The reason of variation in SA rates might be some weeds were damaged due to repeated passes of vehicle in the tracks and ultrasonics could not detect the shorter (damaged) weeds.

The chemical saved with SA was 69.22% with 22.67% weed cover and 82.50% with 18.13% weed cover in track 1 and in track 2, respectively (Figures 5 and 6). Based on these results, the VR sprayer could be used for in-season SA of agrochemicals in wild blueberry cropping systems to significantly reduce the amount of agrochemical usage and also reduce environmental pollution.

Fig. 5: Maps showing two tracks with weeds coverage in field1 for repeatability test of spot-application and uniform application.

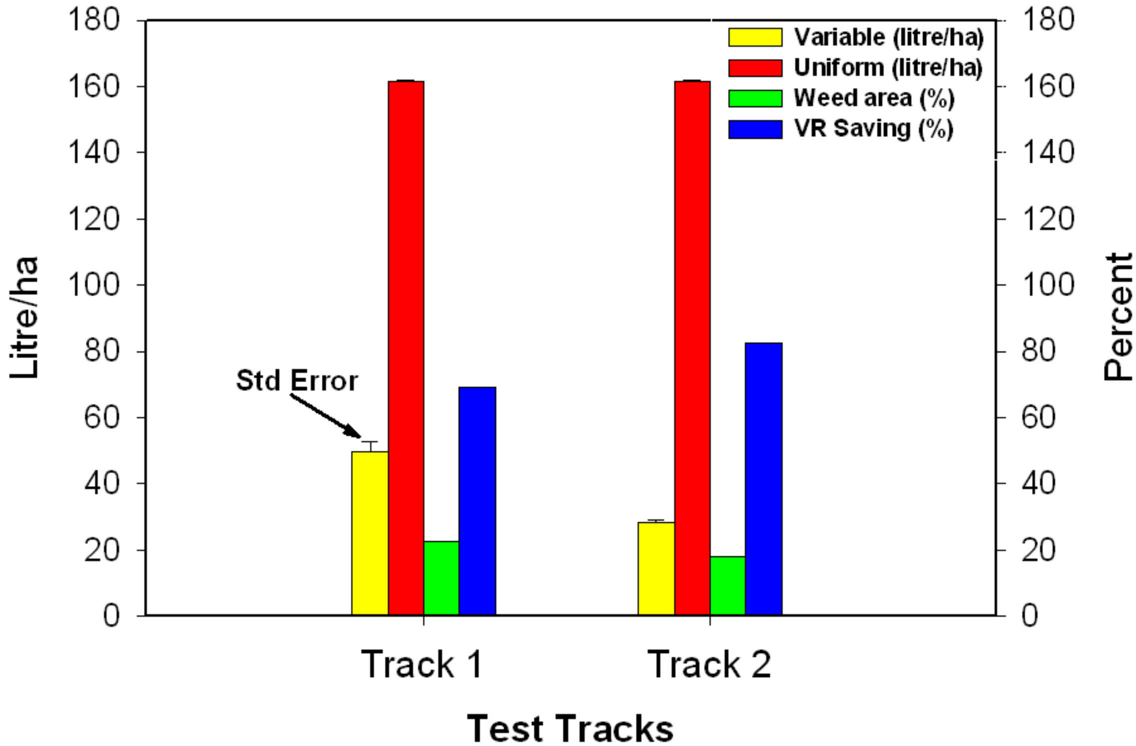

Fig. 6: Comparison of uniform spray application and spot application in field 1.

CONCLUSIONS

The control system of VR sprayer proved very efficient at detecting tall weeds and spray correctly at an actual lag time of 0.054 second. The benefits of VR sprayer control system are: i) easy user-friendly setup on a touch screen- no complicated DIP switches and dials; ii) wireless convenience- setup is possible some distance from the controller; iii) automatic compensation for changing ground speed – no need to manually readjust sensors; iii) manual speed input is possible in case there is GPS signal outage; iv) adjustable front and back buffers for precise overlapping of agrochemical applications on targets; v) automatic startup buffer to ensure complete coverage; vi) a single circuit board replaces multiple timers and electronic modules for greater reliability.

The chemical saved with SA was 69.22% with 22.67% weed cover and 82.50% with 18.13% weed cover in track 1 and in track 2, respectively. Therefore, VR sprayer is cost-effective, efficient and accurate enough for in-season spot-application of herbicides to eradicate tall weeds (taller than plants) in wild blueberry fields.

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