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Herbicide weed control on pavements: Advances in application technology

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Summary

In 2008 and 2009 we tested 11 machines from three categories of herbicide application technology: weed wipers, controlled droplet applicators (CDA) and sensor sprayers. Machines were tested on amount of glyphosate use and efficacy of weed control on three types of pavements typical for weed control in urban area. Test plots were over 100 m^2; sufficiently large to do representative measurements. Weed wipers used the least amount of herbicide, less than 0.05 L product ha^{-1}. Sensor sprayers applied between 0.1 and 0.4 L product ha^{-1} depending on weed infestation level, and configuration of the machine. Double the amount of nozzles and sensors on the spray boom reduced herbicide use by about 50%. CDA machines were set to 0.9 to 1 L product ha^{-1} with good efficacy. CDA combined with a sensor gave 40% reduction in herbicide use in one trial. CDA machines had smaller ED_{90} (effective dose 90% control) values then the sensor sprayers. This confirms that glyphosate application in small and uniform droplets with less water are more effective. All machines tested complied with the dose cap of the SWEEP system, which is important for achieving sustainable weed control on pavements.

Key words: Herbicide efficacy, sustainable weed control, hard surface, urban area

Introduction

Herbicide weed control on pavements has the lowest direct costs compared to alternative non-chemical methods, such as brushing, flaming and hot water and/or air treatments. Costs of weed control on pavements may differ by a factor of 2–4 depending on methods and frequencies per year in relation to maximum acceptable level of weed growth (CROW, 2008). Negative public perception of pesticide use in urban areas and adverse effects on drinking water production (Bannink, 2004) resulted in various national action plans to reduce or stop pesticide use in urban areas (Kristofferson *et al.*, 2008).

In the Netherlands, only a few herbicides are registered for use on pavements to control weeds, of which glyphosate is by far the most used. About one out of five municipalities voluntarily do not use herbicides to control weeds on pavements. In the other municipalities and on industrial sites, professional herbicide weed control on pavements is done under the SWEEP guidelines (Kempenaar *et al.*, 2007). The SWEEP system provides guidelines for sustainable use of herbicide and non-chemical weed control methods on pavements. Herbicide use is only allowed if applied with selective application technology and additional emission reducing measures are implemented. A life cycle assessment study on different weed control methods showed that an integrated approach with combinations of non-chemical and herbicide weed control under SWEEP guidelines has the lowest environmental impact (Kempenaar *et al.*, 2006, 2007).

After the introduction of the SWEEP system in The Netherlands in 2006, several technical innovations have taken place. In this manuscript we describe results of a study in which improved herbicide application technologies were tested on herbicide use and efficacy. Technologies tested were different models and configurations of weed wipers, controlled droplet applicators and sensor sprayers. In particular we tested if different technologies could comply with the dose cap of the SWEEP system (which is maximum 1 L Roundup evolution per ha per treatment at the level of a working unit (2–50 ha) and maximum 2 L per year) under representative conditions. In addition, we tested if efficacy was influenced by application technology.

Materials and Methods

Herbicide use experiments

Herbicide use on typical weed situations on pavements was studied in two years (Fig. 1). The tests were done on representative paved area of about 100 m² with uniform weed infestations.

In June 2008, experiment 1, the experimental site was a part of a sidewalk in a residential area in the municipality of Barendrecht. The side walk was paved with typical 30 cm × 30 cm × 4 cm (l × w × h) concrete tiles on a sandy underlay. Main weeds on the pavement were *Sagina procumbus*, *Poa annua*, *Polygonum aviculare*, *Festuca rubra* and *Poa pratensis*. The number of weeds was *c.* 50 plants per m² at the time of treatment. Soil cover by the weeds was on average 1.4% (47 100 × 50 cm digital images were assessed with ImagJ pixel analysis software; the minimum was 0.4%, the maximum 3.7%). The weed infestation on the sidewalk was classified as a A-B situation according to the CROW scale (CROW, 2008, p. 18.): *c.* 20% of the joint area was covered with weeds, and weeds small (2–5 cm high).

In July 2009, experiment 2, the experimental site was parts of traffic roads on Wageningen Campus (offices and laboratories park). The trials were done on roads with either red clay bricks (18 cm × 6 cm) (l × w) or grey concrete (20 cm × 10 cm) (l × w) bricks. On the red brick road, main weeds were *Sagina procumbus*, *Poa annua*, *Plantago major*, *Polygonum aviculare*, *Festuca rubra*, *Poa pratensis* and *Agrostis stolonifora*. The number of weeds was *c.* 130 plants per m² and soil cover by weeds was 4.8% (four images; minimum 2%, maximum 7%). The weed infestation on the red brick road was classified as C situation according to the CROW scale: > 50% of the joint area was covered with weeds, few weeds > 10 cm high and clumpy. On the grey brick road, main weeds were *Sagina procumbus*, *Poa annua*, *Plantago major* and *Polygonum aviculare*. The number of weeds was *c.* 40 plants per m² and soil cover by weeds was 2.1%: four images; minimum 1%, maximum 3.5%). The weed infestation on the grey brick road was classified as A-B situation (see 2008). The clay brick road was over 25 years old and the concrete brick road 10 years old. Traffic was not intensive on both roads (< 20 automobiles per day, 100–300 bikes per day).

Fig. 1. Images of pavements on which herbicide use was tested: concrete tiles (left top), red brick (middle) and grey brick (right). Also a green pixel image (4% green) of top left picture is shown.

Three types of herbicide application technology were tested: weed wipers (WW), controlled droplet applicators (CDA) and sensor sprayers (SS). In total 11 configurations of these three types of technology were tested, divided over two experiments. Details on the different machines, models and brands are shown on www.dob-verhardingen.nl (Kempenaar, 2010). Hereafter important settings and information is summarised per machine tested in Tables 1 and 2.

Table 1. *Machines and settings in experiment 1 (2008)*

Machine (type)	Application width (m)	Spray release per unit/ nozzle (L min^{-1})	Spray deposition (L ha^{-1}) @ 6 km h^{-1}
GreenTouch (WW)	1.2	Weed wiping	-
Rotofix (WW)	0.6	Weed wiping	-
LaagVolumeSpuit (CDA)	1.1 (three CDA-units horizontally under a hood)	0.035 L min^{-1} per unit	10
Mankar Tramus (CDA)	1.2 (two CDA-units vertically under a hood)	0.0054 L min^{-1} per unit	0,9
Weedseeker 65.01 (SS)	1.2 (four 65.01 nozzles on spray boom)	0.36 L min^{-1} per nozzle @ 2.5 bar	56 (80)
Weed-IT MKI model 2002 (SS)	1.4 (seven 40.01 nozzles on spray boom)	0.23 L min^{-1} per nozzle @ 3 bar	115 * (134)
Weed-IT MKII model 2007 (SS)	1.04 (thirteen 25.0033 nozzles on spray boom)	0.14 L min^{-1} per nozzle @ 3.2 bar	117 * (175)

*Sensor sprayers spray variable doses width one or more nozzles open. Spray deposition of one nozzle open is shown. Tank mix concentrations should be based on this figure. Between brackets spray deposition is shown if all nozzles are used.

Table 2. *Machines and settings in experiment 2 (2009)*

Machine (type)	Application width (m)	Spray release per unit/ nozzle (L min^{-1})	Spray deposition (L ha^{-1}) @ 6 km h^{-1}
Mankar 110P Select (CDA)	1.2 (two CDA-units vertically under a hood)	0.0054 L min^{-1} per unit	0.9
LaagVolumeSpuit (CDA)	1.1 (three CDA-units hori-zontally under a hood)	0.035 L min^{-1} per unit	10
Mankar Unima City (Sensor + CDA)	1,2 (four sensors+CDA-units vertically under a hood)	0.0029 L min^{-1} per unit	1
Weedseeker 65.01 (SS)	1,2 (four 65.01 nozzles on spray boom)	0.36 L min^{-1} per nozzle @ 2.5 bar	56 * (80)
Weedseeker 40.0067 (SS)	1.2 (four 40.0067 nozzles under a hood)	0.23 L min^{-1} @ 2.5 bar	61 * (120)
Weed-IT MKII model 2009 (SS)	1.04 (thirteen 40.0033 nozzles on spray boom)	0,10 L min^{-1} per nozzle @ 1.8 bar	83 * (125)

* See comment under Table 1.

The machines were configured and calibrated by the owners, which were developers or professional users. Liquid release during operation on the test plot was determined by driving the machines over the net test plots with a length of 100 m. The width of treatment was equal to the width of the machine (0.6–1.4 m, see Tables 1 and 3). If liquid release was small, two or three drives were made over the plots. Depending on technology, one of two methods was applied to measure liquid release. In the case of weed wipers (WW), the weight difference of the herbicide tank was determined before and after operation. In the other cases, liquid releases by individual nozzles or rotary applicators were collected in plastic bags, and the net weight of the liquid in the bags was determined per test run of a machine. The tank concentration of Roundup evolution was 100%, 80% or 10% according to technical instructions of the WW or CDA machines. The tank concentration of the sensor sprayers, which only sprayed the spots on the plot where weeds were detected, was set to a reference dose recommendation from a decision support system (DOB-fax, see www.dob-verhardingen.nl), which was to 1% and 100 L spray solution ha^{-1} in 2008 and 2% and 100 L spray solution ha^{-1} in 2009.

Efficacy tests

Next to the test plots for the herbicide use tests on the different pavements in 2008 and 2009, small plots were used to test efficacy of the configurations how the different technologies were used. Because these tests only provide information whether or not the configuration and corresponding dose was effective, we did in 2009 an additional dose response experiment with five of the six CDA and SS technologies tested. Plants were grown in a greenhouse in pots with peat soil. Growth conditions were a day night regime of 18/12 degree C and 80% R.H.

On the day of the dose response experiment (3 July 2009), the plants were placed outside in a design as shown in Fig. 2. The plants were treated with one of six doses: 0, 0.05, 0.1, 0.5, 1 and 3 L Roundup evolution ha^{-1}. Each machine treated six plants (replicates) per dose. Two plant species were tested: *Solanum nigrum* and *Echinogloa crus galli*. Overall six times six times five times two plants were tested. After treatment, the plants were returned to the greenhouse. During the next 3 weeks symptom development was monitored. Three weeks after treatment, the aboveground fresh weight per plant was determined.

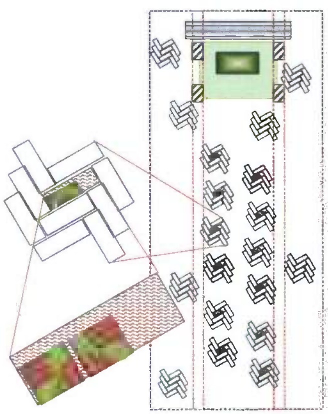

Fig. 2. Scheme showing how plants were arranged during application of one dose with one machine (left) and picture of application of one dose with a Weedseeker sprayer (right).

The data on aboveground fresh weight were analysed with non linear regression analysis in the GENSTAT statistical program (Payne *et al*., 2008). The dose that caused 90% reduction of aboveground biomass (ED_{90}) and standard error were estimated with the program for each machine tested. The Weibull function was used in the program to determine the non linear dose response relationship and the ED_{90}:

$$f(x) = 0 + (d-0)exp(-exp(b(log(x)-e)))$$

where b = angle of slope at ED_{50}, c = lower limit, d = upper limit and e = ED_{50}.

Results

Herbicide use experiments and efficacy check

The 2008 experiment showed a large difference in herbicide use between the three types of application technology (Table 3). Weed wipers by far used the smallest amount of herbicides (< 0.05 L ha^{-1}). The amount of liquid release was that low that is was difficult to do a precise measurement. The sensor sprayers applied less than 1 L ha^{-1} due to selectively spraying of weeds. The MKII applied much less than the other two sprayers (0.1 *vs* 0.4 L ha^{-1}), mainly because it has more sensors and nozzles (treatment width per nozzle is 8 cm wide *vs* 20 to 30 cm wide). The CDA applied the amount of herbicide according to the setting without significant deviation.

Table 3. *Use of Roundup evaluation on sidewalk of the experimental site in 2008*

Machine (type)	Roundup evolution use (L ha^{-1})
GreenTouch (WW)	< 0.05
Rotofix (WW)	< 0.05
LaagVolumeSpuit (CDA)	1
Mankar Tramus (CDA)	1
Weedseeker 65.01 (SS)	0.38
Weed-IT MKI model 2002 (SS)	0.46
Weed-IT MKII model 2007 (SS)	0.06

In 2009 similar results were obtained. Data obtained on both situations tested are averaged in table 4. This time, weed wipers were not tested. The CDA applied the amount according to the setting without significant deviation. The CDA combined with a sensor resulted in 40% reduction of herbicide use. The sensor sprayers even had higher reductions, with MKII the lowest amount of herbicide use (0.13 L ha^{-1}).

Efficacy of the configurations was checked on small plots next to the herbicide use plot. All configurations gave good level of control. Weed wipers gave a little less control because they did not affect the weeds that had not emerged above the tile or brick surface at the day of treatment. The weed wipers simply did not touch these plants.

Table 4. *Use of Roundup evaluation on two roads of the experimental site in 2009*

Machine (type)	Roundup evolution use (L ha^{-1})
Mankar 110P Select (CDA)	0.9
LaagVolumeSpuit (CDA)	1
Mankar Unima City (sensor + CDA)	0.6
Weedseeker 65.01 (SS)	0.32
Weedseeker 40.0067 (SS)	0.20
Weed-IT MKII model 2009 (SS)	0.13

Efficacy test 2009

In an additional experiment we tested if machines and machine configuration had an effect on efficacy by comparing ED_{90} values from dose response tests with five machines. Table 5 shows the estimated efficacy parameter. Machines had a significant effect on the efficacy. CDA showed smaller ED_{90} values than the sensor sprayers. Weedseeker 65.01 and Weed-IT MKII did not differ significantly. Weedseeker 40.0067 was intermediate between CDA and other SS. We cannot conclude that this difference is significant because we had a technical problem with the machine and the test with this machine was delayed 2 h and did not fall in the experimental scheme properly anymore. *Solanum nigrum* had significantly higher ED_{90} values than *Echinogloa crus galli*.

Table 5. *Dose of Roundup evaluation (L ha⁻¹) that resulted in 90% reduction of biomass 2 weeks after treatment under greenhouse conditions*

Machine (type)	ED_{90} value (SE)	
	Solanum nigrum	*Echinogloa crus galli*
Mankar Unima City (sensor + CDA)	0.6 (0.2)	0.2 (0.1)
LaagVolumeSpuit (CDA)	1.1 (0.6)	0.2 (0.1)
Weedseeker 40.0067 (SS) *	0.8 (0.3)	0.4 (0.2)
Weedseeker 65.01 (SS)	1.7 (0.3)	1.2 (0.2)
Weed-IT MKII model 2009 (SS)	1.3 (0.2)	1.1 (0.2)

*Because of technical problem, data should not be compared with those of other machines.

Discussion

Sustainable weed control on pavements requires restrictions on herbicide use. The present study shows that good weed control can be obtained with glyphosate use much less than the recommended dose (*c.* 3–5 L Roundup ha^{-1}; may differ between countries). Less herbicide use reduces the risk of herbicide run off to surface water and percolation to ground water. Run off of glyphosate in small plot, worse case situations may be as high as 23% (Beltman *et al.*, 2006; Carmel, 2006). Under SWEEP guidelines conditions, run off was reduced to amounts of 0.2–5.3% at scale of 2–10 ha (Kempenaar, 2007).

Weed wipers used the least amount of herbicide, less than 0.05 L ha^{-1}. Weedseeker-sprayers applied between 0.2 and 0.4 L Roundup evolution ha^{-1}. Weed-IT MKII, with more sensors and nozzles per m spray boom, applied between 0.1 and 0.2 L product ha^{-1}. Weed IT MKI, tested in 2008 only, applied 0.46 L ha^{-1}. This amount was higher than expected, partly because the working width of the machine was highest and the side nozzle was affected by the grass strip next to the side walk. This nozzle had higher liquid release than the others. This phenomena was not observed for the other machines tested because they had smaller application widths. The CDA-technologies LaagVolumeSpuit and Tramus applied 1 L product ha^{-1}, and the 110 P Select 0.9 L ha^{-1}, according to configurations. The Unima City applied less than the setting (0.6 L product ha^{-1}) because the rotary applicators were switched on only if weeds where detected by the sensor (Weedseeker sensors). Selectivity of the machines increased from CDA-technologies to sensor-sprayers to weed wipers.

The small plot efficacy experiments in 2008 and 2009 confirmed that the configurations allow good level of weed control at the use rates mentioned. In the dose-response experiment in 2009, a good level of control was obtained at a dose of about 1 L Roundup evolution ha^{-1}. CDA-technologies showed better efficacy at this dose than the sensor-sprayers. This difference is explained by the smaller and more uniform droplets applied by the CDA-technologies, resulting in better deposition of the herbicide on the target.

In the herbicide use experiments, the machines were evaluated without any additional handheld equipment mounted on the machines for treatment of weeds outside the spray band. We estimate this use 0.2–0.4 L product ha^{-1}. This amount should be added to the aforementioned experimental data of use per machine if these machines are used in combination with handheld application technologies.

All machines tested in this study complied with the criteria set in the SWEEP system. The results show the potential to further reduce glyphosate use on pavements without losing efficacy with modern application technology. The challenge is to find the optimal integrated approach in which non chemical weed control methods are combined with minimum use of herbicides. Good management should combine these methods. In that case the least environmental effects will be obtained, see the results of Life Cycle Assessment (LCA) studies (Kempenaar *et al.*, 2006, 2007). In fact the LCA will be improved if the reduced use rates from the current study are used in the LCA. Some of the machines tested are used in practice today in the Netherlands. They contribute to the reduction of glyphosate in surface water and the adverse effect on drinking water production. In Fig. 3 we show the increase and decrease in annual average glyphosate concentration in the river Meuse at a point where water is taken for drinking water production. Since 2006, when SWEEP became mandatory, the annual concentration is going down, with in 2010 only one time a higher concentration than the Dutch threshold value of 0.1 $\mu g\ L^{-1}$ (Fig. 3, adapted from data RIWA-Maas/Meuse; Volz, 2011).

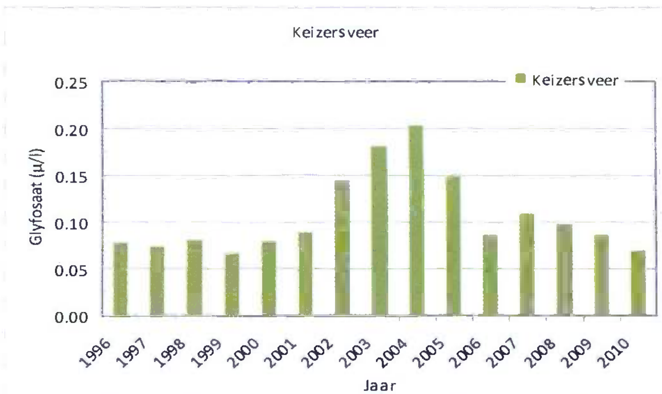

Fig. 3. Annual average concentrations of glyphosate in the Meuse river at Keizersveer in the Netherlands (Source: RIWA-Maas/Meuse/Volz, 2011).

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