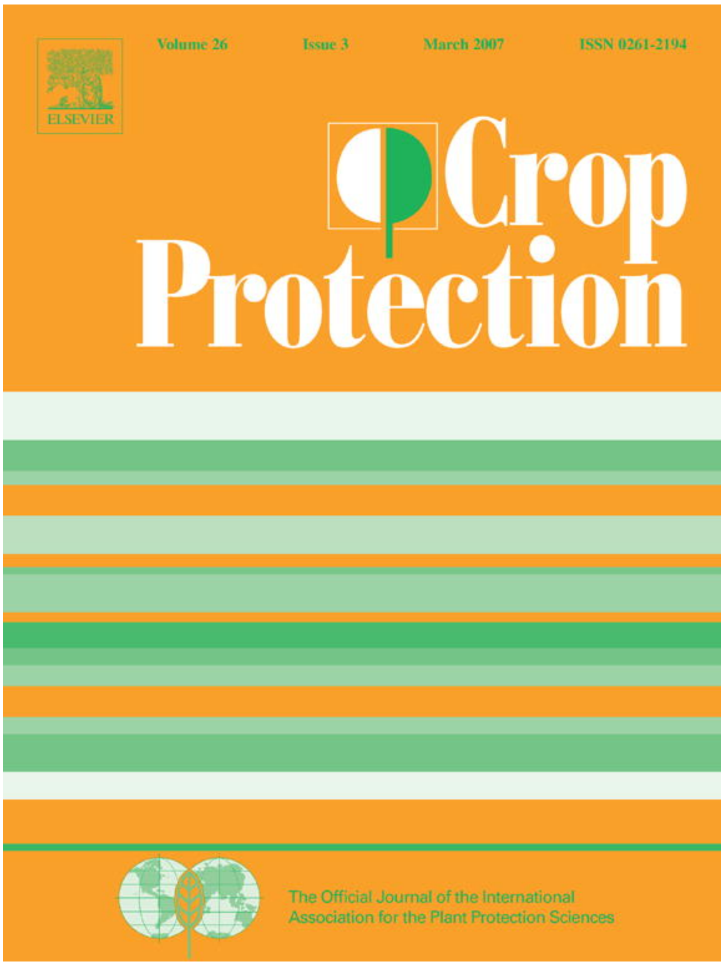
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Trade off between costs and environmental effects of weed control on pavements

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Abstract

An actor-participative project on sustainable weed control on pavements was started in 2000 in the Netherlands. The aim of the project was to develop a new concept of weed management that provides cost-effective and environmentally sound weed control. Early in 2002, practical guidelines were drawn up in support of decision making by managers of pavements, and weed control contractors. The guidelines are focused mainly on reduction of herbicide use and emission thereof. The new concept was tested in 2002 and 2003 in nine Dutch municipalities on defined urban areas of 5–25 ha, which formed units from a construction, hydrology and management point of view. Use of herbicides (mainly glyphosate) was reduced by 11–66% compared to standard practice. Levels of weed control remained good and ecological threshold concentrations in surface waters were not exceeded. Monitoring showed a glyphosate emission factor via the sewage water system of 2% on average. Costs of weed control with the new concept were higher (10–25%) compared to the standard practice control of weeds (using herbicides) on pavements, but much lower compared to alternative (non-herbicide) weed control systems. It is concluded that the new concept provides a useful framework for finding a good trade off between economical and ecological aspects of weed control on pavements.

Keywords: Sustainability; Weed control; Hard surface; Glyphosate; Emission; Pavement management; Herbicides

1. Introduction

Plants colonise pavements and become weeds if conditions allow. The more bare soil in the construction and the lesser the traffic over it, the more likely weed establishment and development will be. Managers of pavements have to consider weed control when weeds affect the functionality, durability and/or aesthetic value of the pavements. Current weed control methods on pavements involve brushing, burning, mowing, hot water treatment and/or herbicide use (Kortenhoff et al., 2001).

In the Netherlands, as in many other countries with temperate climates favourable for weed development on pavements, herbicide use has become an important weed control method. Recognition of possible side effects has lead to banning of some herbicides, e.g. the registration of diuron was ended in 1998 in The Netherlands. Furthermore, agreements and other policies have been implemented in different countries to reduce or phase out herbicide use on pavements (Balder et al., 2003; Helweg, 2003; Kempenaar and Spijker, 2004).

Current weed control methods differ in many respects, e.g., as regards inputs, outputs, side effects, costs and efficacy (Kortenhoff et al., 2001; Saft and Staats, 2002). Fig. 1 summarizes environmental effects of these methods. A standard practice herbicide use system gave the largest

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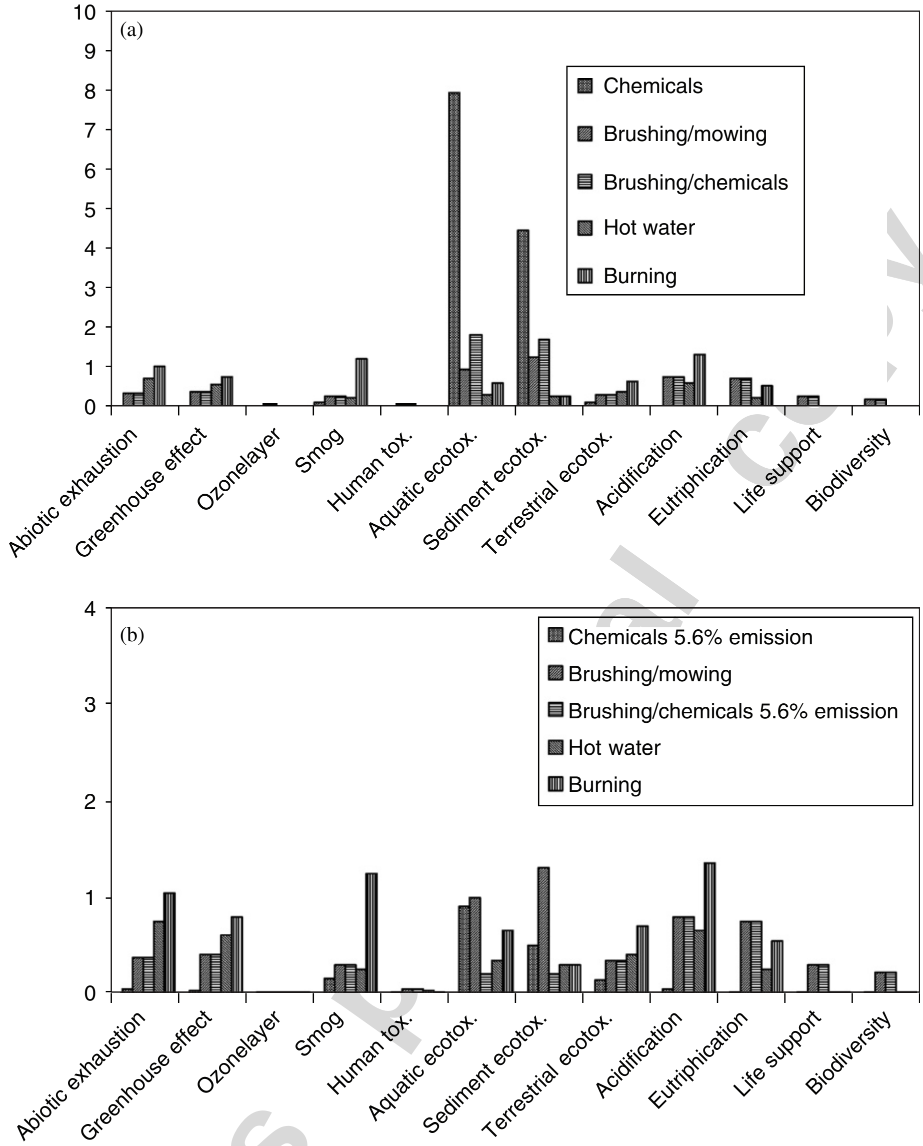

Fig. 1. Life cycle assessment (LCA) of weed control on pavements by Saft and Staats (2002) (a), and highest observed glyphosate emission factor of the new concept projected on this LCA (b). Relative environmental impact scores are presented for 5 weed control systems: chemicals (selective application of glyphosate 2.5 times/year, brushing/mowing (3 times brushing/year plus mowing around obstacles), brushing/chemicals (3 times brushing/year plus glyphosate around obstacles), hot water (2.5 times/year) and burning (4 times/year).

relative environmental impact (mainly on surface water and water sediment), but was at least 2.5 times and on average 6 times more cost effective than the alternative non-herbicide systems (Saft and Staats, 2002). Consequently, managers often prefer herbicide use. In the Netherlands in 2001, 81% of the municipalities applied herbicides on pavements to control weeds (Ekkes et al., 2002). For pavements of industrial sites, harbours, airports and railroads, this percentage will probably be higher.

Today, glyphosate is the most used herbicide on pavements by far in The Netherlands. The maximum permissible concentration (MPC) is 77 $\mu g\,L^{-1}$ glyphosate in surface water (Withagen et al., 2004). The general EU drinking water threshold concentration is 0.1 $\mu g\,L^{-1}$/individual pesticide and 0.5 $\mu g\,L^{-1}$ for all pesticides. The physical and chemical properties of glyphosate (high solubility in water, high sorption to soil particles) make the herbicide very sensitive for running off to surface water, but not for leaching to soil water (Beltman et al., 2001; Ramwell and Hollis, 2003; Luijendijk et al., 2003). In the study of Saft and Staats (2002), a runoff emission factor of 50% for herbicides on pavements is assumed.

In 2000 a project was started in The Netherlands to develop a new system for sustainable weed control on pavements. The system had to meet different objectives related to costs, efficacy and emission. It should allow cost-effective weed control according to existing standards, while herbicide emission should not exceed ecological and drinking water threshold concentrations. The theoretical phase of the project ended in 2001 with the publication of an overview of options (Kortenhoff et al., 2001). The present paper gives an overview of test results for the new concept of weed control. The tests were carried out in specific areas of nine Dutch municipalities.

2. Materials and methods

Fig. 2 summarizes the concept presented in this paper. The concept is based on easy access to relevant weed control information (handbook and website) (Kempenaar, 2004; 〈www.dob-verhardingen.nl〉), simple guidelines to minimize herbicide emission, transparency, and certification. Transparency comes from written agreements between managers and contractors, and compulsory registration of actions and herbicide use. Audits from the envisaged certification system will further increase the transparency.

The emission reducing measures are given in shortlist 1 for managers and annual planning, and shortlist 2 for contractors and operational planning. The shortlists contain specific recommendations and restrictions on use of glyfosate and MCPA. Full details of the shortlists are given by Kempenaar (2004) and Withagen et al. (2004). On 〈www.dob-verhardingen.nl〉, a slightly modified, updated version is given in Dutch and English, summarized as follows:

1. No herbicide use if the pavement is within 10 km upstream of surface water that is used for drinking water production;
2. No herbicide use on 1 m zones of pavements bordering surface waters;
3. No herbicide spraying in 1 m zone around gully pots;
4. No herbicide spraying when weather forecasts are favourable for runoff (probability of rain >40% and >1 mm);
5. Best practices should be applied (use of weed sensors for selective treatment of weeds is compulsory).

Managers that implement the new concept have to promote weed prevention, to define target weed infestation levels in the management area (e.g., based on the class system in Table 2), to plan timing of control methods on the basis of maximum acceptable weed infestation levels, to indicate no-herbicide use areas on maps, and to distribute these maps to the relevant parties.

2.1. Experimental areas

The concept was first tested in 2002 and 2003 in nine municipalities, namely Alblasserdam, Dordrecht, Hendrik-Ido-Ambacht, Giessenlanden, Leiden, Lelystad, Papendrecht, Vianen and Zwijndrecht. These municipalities, with 30,000 to more than 100,000 inhabitants each, are located in the west and central part of the Netherlands. In each

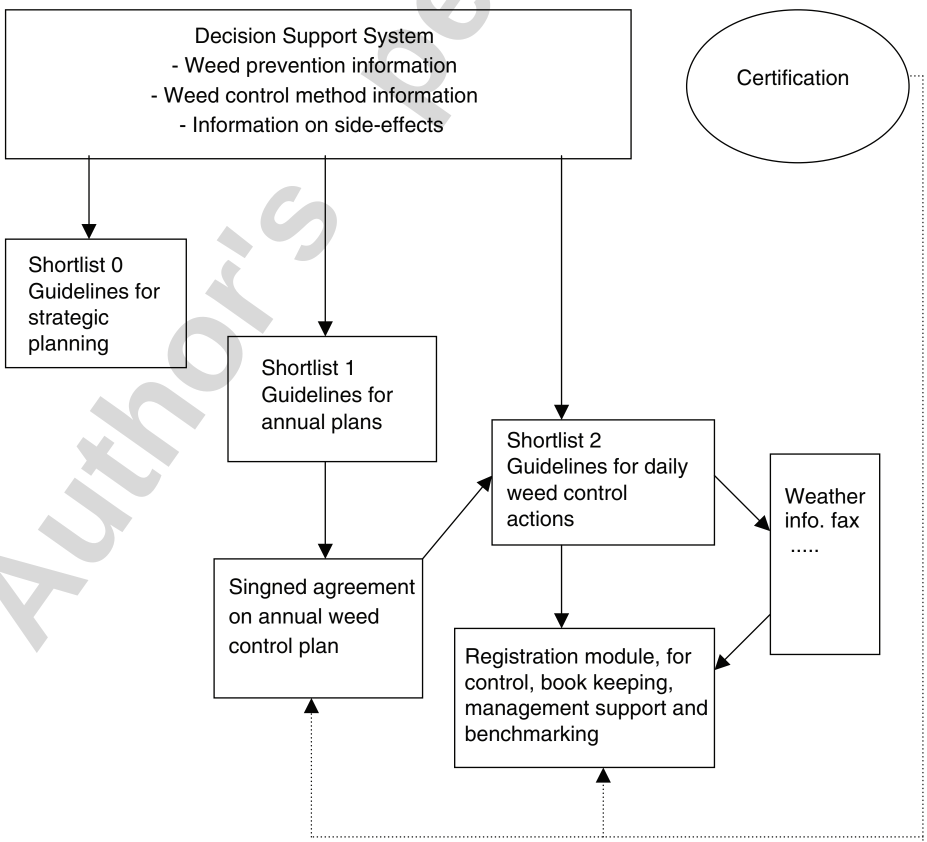

Fig. 2. Diagram of the concept for sustainable weed control on pavements.

municipality, one or two sites (5–25 ha total area and 2–10 ha of paved area) were selected for testing of the concept. Aerial pictures and maps of the sites are given in Withagen et al. (2003, 2004) and on ⟨www.dob-verhardingen.nl⟩. The test sites were considered distinct units based on construction period, hydrology, and from the management point of view. They all had sewage and canal systems suitable for emission monitoring. The municipalities outsourced the weed control by contracting specialized companies to do the weed control on the test sites, based on the guidelines of the new concept.

2.2. Observations in experimental areas

A large monitoring programme was carried out to study herbicide emission (Withagen et al., 2003, 2004; van Zeeland and Kempenaar, 2004). Flow rate proportional (frp) sampling (Withagen et al., 2004) of sewage water was done in eight experimental situations. The frp sampler was installed in the sewage water system of the test site at a location where all the rainwater leaving the site via the sewage system to the water purification system passes by. Frp sampling was done shortly before and after herbicide applications until 20–30 mm rain had fallen on the site. In situations where frp sampling was not possible, point sampling of the sewage water was done at representative positions in the sewage water system, prior to herbicide application and during the first rain event after herbicide application. Point sampling was also done in the surface waters of the test sites at positions where runoff was most likely, and where the sewage water system drained into the surface water. In total, the programme yielded 21 worst-case sewage water samples and 42 worst-case surface water samples. "Worst-case" implies sampling occurred within one to a few hours after the first rain event of >1 mm. The frp sampling method yielded about 1 sample mm^{-1} of rain. Samples were analysed by certified laboratories for glyphosate and AMPA (degradation product of glyphosate) at a detection limit of 0.5 $\mu g L^{-1}$.

Besides emission, the following other aspects of weed management were quantified:

- Weed control methods, timing, and herbicide use on the test site (based on data obtained from registrations by the contractors and managers of municipalities).
- Efficacy of weed control (weed infestation was estimated at 20 random positions in the test site on 3–5 dates/season using the evaluation system in Table 1.
- Costs of weed control/test site (calculated by the managers of the municipalities).

3. Results

The new concept was implemented quite successfully on the test sites, taking into account the many people involved, the novelty of the concept and the scale of the test areas. Timing of weed control activities was aimed at keeping weed infestation levels below the class-3 level (Table 1). The timings were affected by weather forecasts (no spraying when rain was predicted within 24 h), availability of contractors, machines and budgets. On parts of the sites, where herbicide use was not allowed, these areas were marked on maps that were made available to the contractors. On these areas, hand weeding, brushing or burning was done. On most test sites two working rounds of weed control were done per year, in May/June and in September. In 2002, during six rounds of weed control, on average 830 g ha^{-1} glyphosate was applied on paved areas; and in 2003, during 13 rounds, 324 g ha^{-1} of the herbicide was applied. In 2003, MCPA was also applied in six of 13 rounds (Withagen et al. (2003, 2004). Reductions in glyphosate use on the test sites compared to reference sites within the municipalities ranged 11–66% (Table 2).

Table 1
Weed infestation classes for pavements (Withagen et al., 2004)

Class	Weed infestation level on the pavement
1	No weeds
2	Very few small weeds, less than 5% cover of bare soil by weeds
3	Few small weeds, 5–25% cover of bare soil by weeds
4	Some weeds higher than 10 cm or some clumps of weeds, 25–50% cover of bare soil by weeds
5	Many weeds higher than 10 cm or clumps of weeds, soil cover more than 50% by weeds
6	Pavement nearly invisible because of weed cover

3.1. Emission monitoring

Frp sampling showed that glyphosate and AMPA could be detected in the sewage water for up to four weeks following herbicide application, and concentrations were dependent on date and amount of rainfall. Highest concentrations were detected during or shortly after the first rain event (>1 mm precipitation). Fig. 3 shows concentrations of glyphosate in 21 worst-case samples of water of the sewage systems in the test sites. Samples 18–21 represent situations where it rained within 1.5 d after herbicide application. In addition, sample 21 represented the highest glyphosate dose rate applied in the study (1240 g ha^{-1} glyphosate).

Frp sampling data were used to calculate the emission factors of glyphosate, which is defined as the amount of glyphosate emitted from the site divided by the total amount of herbicide applied on the site. Emission factors of different sites are shown in Fig. 4. On average, the emission factor was 2%. The amount of AMPA in the samples was on average less than the amount of glyphosate. The ratio glyphosate:AMPA in the frp water samples was on average 1:0.2, and ranged 1:0.03–1:1.1. Beltman et al. (2001) and Luijendijk et al. (2003) reported emission factors for glyphosate between 15 and 25% for

Table 2
Summary of results of new concept of weed control on test sites of 9 municipalities in 2002 and 2003

Parameter	Result
Herbicide use compared to practice in previous year	−11% to −66%
Surface water quality:	
Concentration glyphosate in surface water (42 samples)	<0.5–8 μg L^{-1}
Number of samples exceeding MPC	0
Number of samples exceeding detection limit (0.5 μg L^{-1})	6 out of 42
Level of weed control during the season	Reasonable to good
Costs of weed control compared to practice in previous year	+ 10% to +25%

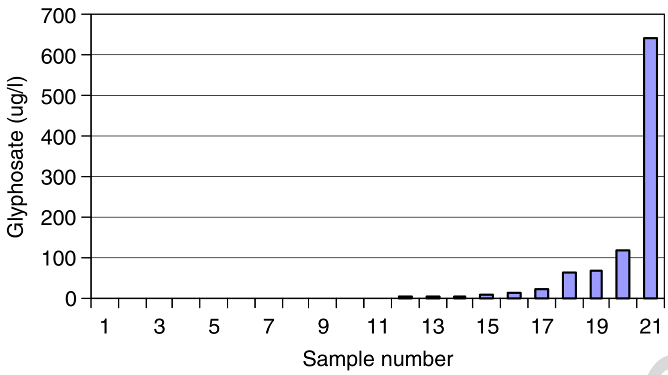

Fig. 3. Concentrations of glyphosate in sewage waters of test sites in 2002 and 2003 at worst-case sampling moments. Sampling before herbicide application showed no glyphosate above the detection limit of 0.5 μg L^{-1}.

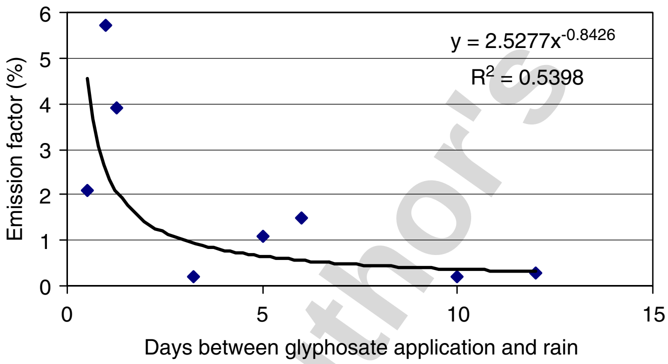

Fig. 4. Relationship between days between spraying of glyphosate on test sites and emission factors via the sewage water system in 2002 and 2003.

worst-case situations. It is concluded that the emission factors observed for the test sites are much smaller than those reported by Beltman et al. (2001) and Luijendijk et al. (2003), and even more smaller than the 50% emission factor assumed by Saft and Staats (2002).

Surface water sampling yielded 42 worst-case samples. The highest concentration in these samples was 8 μg L^{-1} glyphosate (Table 2). In six of the 42 samples, concentrations of glyphosate were below the detection limit. The MPC threshold concentration was never exceeded. An average worst-case glyphosate concentration cannot be calculated because about 85% of the data points were concentrations below the detection limit. If these concentrations are set on 0.5 μg L^{-1}, the average worst-case concentration is smaller than 1 μg L^{-1}, which is in the order of a factor 100 below the MPC of glyphosate. The MPC of AMPA (80 μg L^{-1}) was also never exceeded for the surface water samples.

3.2. Weed control efficacy

Managers of the test sites were satisfied about the level of weed infestation following weed control (Table 2). Average weed infestation levels on the different observation dates/season never exceeded the class-3 level (Withagen et al., 2004). Occasionally, a class-4 or -5 situation was observed on a site, but this was exceptional, limited to a small spot, and often linked to prohibited herbicide use or a spot with obstacles hampering maneuverability of weed control machines. Most common weeds species on the sites were *Erigeron canadensis, Plantago major, Poa annua, Polygonum aviculare* and *Taraxacum officinalis.*

3.3. Costs of weed control

Data on costs generated by this study should only be used as indicative information because commercial tariffs were not applied in most cases. In two municipalities, commercial tariffs were applied, and annual costs of weed control/area of pavement were 0.05–0.15 € m^2 yr^{-1}. The managers of these sites estimated that the costs of weed control according to the new concept were 10–25% higher than costs of standard practice herbicide weed control (Table 2). When compared to non-herbicide weed control systems (Saft and Staats, 2002), weed control according to the new concept was 2–10 times less expensive than such systems.

4. Discussion

Findings demonstrate that restricted use of glyphosate on pavements does not lead to concentrations of glyphosate or AMPA in surface waters above the ecological threshold value, the MPC. Concentrations were at least a factor 10 below this threshold. Despite this positive conclusion, it is also clear from the study that restricted glyphosate use on pavements will result in emission to surface waters and, sometimes (6 out of 42 times), concentrations above the drinking water standard (0.1 μg L^{-1}) will occur. The new concept contains a specific restriction (Materials and Methods, restriction #1) to protect water bodies for drinking water abstraction. The areas designated for the abstraction of water intended for human consumption will be part of a register of protected areas under the EU Water Framework Directive. Standstill principle already applies, and other objectives from the Directive have to be met before 2015.

In additional experiments, the effects of particular restrictions were tested, e.g., if the area around a gully pot was not sprayed, a reduction in emission of 15% was found (Luijendijk et al., 2003). It is concluded that all restrictions and recommendations of the new concept will contribute to a significant reduction of glyphosate runoff, of which three factors in random order determine the eventual emission to a large extent: the amount of herbicide used on the site, rain characteristics after application on the site and the positions where the herbicide are applied. An indication of the extent of emission reduction contributed by the new concept was obtained from observations in Lelystad where standard practice, herbicide control reference sites were also studied. We observed that standard practice had on average $3.4\,\mu g\,L^{-1}$ glyphosate in the surface water samples, and the new concept $0.3\,\mu g\,L^{-1}$, a reduction by factor 10 (van Zeeland and Kempenaar, 2004).

A second conclusion of the present study is that the new concept provides a better framework for finding a trade off between economical and ecological aspects of weed control on pavements. Table 2 shows that good ecological quality of surface water is guaranteed while efficacy remains good and costs increase only a little compared to standard practice herbicide control of weeds. Combined with the restriction to protect surface waters assigned for drinking water production, the new concept appears to be a positive step towards more sustainable weed management on hard surfaces. This can be visualized if the observed emission factors are projected on the weed control life cycle assessment of Saft and Staats (2002). Impact scores for the herbicide system drop by about 90% if the highest observed emission factor of 5.7% is used instead of 50% (Fig. 1(b)).

From 2004 onwards, the project will focus on further testing of the concept, promotion of weed prevention, implementation of the concept at the level of whole municipalities and large industrial sites, extension, communication and certification. So far, weed managers and weed control contractors were involved. Project developers and managers of (new) infrastructures have to become involved as well in order to give weed prevention a better chance and to keep preventative control methods environmentally acceptable. The certification activity has to safeguard that the system will be applied by hard-surface managers in the Netherlands. The first municipality was certified for weed control according to the new concept in September 2005.

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References

Balder, H., Strauch, K.H., Backhaus, G.F., 2003. In: Proceedings of the Second International Symposium on Plant Health in Urban Horticulture, Berlin, August 27–29, 2003, pp 155–169. Mitteilingen aus der Biologischen Bundesanstalt für Land- und Forstwirtschaft, Berlin-Dahlem, D.

Beltman, W.H.J., Wieggers, H.J.J., de Rooy, M.L., Matser, A.M., 2001. Afspoeling van amitrol, atrazin en glyfosaat vanaf betonklinkerverharding; veldproeven en simulaties. Report 319. Alterra, Wageningen, NL.

Ekkes, J.J., Horeman, G.H., Besseling, P.A.M., van Esch, J.W.J., 2002. Evaluatie Bestuurlijke Afspraken Uitvoering MJP-G Openbaar Groen. Eindevaluatie van de taakstellingen. Report 2003/179 (in Dutch, title in English: Evaluation of the national covenant on pesticide use in public areas). Expertisecentrum LNV, Ede, NL.

Helweg, A., 2003. In: Abstract book of International Symposium on Non-Agricultural Use of Pesticides, Environmental Issues and alternatives, May 7–9 2003, Copenhagen. The Royal Veterinary and Agricultural University, Copenhagen, DK.

Kempenaar, C., 2004. Handleiding DOB-systeem, Version 1. Plant Research International, Wageningen, NL.

Kempenaar, C., Spijker, J.H., 2004. Weed control on hard surfaces in The Netherlands. Pest Manage. Sci. 60, 595–599.

Kortenhoff, A., Kempenaar, C., Lotz, L.A.P., Beltman, W.H.J., den Boer, L., 2001. Rational weed management on hard surfaces. Note 69A. Plant Research International, Wageningen, NL.

Luijendijk, C.D., Beltman, W.H.J., Wolters, M.F., 2003. Measures to reduce glyphosate runoff from hard surfaces. Note 269. Plant Research International, Wageningen, NL.

Saft, R.J., Staats, N., 2002. Beslisfactoren voor onkruidbestrijding op verhardingen 'LCA, risico-beleving, kostenanalyse en hinderbeleving'. Document 0205 (in Dutch, title in English: Decision factors for weed control on pavements 'Life cycle assessment, costs analysis and perception'). University of Amsterdam, NL.

Ramwell, C.T., Hollis, J.M., 2003. Herbicide dissipation on concrete and asphalt. In: Abstract Book of International Symposium on Non-Agricultural Use of Pesticides, Environmental Issues and alternatives, May 7–9 2003, Copenhagen. The Royal Veterinary and Agricultural University, Copenhagen, DK, 2003, p. 39.

Van Zeeland, M.G., Kempenaar, C., 2004. Duurzaam OnkruidBeheer op verhardingen. DOB-project Lelystad 2003. Study Report. Plant Research International, Wageningen, NL.

Withagen, A.C.L., van der Horst, C.L.M., Beltman, W.H.J., Kempenaar, C., 2003. Resultaten monitoring afspoeling glyfosaat in 2002 in 3 proefgemeenten. Note 230 (in Dutch, title in English: Monitoring Runoff Glyfosate in 2002 in 3 Municipalities). Plant Research International, Wageningen, NL.

Withagen, A.C.L., van der Horst, C.L.M., Beltman, W.H.J., Kempenaar, C., 2004. Resultaten monitoring afspoeling glyfosaat en AMPA en waarnemingen van onkruidbeelden in zeven proefgemeenten in 2003. Note 297 (in Dutch, title in English: Monitoring Runoff Glyfosate and Weed Control Efficacy in 2003 in 7 Municipalities). Plant Research International, Wageningen, NL.