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Preventive Weed Control on Pavements: Reducing the Environmental Impact of Herbicides
Part 1: A Field Survey Study

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Summary
To be proactive in minimizing pesticide use - in view of protecting surface water - Flemish authorities agreed to phase out the use of herbicides on public pavements in Flanders (northern region of Belgium) by 2015. At present most municipalities use chemical herbicides (mainly glyphosate) to control weed growth on road pavements. However, this imposes a serious environmental threat because of the large runoff emissions from these hard surfaces. This highlights the need for more research into alternative weed control strategies on pavements. The aim of this study (as first part of an extensive research program) was to explore weed growth on paved areas in Flanders, in relation to various abiotic and technical factors concerning the pavement.

To that end, an extensive field survey was conducted on about 160 public modular element pavements across Flanders. For each location a score for street scene perception in relation to weed growth was determined. In addition, a large set of possibly influential parameters (environmental, technical and design aspects) was defined for each pavement. Overall, it was found that several environmental (light regime, intensity of use), technical (joint width, joint sealing compound) and/or construction (design, finishing) characteristics affect the weed growth on pavements. Therefore, preventive weed control starts as from the design and construction phase of the paving by taking those important aspects into account. The results of the study may contribute to the setting up of preventive weed control strategies in view of (further) reducing herbicide use on road pavements and thus minimizing the impact on surface water quality.

Keywords: preventive weed control; concrete block pavements; herbicides reduction; surface water quality; field survey; design criteria

1. Introduction

Preventing and controlling weed growth on public roads has been an important task for municipalities and cities since ever. On those paved areas weeds are often undesirable because they are unsightly, may be harmful to the functionality of the pavement and may cause health problems (Benvenuti, 2004). For that reason, weed control remains a current topic. As a proactive measure in view of minimizing pesticide use to protect surface water, Flemish authorities have decided to phase out the use of herbicides on public pavements in Flanders (northern region of Belgium) by 2015 (Flemish Government, 2008). Indeed, hard surfaces are often designed to encourage either rapid water infiltration or surface run-off in order to avoid flooding. This implies an increased environmental impact potential due to excessive use of herbicides on pavements (Saft and Staats, 2002; Ramwell, 2005). Water quality monitoring studies have shown that there is a disproportionate contamination of surface water by non-agricultural pesticide use (Kempenaar et al., 2007; Hanke et al., 2010). Consequently, many countries, including Belgium, have severely restricted the use of herbicides for weed control on pavements in order to be in line with the European Directives concerning water quality (Kristoffersen et al., 2008).

The above-mentioned issues highlight the need for more research into alternative weed control strategies on pavements when herbicides will no longer be in use and/or will be more strictly regulated. Indeed, weed growth and applied weed control strategies in paved areas have not been extensively studied in Flanders up till now. Although several alternative non-chemical weed control methods are known (Rask and Kristoffersen, 2007), details about long-term effectiveness and treatment frequency remain unclear. Furthermore, a well thought-out pavement design, a proper choice of materials (e.g. joint sealing compound) and optimal finishing of the construction may help to prevent future weed control problems from the start (Guldemond et al., 1997). In this respect, clear guidelines and recommendations are still missing though (in Flanders) and a further sensitization of all stakeholders is necessary. This forms the basic line of approach for the present work.

This study is part of a joined research project (Boonen et al., 2009) which aims at establishing an overview of different available preventive as well as curative weed control strategies, considering their efficacy, cost and environmental impact. The main goal is to draw up directives for an economic and ecological weed management program for public roads in view of optimal street scene conditions from an aesthetic, functional and safety point of view. A first phase consisted of a field survey study in order to explore weed growth on paved areas in Flanders in relation to environmental conditions, technical parameters of the pavement and applied weed control methods. Details about the botanical composition of the weed flora and how it is influenced by the above parameters are discussed elsewhere (Fagot et al., 2011). The present paper will focus on the impact of pavement design criteria, technical characteristics and maintenance strategies on weed growth on pavements and on the overall street scene perception.

2. Materials and methods

Because joints and open spaces are more susceptible to dirt buildup and weed growth, the investigation was concentrated on modular element surfacing (semi-open pavements) such as concrete paving blocks, concrete paving tiles, brick setts and stone setts. Of course, extrapolation to other pavement types is possible. In order to identify weed types as well as major weed growth factors, a field survey study was conducted.

2.1 Vegetation survey

In autumn 2008, a vegetation survey was carried out on 163 public pavements at 34 locations across Flanders (Belgium) in order to obtain a good overview of the existing weed flora that has to be controlled. All surveyed pavements consisted of small modular paving elements and concerned different functions, viz. footways, cycle tracks or car parks. On each pavement, the weed flora in paving joints was recorded according to well-known scientific methods in the field (Fagot et al., 2011). In this way, species importance (expressed in %) and abundance, the coverage (%) of the joints by weeds (hereafter named joint coverage) and a score for street scene perception regarding weed growth could be derived. The “street scene score” is defined as the people’s perception of street cleanliness with regard to weed growth on paved areas and varies on an ordinal scale of 2-10. These scores take into account average weed coverage of joints and plant height. Higher scores correspond to a better street scene perception (see Figure 1). Indeed, the street scene perception by managing authorities and citizens does not only depend on total weed coverage but also on vegetation height. Generally, high-growing species will have a more negative impact on public perception of street cleanliness than low-growing species. Of course, it is not always necessary to aspire to a score of 10. Depending upon the pavement function and/or the available means for weed control, a lower street scene quality may be determined, preferably in consultation with the road user.

	Vegetation height				
Joint coverage	< 1 cm	1 - 3 cm	4 - 6 cm	7 - 10 cm	> 10 cm
1 - 6 %	10	9	8	7	6
6 - 16 %	10	8	7	6	5
16 -26 %	10	7	6	5	4
26 - 51 %	10	6	5	4	3
51 - 100 %	10	5	4	3	2

Figure 1 – Determination table for the street scene score in relation to weed growth, illustrated with three examples.

In addition, for each pavement a set of environmental conditions and technical characteristics that could possibly influence weed composition and street scene score was determined. Recorded environmental conditions were *light regime* (sunny, semi-shaded [i.e. scattered shading or shading during only part of the day], shaded), *environmental setting* (urban, suburban, rural, forest), *function* (footway, cycle track, car park), *intensity of use* (high, medium, low). Furthermore, the following technical characteristics were measured: pavement dimensions, *modular element type* (conventional concrete paving blocks, permeable concrete paving blocks, brick setts, concrete paving tiles, stone setts), *joint width* (narrow: 0-2 mm, medium: 2-5 mm, wide: >5 mm), *joint sealing material* (type, grading and contamination), *water permeability* (determined by means of the double-ring test method as described by Beeldens et al. (2009)).

2.2 Data analysis

Analysis of the weed community composition and data of species importance was performed using specific statistical methods which are described in more detail elsewhere (Fagot et al., 2011). In this way, it was possible to determine the influence of the set of parameters *light regime*, *environmental setting*, *function*, *intensity of use*, *modular element type* and *joint width* on street scene perception, number of weed species, weed coverage (%) and importance of annual, biennial and perennial weeds. Only the main results of this analysis will be summarized hereafter (see section 3).

Concerning the *joint sealing compound*, laboratory tests were performed on *in situ* collected samples for a subset of approximately 50 locations amongst the initial 163. Because of too narrow joints, it was indeed in many cases impossible to obtain a representative sample of the joint sealing compound. The tests included determination of the organic matter content through the ignition loss technique (CMA 2009/2/II/2.A, 2009) as well as of the grading through sieving in accordance with NBN EN 933-1 (2006). Afterwards, the correlation between experimentally obtained parameters for the joint sealing compound (organic matter content and certain grain size parameters) and the corresponding weed growth (in terms of street scene perception and joint coverage) was investigated.

Lastly, an attempt has been made to discern important design and/or construction criteria which affect weed growth on pavements. Expressing the design or finishing of a pavement quantitatively is not a straightforward thing to do. On the basis of other sources (Guldemond et al., 1997; VMM, 2009), the surveyed locations were screened for possible design examples with specific high or low street scene scores as well as for problematic cases. Problems often relate to the joint around obstacles in the hard surface, the finishing of edges and shoulders, the installation and finishing of drainage channels (gutters), the number and size of joints and the adequacy for the intensity of use. Based on these case examples, a selection of well-defined design characteristics could be established to evaluate all 163 locations (see Figure 8 and section 3.2). In this way, the link between pavement design and/or construction and weed growth could be studied.

3. Results and discussion

A total of 88 different weed species were recorded on the 163 pavements in the survey. The most abundant weeds are shown in Figure 2, and mostly concern perennials and/or species which are hard to control thermally or mechanically. Apart from the class Musci (mosses), the five most important higher plant species found in pavement joints were *Poa annua* L. (annual meadow-grass), *Sagina procumbens* L. (procumbent pearlwort), *Conyza canadensis* (L.) Cronq. (Canadian horseweed), *Taraxacum officinale* F.H. Wigg. (dandelion) and *Plantago major* L. (greater plantain). Results for Flemish pavements are quite similar to those found by Melander et al. (2009) in other European regions.

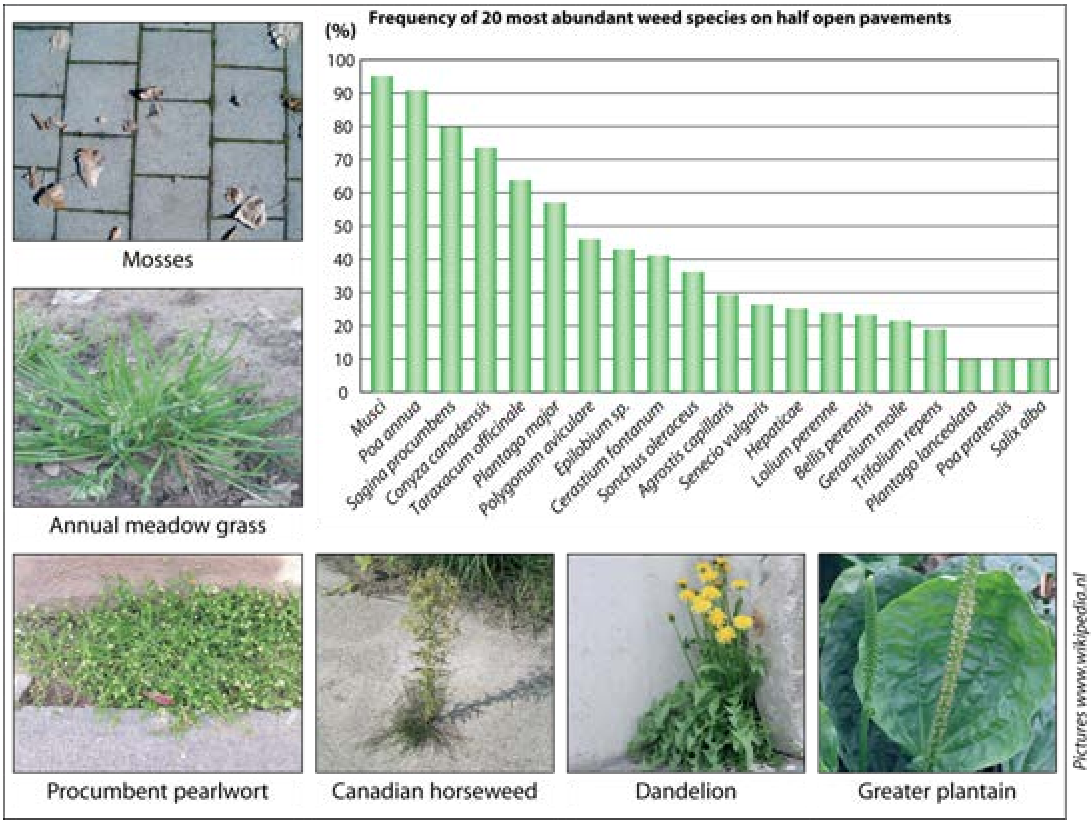

Figure 2 – Most frequent weed species on semi-open pavements in Flanders.

3.1 Influence of environmental parameters[1]

Light regime (sunny, semi-shaded, shaded) has no significant impact on the street scene perception (score), joint coverage or the number of weed species, but it does affect the species composition. In sunny places mostly perennial weeds are prevalent, while semi-shaded or shaded pavements reveal a higher importance of annual and biennial weeds.

Infrequently used pavements show a worse street scene perception compared to more intensively used pavements. They are characterized by a higher number of weed species and a high importance of perennials (see Figure 3).

Lastly, it appeared that the *function* or *environmental setting* of the pavement hardly affects weed growth. Of course, these parameters do matter when establishing the limits for an acceptable street scene perception.

In conclusion, these important environmental parameters (intensity of use, light regime) should be taken into consideration in the design phase as a means for future weed control.

[1] Only the main results are given here; more details can be found in Fagot et al. (2011).

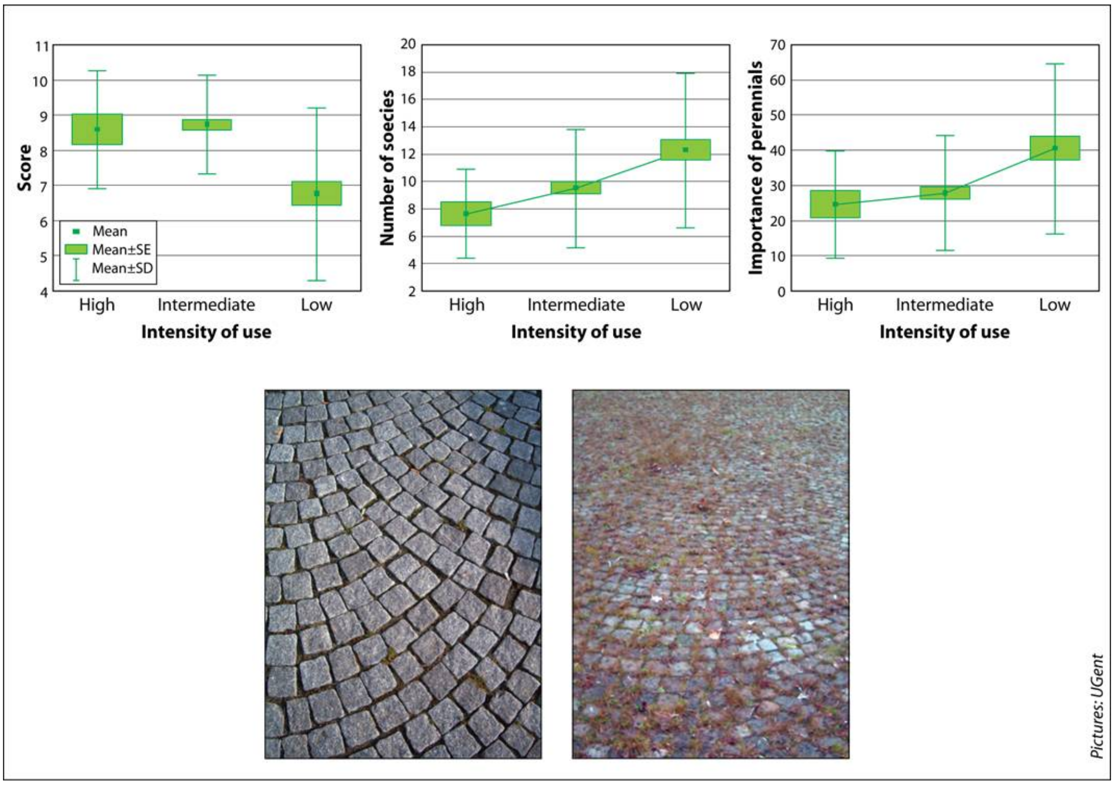

Figure 3 – Impact of intensity of use on weed growth.

3.2 Technical characteristics of pavements

Joint width and modular element type

Firstly, the *joint width* between modular paving elements (narrow, medium or wide) proves to be an important technical parameter with respect to weed growth. Regarding street scene score as well as joint coverage, narrow joints score significantly better than medium or wide joints (see Figure 4). A smaller joint obviously leaves less space for the plant to grow and contains less water and nutrients.

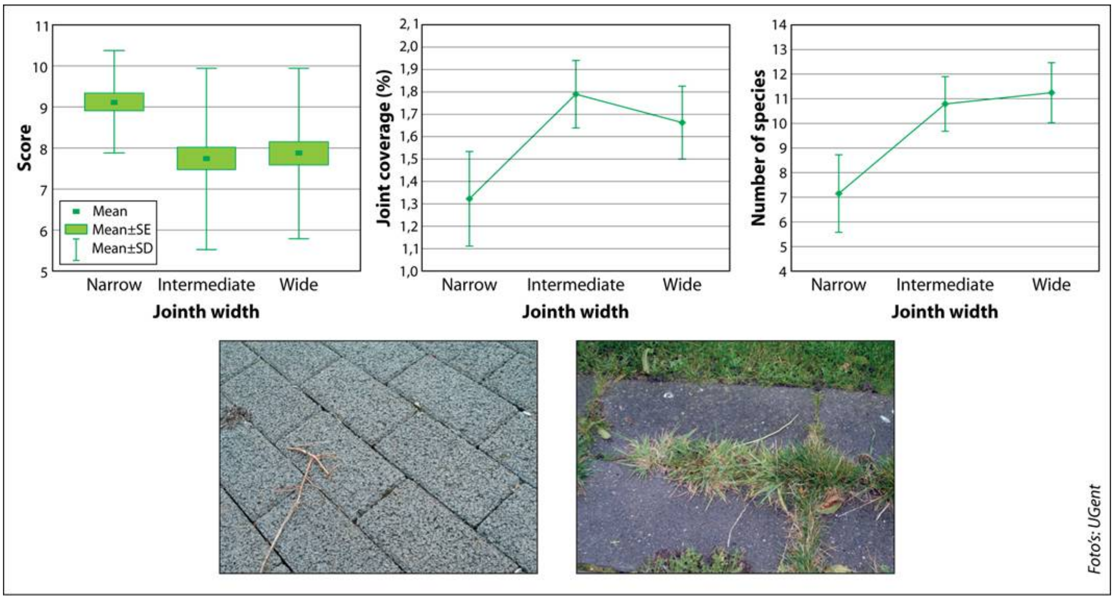

Figure 4 – Effect of joint width on weed growth.
Among the different *types of modular paving elements* with narrow or medium joints (up to 5 mm), there are few differences noticeable. Joint coverage and number of perennials are slightly higher for brick setts as compared to conventional and permeable concrete paving blocks, but street scene perception is similar for all types. For permeable concrete paving blocks the high importance of moss is striking, which is probably due to the higher porosity of the material's surface.

Analysis of the collected statistical data indicates no clear connection between street scene score and joint coverage on the one hand, and water permeability of the pavement on the other hand. Here, data for the water permeability of the pavement surface were subdivided in 4 distinct classes (see graph in Figure 5), viz. impermeable ($k < 10^{-7}$ m/s), bad/mediocre ($10^{-7} < k < 10^{-6}$ m/s), good ($10^{-6} < k < 10^{-4}$ m/s) or very good ($k > 10^{-4}$ m/s). The variability of the data within one class of permeability (as evidenced by the large standard deviations in Figure 5) suggests other parameters (see Fagot et al., 2011 and below) are (more) influencing the weed growth here. Inspection of the surveyed locations shows that permeability is durable in time though, even in the case of a lower street scene score (see pictures in Figure 5).

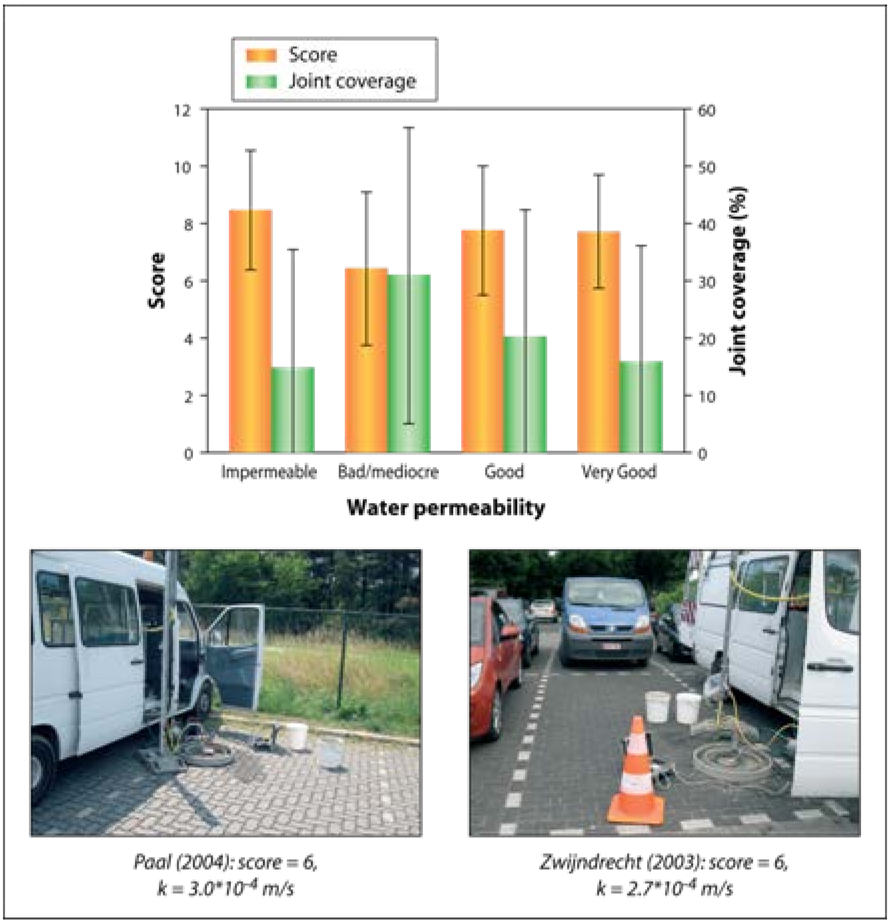

Figure 5 – Water permeability (k) and street scene score (measurements of 2009). Error bars correspond to standard deviations for each class of permeability.

Joint sealing compound - On a subset of 50 locations in the field survey, a sample of *joint sealing compound* was collected to determine some technical characteristics (see section 2.2). After many years of use in outdoor conditions, most of these joint sealing compounds are contaminated with dirt, soil, organic waste, etc. The organic matter content (OM) is an indirect measure of that contamination. Figure 6 shows that the score for street scene perception decreases as a function of OM content (%). More organic material eventually means more moist and nutrition for the plant. For higher OM percentages this correlation becomes less sharp, probably because other factors such as intensity of use and applied weed control start to play a role here.

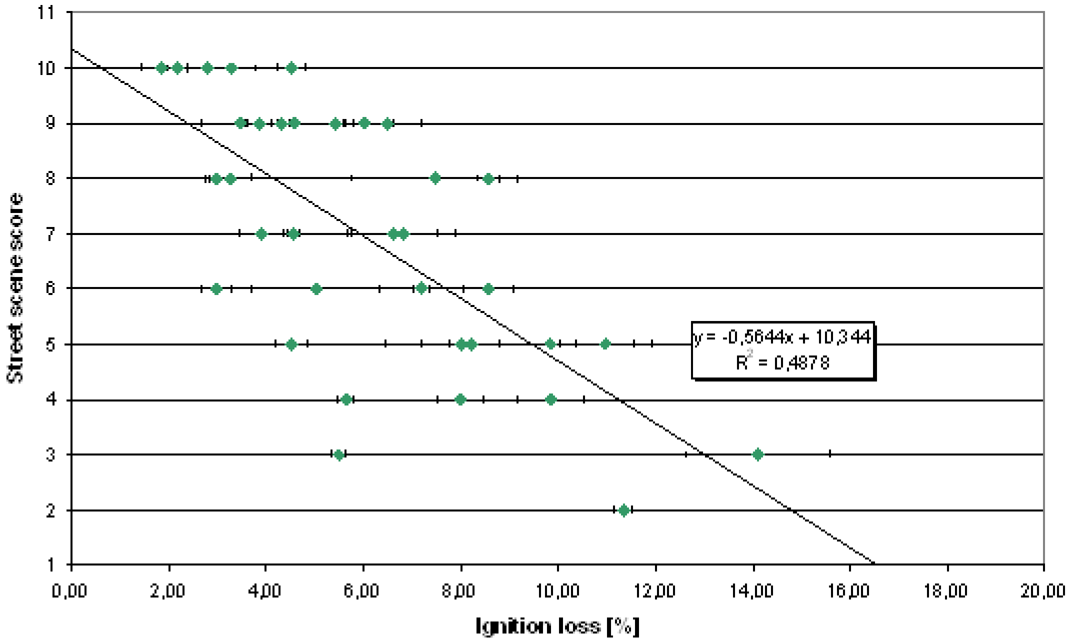

Figure 6 – Correlation between OM content (determined by means of the “ignition loss” method) of *in situ* joint sealing compound and street scene score in relation to weed growth.

This strong correlation between organic matter content, thus contamination of the pavement, and weed growth on it, confirms in a quantitative manner the intuitive rule that a regular sweeping of the surface (e.g. Kempenaar et al., 2009) to remove dirt and soil from the joints, can substantially prevent or diminish weed growth in the first place. Moreover, refilling of the joints over time with “fresh” joint sealing compound, could also contribute in such an overall, *preventive maintenance strategy*.

As for the particle size analysis of the “in-place recovered” joint sealing compounds, a number of quantitative indicators which influence the weed growth on pavements could be distinguished, viz. *fines content* (particles < 0.063 mm), fraction of *coarse* materials (between 0.2-2 mm), average particle size μ and dispersion σ, and fineness modulus f_m (as defined in NBN EN 12620, 2008)[2]. These parameters are probably related to the amount of water available for the plant. An example is given in Figure 7, which shows the relation between weed growth and different classes of materials classified by their fines content (fraction < 0.063 mm) and the fraction between 0.2-2 mm.

[2] Fineness modulus (f_m) is normally calculated as the sum of cumulative percentages by mass retained on the following sieves (mm), expressed as a percentage:
FM = Σ {(> 4)+(> 2)+(>1)+(> 0,5)+(> 0,25)+(> 0,125)}/100

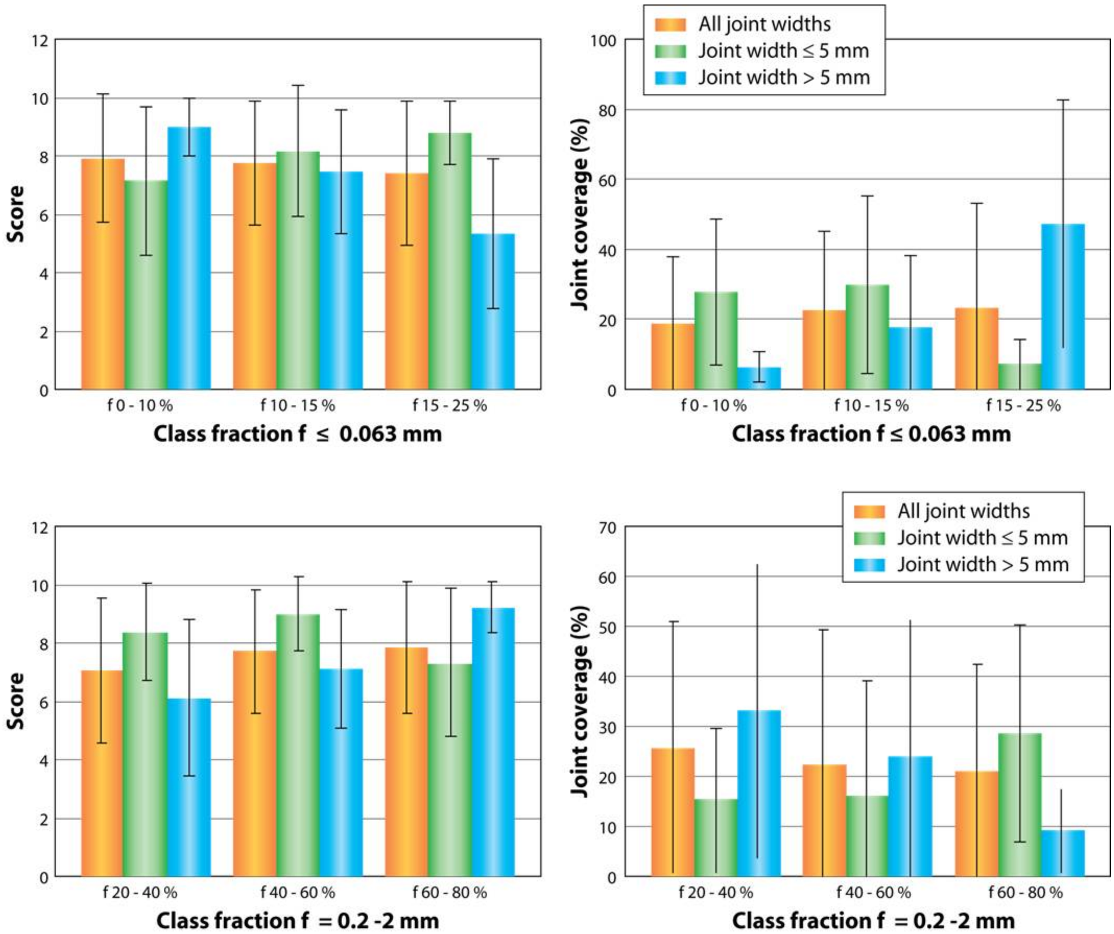

Figure 7 – Correlation between particle size parameters of *in situ* joint sealing compounds and weed growth on pavements. Different classes of materials are distinguished depending upon the fraction *f* of fines (< 0.063 mm) and coarser grains (0.2-2 mm). A subdivision of the data is made based on joint width.

Overall results seem to indicate that the less *fine material* (fraction fines ≤ 0.063 mm less than 10 %, fraction 0.2-2mm more than 60 %, fineness modulus f_m greater than 1.5) is present in the joint sealing compound, the better the score for weed growth (lower joint coverage and higher street scene score). In other words, a concentration of predominantly *coarser grains* (0.2 till 2 mm) leads to reduced weed growth. This is particularly clear for joint widths larger than 5 mm (see Figure 7). For narrow joints, the difficulty to obtain a representative sample of the joint sealing compound *in situ* enters into play. Moreover, vegetation height is limited anyway in these small joints and moss growth could thus have a larger impact on the street scene score (cf. definition in Figure 1). Hence, figure 7 shows no univocal effect for joints smaller than 5 mm.

For larger joints (> 5 mm), there is a clear relation with the particle size parameters and the results hold some practical implications for the choice of joint sealing compound. Of course, one must bear in mind that it concerns *in situ* contaminated joint sealing compounds (thus, with a certain percentage of OM) and mainly *sands* (grain size 0/2) and no coarse aggregates (such as porphyry 2/4 or 2/6). However, the influence of the type of joint sealing compound and the possible weed inhibiting effect is not the main subject of the current study. That matter is studied in more detail in another part of the joint research programme (see section 1; Boonen et al., 2009; and Boonen et al., 2012). In any case, the results on joint sealing compounds found here indicate that contamination of the joint sealing compound must be prevented and/or removed as much as possible (for instance, by regularly sweeping the pavement), and that a proper choice of the joint sealing compound in terms of weed prevention requires a certain knowledge of the grading of the material.

3.3 Design and/or construction criteria

In a last part of the study, the relation between weed growth and the design or construction of the pavement was investigated, as described above. Based on a subset of locations (25 best and 25 worst locations with regard to street scene score), six design categories with well-defined construction features could be specified in order to evaluate all locations within the field survey, as shown in Table 1 and illustrated in Figure 8.

Table 1 – Design features in relation to weed growth and example of subsequent evaluation of locations

Design characteristic	Location X	LocationY	…
A) ***Presence of an adjacent "green zone"***	X	O	
B) ***Finishing of borders and edges*** (minimum 1/2 paving element, stretcher course, joint widths, etc.)	O	O	
C) ***Subsidence/Unevenness***	X	X	
D) ***Presence of obstacles*** (street furniture, poles, bus shelters, etc.)	O	X	
E) ***Edge locking/Kerbing***	X	O	
F) ***Paved drainage channel***	O	X	
X = OK, O = not OK			
Example: evaluation of location X			

Criterion	A	B	C	D	E	F
Score	1	0	1	0	1	0
Weight	*0.21*	*0.19*	*0.17*	*0.17*	*0.14*	*0.12*
Weighted score	**0.21**	**0**	**0.17**	**0**	**0.14**	**0**
TOTAL	***0.52***					

Subsequently, for each location from the survey a score[3] (0 or 1) can be attributed to each specific design category as demonstrated in Table 1. Moreover, each category has a different weight depending on its importance for weed growth on the pavement. This weighting also allows achieving a sharper correlation between weed growth and design of the pavement (see also Figure 9). That weight was determined based on the previously mentioned subset of locations, by calculating the relative occurrence in this subset (by summing up the number of zeros respectively ones for the 25 worst respectively the 25 best locations, and normalizing to bring the sum of weights to one) for each design feature.

Lastly, the sum of the weighted scores for each of the six categories yields a global *design score* (between 0 and 1) per location on the basis of which the locations can be divided into four distinct *design* or *construction classes* – ranging from *very bad* (K1, score = 0-0,3) to *very good* (K4, score = 0,75-1).

Figure 8 – Correlation between design features and weed growth.

The results thus obtained and shown in Figure 9, demonstrate a clear link between the design or construction class and weed growth on the pavement (average street scene score and joint coverage). Higher design scores lead to a significantly better score and a lower joint coverage. Moreover, this relation was also found to be independent of the joint width of the pavement; subdivision of the data according to joint width, as was done for the particle size parameters (see Figure 7), did not change the overall trend, underlining the true importance of proper design and construction. This is, to the author's knowledge, the first time a quantitative connection has been made between the design – an intrinsically qualitative feature – and weed growth on the pavement itself!

Overall, these findings indicate (quantitatively) that weed prevention and control is influenced and can be commenced as from the design and construction phase, by taking into account

[3] Mostly by a simple "yes/OK (1) or no/not OK (0)"-answer to the design question, e.g. "Is there an adjacent green zone present next to the paved area in question?" Yes = score 0, No = score 1.

several important pavement design criteria, as shown in Figure 8. Most of the design features also correspond to or are in line with existing technical guidelines (e.g. BRRC, 2009).

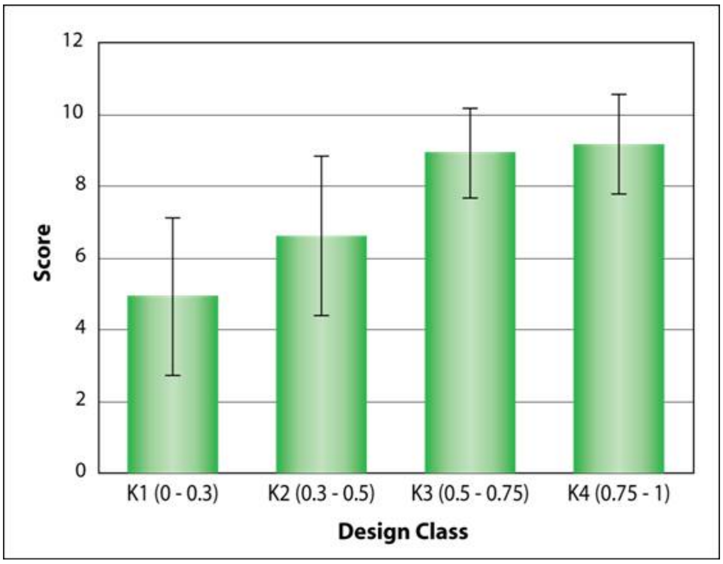

Figure 9 – Correlation between design/construction of pavement and street scene score in relation to weed growth.

4. Conclusions

Results of this field survey study in the Flanders area clearly reveal that weed control on hard surfaces begins as from the design and construction phase. Indeed, weed growth on modular element pavements can be significantly reduced and even prevented if in the design and construction phase the most important (environmental) influential parameters and technical characteristics affecting weed growth are taken into account.

More intensive weed growth observed in wide joints filled with fine-grained sand for instance points out the importance of correct joint finishing (also at the borders of the pavement) as well as of a proper choice of the joint sealing compound. An integrated weed control system comprising *preventive* (design, construction) as well as *curative* (flaming, brushing, etc.) measures is a *must*. Curative techniques may only be considered in a second phase, after weed prevention strategies have been applied.

Based on the results obtained here, several important prevention strategies for weed control on pavements can be postulated:

- design and construct pavements fitting harmoniously into the existing street scene (green zone, city centre, etc.);
- apply correct thickness design (as a function of the expected traffic load) to avoid future damages;
- design and construct appropriate pavements for future (curative) weed control (for instance, by ensuring accessibility for machines);
- design and construct adequate pavements for the expected intensity of use;
- choose the proper joint sealing compound (type, grading and/or physico-chemical nature) in accordance with the modular element type (joint width, function, location);
- inspect joint widths during construction;

- carefully finish pavements at the borders and/or around obstacles;
- provide adequate edge locking with kerbs;
- prevent contamination of joints (for instance, by regularly sweeping the pavement and/or refilling the joints with “fresh” material).

By taking into account the above-mentioned aspects and applying the rules of “good practice” (e.g. BRRC, 2009) during construction, a lot of problems concerning weed growth on pavements can be precluded preventively. In that way, herbicide use on road pavements and, consequently, the impact of herbicide emissions on the environment may also be significantly reduced.

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