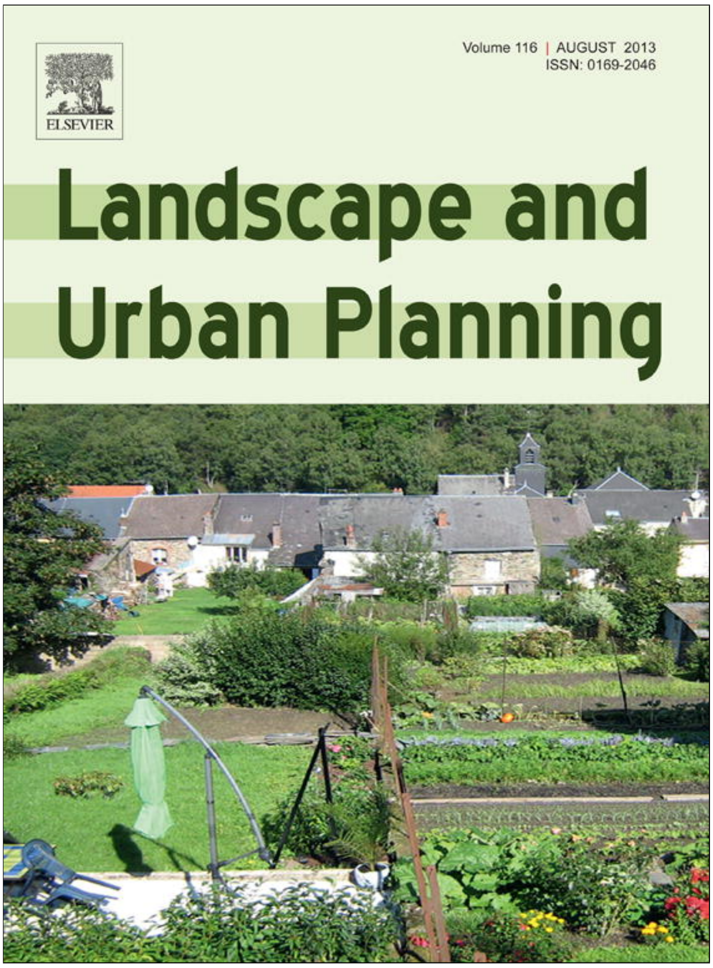
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Research paper

Garden management and soil fertility in Flemish domestic gardens

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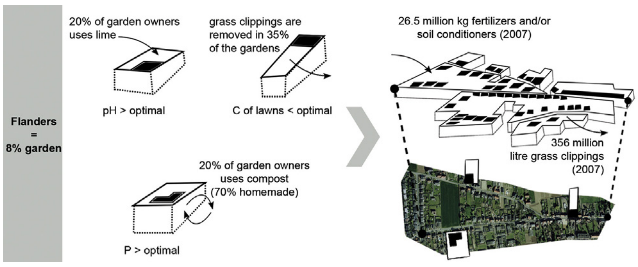
HIGHLIGHTS

- Gardens are not part of environmental monitoring despite their territorial coverage.
- We collected explorative and indicative environmental data on domestic gardens.
- Gardeners use 0.07 kg fertilizer and remove 2.3 l grass clippings per m^2 garden.
- Garden soils have a higher pH and P, lawns a lower C than optimal agronomic standards.

GRAPHICAL ABSTRACT



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ABSTRACT

Collectively domestic gardens form an important landscape component, but environmental and land use policies tend to ignore domestic gardens. This paper investigates nutrient cycling in domestic gardens: fertilizer and soil conditioner use, composting, removal of grass clippings and the soil fertility states in the case of Flanders (the northern part of Belgium). Data was assembled from an internet survey about garden management and a database on soil fertility of domestic gardens. The combined analysis of these data reveals new insight in the link between garden management and the chemical condition in gardens (in terms of soil carbon content, pH and phosphate). Flemish gardeners used 0.07 kg fertilizer and removed 2.3 l grass clippings per m^2 garden in 2007. Meanwhile, garden soils appear to have a higher pH and phosphorus content and lawns a lower carbon content than optimal agronomic standards. These insights show that gardens are a dynamic socio-ecological system with considerable nutrient flows from and to the household and the environment, indicating the need for more detailed and systematic environmental monitoring. This way, domestic gardens can be compared to agriculture, horticulture and other land use types. This and complementary research helps to complete insights in the dynamics across complex rural and urban landscapes. Future research should take into account, among other things, prevailing practices and habits of garden owners.

1. Introduction

The fabric of urban and residential areas does not solely exist out of buildings, roads and artificially surfaced areas. Unpaved land, including parks and gardens, makes up a large part of urban cores and of semi-urban residential areas, villages, hamlets and sprawled development (Daniels & Kirkpatrick, 2006; Gaston, Warren, Thompson, & Smith, 2005; Gill et al., 2008; Smith, Gaston, Warren, & Thompson, 2005), resulting in complex mosaics of vegetative land cover and multiple land use (Foresman, Pickett, & Zipperer, 1997). This paper focuses on domestic gardens: gardens intimately and spatially associated to a building, within the confines of a single parcel. They are essentially private elements, and so tend to be absent from public and political attention. In Flanders, the northern part of Belgium, domestic gardens take up a significant part of urban as well as of suburban and rural areas. According to Bomans, Dewaelheyns, and Gulinck (2011), 8.2% of the Flemish area is covered by domestic gardens, a figure comparable to the

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regional forest cover of 10.8% (Thoen et al., 2002). There are few studies giving figures for garden cover in other countries. Between 22 and 27% of the total area within the administrative boundaries of five U.K. cities consists of gardens (Loram, Tratalos, Warren, & Gaston, 2007) and the vegetated garden area occupies 46% of the residential area in New Zealand (Mathieu, Freeman, & Aryal, 2007).

According to Mathieu et al. (2007), gardens are the least understood ecological habitat type when compared to other types of urban greenspace. This being said, it is interesting to note that scientific literature strongly focuses on gardens in an urban context, while rural gardens are much less present in the research picture. In countries with dispersed housing and dilute urban sprawl, like Belgium (Kasanko et al., 2006), many gardens are to be found in a rather rural or semi-urban context. Scientific literature shows a growing academic attention for characteristics, functions and services of gardens (e.g. Cameron et al., 2012; Gaston et al., 2005).

In general, these papers seek proofs of positive contributions of gardens. Gardening is often promoted as an environmental friendly pastime (Cameron et al., 2012). But gardening, an intimate interaction between society and environment (Cook, Hall, & Larson, 2012; Martin, Warren, & Kinzig, 2004), can also have negative impacts on the environment (Steinberg, 2006). The widespread character and popularity of gardening should trigger research on its environmental effects (Clayton, 2007). Of particular interest are the health and environmental impacts of the application of chemicals (essentially fertilisers, herbicides and pesticides) in gardens (e.g. Grey, Nieuwenhuijsen, Golding, & Team, 2006). As Collins et al. (2000) state clearly, people mobilize nutrients and pollutants. The results of a survey by M.A.S., VVSG vzw, VVP, and OVAM (2007) questioning 500 inhabitants spread over 38 Flemish municipalities, revealed that 49% of the respondents uses chemical products and/or mineral fertilisers in garden management.

The dearth of environmental information concerning gardens and their soils is stressed by several authors, such as Lorenz and Lal (2009) who report the scarcity of data about soils in urban areas, and Kaye, Burke, Mosier, and Guerschman (2004) who point to a gap in the knowledge of regional biogeochemical fluxes because of the exclusion of urban lawns and gardens from analyses and monitoring programs. This latter is based on the assumption that the urban land area is too small to contribute significantly to biochemical fluxes. Research meanwhile illustrated the significance of territorial coverage by gardens, indicating the possibility of large fluxes.

So far, the overall influence of domestic gardens on the environment has not been systematically investigated, probably due to reasons which can also help to explain their absence from environmental and land use policies. The physical fragmentation in property and size of gardens (Zmyslony & Gagnon, 1998) results in an extreme heterogeneity in composition and management (Van Delm & Gulinck, 2009). Because of this diversity, it is a challenge to conduct a systematic data collection on environmental aspects of gardens. Next to this, access to data is limited because of the private character of domestic gardens. Collecting a body of data on garden management characteristics in regional perspective requires the involvement of a large number of individual garden owners.

Fertilization of garden soils is one of the key entries to bring domestic gardens on the agenda of regional environmental monitoring and policy. Research on this topic is often limited to fertiliser use on home lawns while literature review provides mainly information from the United States. The use of mineral fertilisers for maintaining lawns leads to nitrogen excesses (Kaye, Groffman, Grimm, Baker, & Pouyat, 2006; Lorenz & Lal, 2009; Zhu, Dillard, & Grimm, 2004) and contributes significantly to greenhouse gas emissions (Howarth, Boyer, Pabich, & Galloway, 2002). Both Livesley et al. (2010) and Bijoor, Czimczik, Pataki, and Billings (2008) observed a peak emission of nitrous oxide due to the application of lawn fertiliser, with lawns emitting up to ten times more nitrous oxide than neighbouring agricultural grassland (Livesley et al., 2010). Livesley et al. (2010) suggest that reducing fertiliser application to lawns can help mitigate greenhouse gas emissions. An interesting alternative for mineral fertilisers is compost, offering a lower carbon cost alternative for supplementing a mineral nitrogen fertiliser (Lillywhite and Rahn (2008) in Cameron et al. (2012)) and displacing pollution, energy and other externalities associated with the extraction and transport of mineral fertilisers (Favoino & Hogg, 2008).

This paper explores the impact of domestic garden management on soil fertility. The focus lies on fertilisers and soil conditioners, home compost and the removal of grass clippings. The paper seeks to initiate a methodology in combining the results of two independent sources of information: an internet survey on garden management and a database on garden soil fertility. The specific objectives of the internet survey were twofold: (i) identify used fertilisers and/or soil conditioners, the destination of grass clippings and the composting practices and (ii) quantify the applied amounts of the fertilisers and soil conditioners and of the removed grass clippings. The specific objective of the soil fertility study was to assess the soil fertility status of Flemish gardens, in comparison to that of arable land and pastures. Bringing together these results with scientific literature sheds light on the environmental impact of management practices in the complex of domestic gardens in Flanders and on the needs of further research.

2. Methods

To allow an analytical approach of the individual private garden in an environmental context, a garden is conceptualized as an input–output model (Collins et al., 2000; Van Leeuwen, 1981). The physical 'garden system' is defined in this paper as follows. A domestic garden is spatially related to a dwelling that is privately owned or rented. It is defined as the part of a residential parcel with exclusion of the associated house. Pasture for recreational farming or extensive woodlots, as well as storage space for building materials or refuse are excluded from this definition. In accordance with Cameron et al. (2012), it is a precondition that residents have autonomy over the garden management, although responsibility can be delegated to professional gardeners. Allotment garden sites and dispersed gardens without spatial correlation to a dwelling are not considered.

2.1. Internet survey

Data on the use of fertilisers and the processing or removal of organic garden waste was collected by means of an anonymous online survey among garden owners in Flanders (www.tuinenquete.be). This internet survey was part of a broader research project, in which data on 285 garden variables was collected. These variables include characteristics of physical dimension, garden management and the household. From these 285 variables, those concerning the selected management categories (fertiliser use, compost and grass clippings) were extracted (Table 1). The internet survey was direct, meaning that the respondents were informed about the goal of the research (Malhotra & Birks, 2003). The advantages of an internet survey are plural. Answers are automatically stored in a database, the whole survey can be conducted at high speed and low-cost (Couper, Kapteyn, Schonlau, & Winter, 2007; Malhotra & Birks, 2003; Reips, 2002; Roth, 2006) and a large number of respondents from different regions can be reached easily (Reips, 2002). There are also fewer organizational problems, the survey is easily accessible and participation is more voluntary compared to surveys by telephone or door-to-door (Roth, 2006). Attention was given to self-selection,

Table 1
Qualitative management variables.

Use of purchased fertilisers and/or soil conditioners
Number of times a year soil fertilisers and/or soil conditioners are used in the garden
Fertilisers and/or soil conditioners, used during 2007: Compost (own home, garden centre, compost producer, local communal recycle centre or other), Peat, Organic fertiliser, Mineral fertiliser, Lime, Potting compost, Bark, Chopped wood
Frequency of lawn mowing
Use of mulch mowing
Destination of grass clippings: Vegetables, Fruit and Garden waste-collection, home compost, collection on a pile or in a pit without the intention to compost, mulch layer on the lawn, local communal recycling centre, other destination outside the garden
Number of times a year the owner prunes
Destination of prunings: selective waste collection, collection on a pile or in a pit without the intention to compost, home compost, local communal recycle centre, used in the garden after wood chopping, used in recycle gardening, used in the fireplace, other

drop-out and survey design quality as suggested by Reips (2002), all known factors in the reliability of internet surveys. Efforts to avoid drop-out were among other things the organization of the questionnaire in thematic blocks, giving the respondents an idea on their progress within the questionnaire, leaving out non-relevant questions based on former answers and the prospect of a reward. To be able to pick up a feasible bias towards more passionate and ecological gardeners, the respondents had to score two theses ("I see myself as a passionate gardener" and "I see myself as an ecological gardener") in a Likert scale with five response alternatives (1 totally disagree – 5 totally agree), a number sound enough when considering reliability and validity (Lozano, García-Cueto, & Muñiz, 2008).

The design of the questionnaire was split up in three phases: (i) a trial questionnaire, (ii) a first questionnaire and (iii) the final questionnaire. The trial questionnaire was based on a full list of variables, composed by a group of thirteen environmental and/or garden experts. These variables were translated into unequivocal survey questions, since misinterpretation results in a bias (Malhotra & Birks, 2003). Comparison of quantitative results asks for uniformity in the answers. Respondents were offered both a range of units to choose from and an illustration on the volumes of well-known reference items in common garden management, like a bucket (10 l), a small (35 l), medium-sized (55–60 l) and large (70–75 l) collection tray of a lawn mower and a wheelbarrow (80–85 l). The trial questionnaire as well as the offered range of units and illustrations were tested by means of four test-visits to voluntary garden owners, resulting in an improved formulation of the questions and a selection of the easiest way for respondents to quantify fertilisers and organic waste (Table 2). The questionnaire was then built into a website and tested by twenty test-respondents during a period of two weeks to (i) verify the phrasing of the questions once more and (ii) to detect possible technical problems. Once launched, respondents were invited by e-mail to participate in the survey and asked to distribute the survey among family, friends, colleagues and acquaintances, the so called 'snowball-effect' (Malhotra & Birks, 2003). As a complementary promotion strategy, the questionnaire was linked to several websites and included in the Google search engine. After a predefined period the survey closed for participation but remained on-line for consultation. The MySQL-database was exported to Excel and prepared for data processing and analysis.

To decide on the minimal number of respondents (n_0) to consider for analysis, the following equation was used (California Department of Resources Recycling and Recovery, 2010): $n_0 = z^2 p(1-p)/r^2$, with $z = 1.96$ (value for the 95% confidence interval), $p = 0.5$ (estimator for the unknown participation level of 50%), and $r = 0.05$ (5% accuracy level). A total of at least 385 surveys must be completed when an infinitely large population is assumed. An infinitely large population was chosen because the total number of gardens or garden owners and tenants in Flanders is not exactly known. Of all the respondents, those who have been managing their garden for at least 12 months were retained for further analysis.

Statistical analyses were conducted by means of SPSS 15.0 at a significance level of 0.05. Text variables were encoded into numeric variables. The continuous variables were classified in self-defined groups by means of 'Visual Binning' (Norusis, 2006). The latter was necessary to correlate ordinal and continuous variables. We assumed that the respondents were capable of estimating the amounts of fertilisers used and the amounts of organic waste exported. Since the main goal of this pilot survey was to form an idea of orders of magnitude rather than giving a detailed quantitative analysis, such approximate estimations are acceptable in our opinion. A help-page could be consulted anytime during the survey, explaining the term garden and the units for quantification. Descriptive statistics were used for the analyses of the quantifications.

Table 2
Selected units for quantitative management variables.

Quantitative management variables	Selected units
Solid fertilisers and/or soil conditioners used in the garden in 2007	Kilogram
Liquid fertilisers and/or soil conditioners used in the garden in 2007	Litre
Grass clippings removed from the garden in 2007	Litre
Prunings removed from the garden in 2007	Bundle, length of 1 m, diameter of 30-40 cm

2.2. Soil sampling and analysis

Soil fertility was assessed by means of data from the soil database of the Soil Service of Belgium (SSB). This database consists of more than 14,500 analyses carried out on 1817 soil samples from both domestic and public gardens in Flanders, taken between August 2007 and July 2009 (Table 3). Public gardens were analyzed together with private gardens, since (i) the proportion of public gardens accounted for less than 5% of the total database and (ii) their soil fertility status matched those of private gardens. The garden samples were not taken randomly, but originated upon request by the establishment of new gardens, because of observations of poor plant growth or by interested home gardeners. The observation of poor plant growth does not necessarily mean that less-fertile gardens are over-represented: unfavourable proportions between nutrients can be due to either lack or excess of fertilization, and

Table 3
The number of soil samples and analyses from domestic and public gardens in Flanders, carried out by SSB (August 2007–July 2009).

Garden type or component	Number of soil samples	Number of analyzed parameters[a]
Garden under construction	483	3864
Vegetable garden	393	3144
Ornamental garden	420	3360
Lawn	483	3864
Greenhouse	38	342
Total	1817	14,536

[a] Soil texture, acidity, carbon content, amount of P, Mg, K, Na, Ca and salt concentration (only in greenhouses).

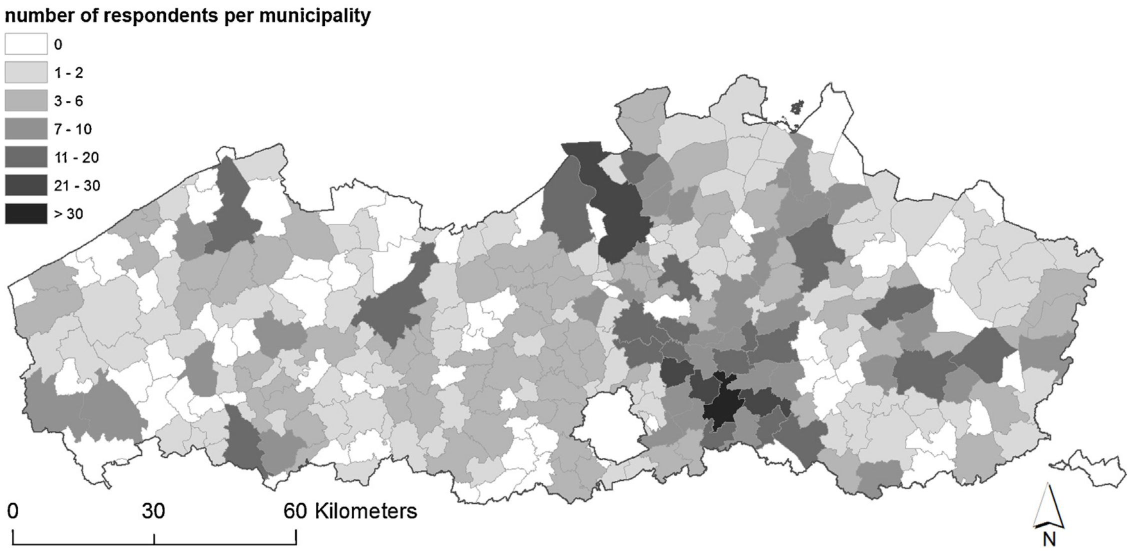

Fig. 1. Geographical distribution of the respondents (N = 1138) in Flanders. Number of respondents per municipality.

this can lead to antagonisms in the uptake of minerals, causing symptoms of deficiency as well as of excess of nutrients.

The following parameters will be discussed: acidity (pH), carbon content (C) and the amount of phosphorus (P).

In the ornamental and vegetable gardens and in gardens under construction at least 25 subsamples of the soil were taken down to a depth of 23 cm. In lawns, at least 35 subsamples were taken down to a depth of 6 cm. The samples, each at least weighing 600 g, were stored in a cotton bag and labelled with a barcode. Next to the soil sample, information of the sampled garden was recorded on an information sheet. The pH was measured in a potassium chloride (KCl)-solution, resulting in a more stable measurement than one using an aqueous solution because the measurement is made independent of the moment of sampling (ISO 10390:2005). The carbon content was determined in accordance with the adapted Walkley–Black method and expressed in percentage by weight (Walkley & Black, 1934). The P content was determined using Inductively Coupled Plasma after extraction in ammonium-lactate. The results were expressed in mg per 100 g of air-dried soil. Both the sampling procedure and the analytical methods used by SSB are BELAC-accredited (BELAC, 127-TEST).

In order to interpret soil analyses, SSB relies on soil fertility classes for the different soil fertility variables related to the agricultural standards of optimal plant growth. The agricultural standards provide a clear and interpretable reference and moreover, they make it possible to make comparisons with agricultural land. The soil fertility classes are based on extensive field research combined with 65 years of experience in the agricultural and horticultural sectors. The knowledge gathered from long- and short-term field trials is integrated in response and surplus functions, which are at their turn integrated in BEMEX, a fertiliser expert system (Vandendriessche, Bries, & Geypens, 1996). The soil fertility classes are defined for specific garden types or component (ornamental, vegetable, lawn, greenhouse) and take soil texture and organic matter content into account. For each garden type, seven soil fertility classes were distinguished ranging from 'very low' to 'very high'. The adjectives "low" and "high" mean that they are situated outside the optimal ranges. In the optimal zone (i.e. the middle soil fertility class), most plants will show an optimal growth, provided that rational fertilization and liming is applied. The optimal zone is not only an agronomic optimum (optimal plant growth), but is also an environmental optimum since it corresponds to a minimal amount of nutrient leaching (Elsen, Tits, & Vandendriessche, 2010).

3. Results and discussion

3.1. Internet survey

During the period from 17th of October 2007 to 1st of February 2008, the first page of the survey was opened 5942 times. In total, 62% of these respondents completed the inquiry, giving a total drop-out rate of 38%. Analyzed per page, the highest drop-out rate occurred at the first page and was 22%. An analysis of the time records suggests that respondents had a first look at the survey during working hours, probably to decide whether or not to participate with the survey at home after work. This drop-out rate could have been avoided by giving exemplary questions or a warming-up exercise in the survey introduction, as mentioned by Reips (2002). The low drop-out rates after the first page, ranging between 4.7 and 0.3%, might be the result of the measures built-in against drop-out. From the initial 3680 respondents that completed the survey, 1138 respondents were withheld for further analysis, representing 1.39 km^2 of surveyed garden area. This is 0.13% of the total garden area in Flanders according to Bomans et al. (2011). There was a non-uniform geographical distribution of the respondents, with the city of Leuven and its periphery as relatively overrepresented (Fig. 1).

The bar charts of the 'Likert' scores of all respondents (N = 1138) are shown in Fig. 2. For both theses, "I see myself as a passionate gardener" and "I see myself as an ecological gardener", the largest group declares itself to be rather neutral. A minority, being 2 and 4%, had no opinion about their degree of respectively passion for gardening and ecological gardening. Since no skewness or edge peaks are observed, we expect to have no bias towards more ecological and/or passionate gardeners, of which one can assumes they would be more likely to complete the survey.

3.2. Fertilisers and/or soil conditioners

About half of the respondents (52%) stated to use fertilisers and/or soil conditioners at least once a year. Of these 592 respondents, 38% uses fertilisers twice a year, and 10% five times per year. Translated to garden areas, frequent use of purchased solid fertilisers occurs on 36% of the surveyed garden area, for liquid fertilisers this is 35% of the surveyed garden area. Less than once per year application occurs in 22% of the surveyed gardens. In 11% of the surveyed gardens, purchased fertilisers and/or soil conditioners are used only once when planting in the garden. No purchased fertilisers and/or soil conditioners are used at all in 15% of the surveyed gardens.

More than half of the respondents who regularly use purchased fertilisers and/or soil conditioners can estimate the quantities used in 2007 (Table 4). They used on average 0.07 kg per m^2 of garden surveyed. For comparison, this is double the amount applied on grass areas registered by Jo and McPherson (1995) within two neighbourhoods in northwest Chicago. Lime, compost and organic fertilisers are the most frequently used products, each being used in 30% to 35% of surveyed gardens (Fig. 3). The majority of the compost used in gardens is home-made (70%).

3.3. Grass clippings

Lawn is mown more than 10 times per year by 81% of the respondents. Mowed grass lawns are sources of carbon dioxide (Lorenz & Lal, 2009), a statement underpinned by Jo and McPherson (1995) who calculated a principal net carbon release from grass/lawn maintenance: at an annual mowing frequency of around 20 times, grass mowing returned annually 1.5 times the carbon sequestrated. The recorded annual mowing frequency in Flanders is half the frequency recorded by Jo and McPherson (1995), so we expect the net carbon release effect due to mowing to be less. In 35% of the gardens, grass clippings produced in 2007 were removed to a destination outside the garden (Fig. 4). For the respondents able to quantify,

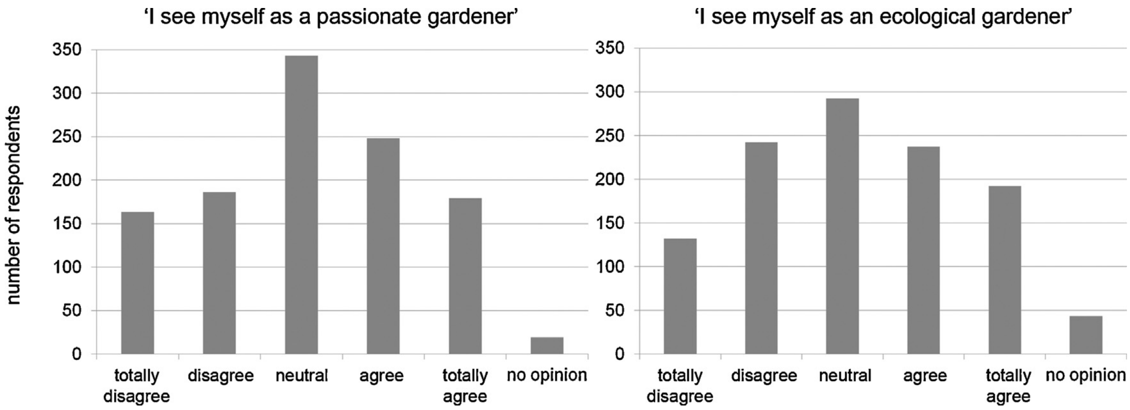

Fig. 2. Passion for gardening and degree of ecological gardening. Bar charts of the Likert-scores for the theses "I see myself as a passionate gardener" (Left) and "I see myself as an ecological gardener" (Right) (*N* = 1138). The Likert-scores are [1] totally disagree [2] disagree [3] neutral [4] agree and [5] totally agree.

Table 4
Amount and intensity of used fertilisers and/or soil conditioners for Flanders in 2007.

	Total	Average per garden	Average per m^2	Average per km^2
N = 381[a] (number of respondents able to quantify the imported amount)				
Solid fertilisers and/or soil conditioners used in the garden in 2007 (kg)	33,232	87.2	0.067	67,058
N = 248[b] (number of respondents able to quantify the imported amount)				
Liquid fertilisers and/or soil conditioner used in the garden in 2007 (l)	388	1.6	0.0008	811

[a] Only those gardens where solid fertilisers and/or soil conditioners were used in 2007.
[b] Only those gardens where liquid fertilisers and/or soil conditioners were used in 2007.

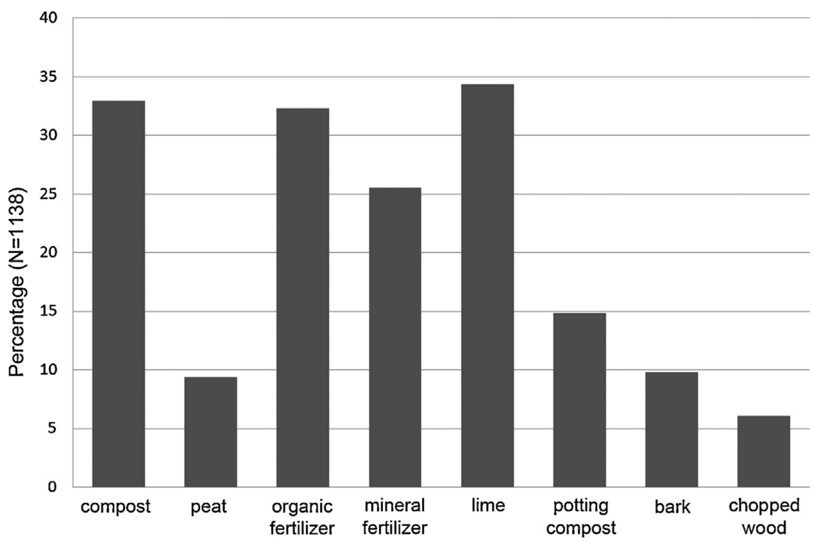

Fig. 3. Used fertilisers and/or soil conditioners. The percentage gives the share relative to the total number of surveyed gardens (*N* = 1138).

the estimated amount of the grass clippings that was removed is 2.3 per m^2 (Table 5). The main share of exported grass clippings is removed with the selective waste collection of vegetables, fruit and other garden waste or is brought to the local recycle centre. A small fraction of the grass clippings is exported to the neighbourhood as feedstuff for animal keepers or is disposed as clandestine dumping. The majority of the grass clippings, being 53% is processed within the garden through composting (53%), as a mulch layer on the lawn (23%) or collected on a pile or in a pit without the intention to compost (23%).

3.4. Soil sampling and analysis

The geographic distribution of the soil samples in Flanders is shown in Fig. 5. Per analyzed parameter, the distribution of the sampled gardens according to the different soil fertility classes is given. The effective values of pH and carbon content per soil type for (i) gardens under construction, vegetable gardens an ornamentals gardens, (ii) garden lawns and (iii) greenhouses are given in Appendix A, as well as the effective values of phosphorus content per soil type.

3.5. Acidity (pH)

In general, the pH of the majority of the sampled gardens is higher than optimal pH levels according to the agronomic and environmental optimal standards (Table 6 and Appendix A Tables A1–A3). For vegetable and ornamental gardens an optimal pH lies between 5.2 and 5.6 in sandy soils and between 7.2 and 7.7 in clay soils. For lawns, the optimal pH lies between 5.1 and 5.6 in sandy soils and between 5.7 and 6.4 in clay soils. In the category 'gardens under construction', 23.4% have a pH that is too low and approximately 60% have high pH. Similar observations are made for vegetable gardens (67% high), ornamental gardens (72% high) and greenhouses (66% high). Almost 73% of the lawns have a high pH. The above results indicate that the majority of sampled

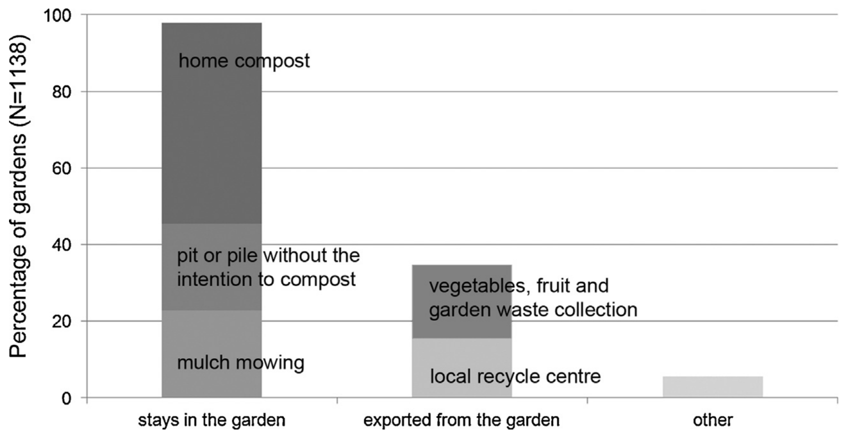

Fig. 4. Destination of grass clippings. Since grass clippings can have several destinations per garden, the percentages should be interpreted per destination for the 1138 gardens.

Table 5
Amount and intensity of removed grass clippings and prunings for Flanders in 2007.

	Total	Average per garden	Average per m^2	Average per km^2
$N = 181$[a] (number of respondents able to quantify the removed amount)				
Grass clippings removed from the garden in 2007 (l)	347,354	1919	2.3	2310,347

[a] Only those gardens where grass clippings were removed in 2007.

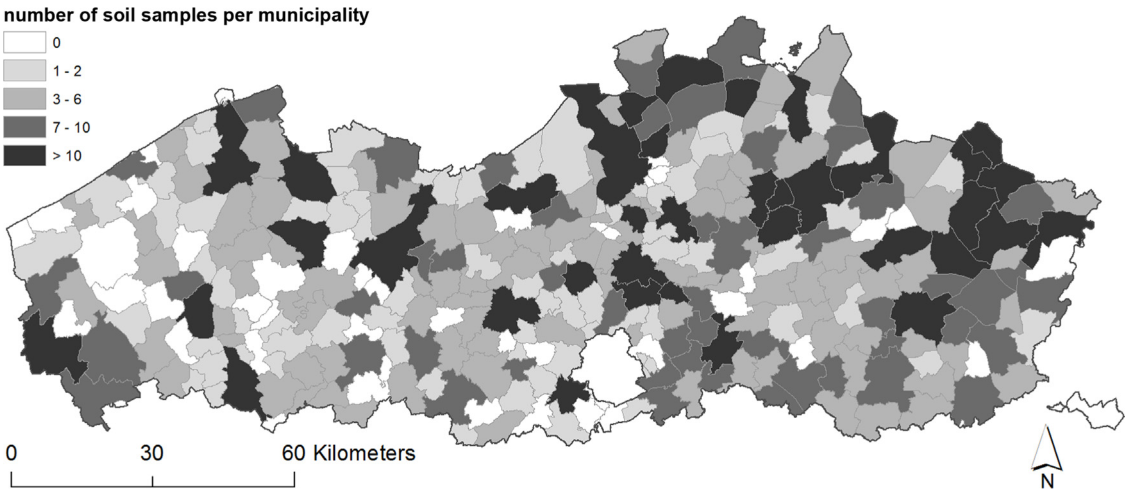

Fig. 5. Geographical distribution of the sampled domestic and public gardens ($N = 1817$) in Flanders (August 2007–July 2009). Number of soil samples per municipality.

Table 6
Distribution (in %) of the sampled gardens according to soil acidity classes (pH), 2007–2009.

pH	Gardens under construction	Vegetable garden	Ornamental garden	Lawn	Greenhouse
Very low	2.5	1.3	1.2	2.3	2.6
Low	9.5	7.4	4.8	2.9	2.6
Rather low	11.4	6.4	7.4	8.5	13.2
Optimal	17.0	18.1	14.5	13.5	15.8
Rather high	17.6	19.1	18.3	14.9	18.4
High	20.7	27.5	24.8	23.6	26.3
Very high	21.3	20.2	29.0	34.3	21.1

Table 7
Distribution (in %) of the sampled gardens according to the different soil fertility classes for carbon content, 2007–2009.

	Gardens under construction	Vegetable garden	Ornamental garden	Lawn	Greenhouse
Very low	7.9	2.3	4.5	26.9	0.0
Low	7.7	2.5	6.4	37.1	2.6
Rather low	12.0	5.9	11.0	14.7	15.8
Optimal	40.0	30.3	35.7	18.2	39.5
Rather high	27.1	46.1	31.9	2.1	18.4
High	5.0	12.9	10.0	0.8	23.7
Very high	0.3	0.0	0.5	0.2	0.0

gardens, especially lawns and ornamental gardens, have been limed excessively. Also frequent applications of organic fertilisers and soil conditioners (especially compost) contribute to the alkalisation of the gardens. Too high pH values result in an impaired absorption of different nutrients (Lucas & Davis, 1961; Pettinger, 1935). Due to the lowered availability of micronutrients (Mn, Fe, Zn, Cu), lawns will become less vigorous and turn yellowish (Loué, 1986).

3.6. Carbon content (C)

Most garden types have normal to high carbon content (Table 7 and Appendix A Tables A4–A6). For gardens under construction, 40% have a normal carbon content, while 27.6% are low in carbon and 32.4% have a high carbon content. In ornamental gardens, a higher proportion of the sampled gardens (42%) has a high carbon content. In vegetable gardens, more than half of the sampled gardens (59%) have a high carbon content. In contrast to gardens under reconstruction and the other garden components, most sampled lawns (79%) have a carbon content that is too low. The results of the internet survey indicates a possible cause, as grass cuttings appear to be removed from the lawn in most gardens. The removal of grass clippings indeed reduces organic matter inputs into the garden soil (Craul (1999) in Lorenz and Lal (2009)). Only 23% of the grass clippings remaining in the garden are left as a mulch layer on the lawn. These results indicate the potential of Flemish lawns to be mobilized as a net sink for atmospheric CO_2 (Lorenz & Lal, 2009; Zirkle, Lal, & Augustin, 2011). Jo and McPherson (1995) indicated that the carbon storage within the top 100 of soil profile can be as high as in the entire vegetation biomass above ground in urban residential greenspace.

3.7. Plant nutrients: phosphorus (P)

In general garden soils are characterized by high phosphorus contents (Table 8 and Appendix A Table A7). This is the most pronounced in vegetable gardens of which more than 89% have a high phosphorus content. Also in greenhouses the majority of the analyzed samples (68.5%) have a high phosphorus content; 37% even have very high phosphorus content. These (very) high concentrations of phosphorus are probably due to excessive fertilization. The results of the internet survey confirm high inputs and frequent use of fertilisers and soil conditioners. Also compost, with an average P-content of 7 kg P_2O_5/tonne fresh weight and a dry matter percentage of 70% (700 kg DM/tonne of fresh weight) (Vlaco, 2012), was applied in 20% of the gardens according to the respondents. These figures correspond well with average figures from the Netherlands: 696 kg/DM tonne fresh weight and 6.3 kg P_2O_5/tonne fresh weight (van Dijk & van Geel, n.d.). The high phosphorus values do not necessarily have a negative influence on the plant growth, but they do indicate that gardeners on average could do with less phosphorus fertilization.

3.8. General discussion

The results presented here shed new light on gardens as a dynamic type of land use and provide indicative orders of magnitude and eventually trends on fertiliser use, composting and grass clippings removal. The data suggest that management of domestic gardens risks to contribute to negative externalities to the environment. The environmental impacts of the garden management depend on management practices at the level of the single garden. As individual and private units of space, gardens risk to be neglected as trivial items in perspective of regional strategic

Table 8
Distribution (in %) of the sampled gardens according to the different soil fertility classes for phosphorus content, 2007–2009.

	Gardens under construction	Vegetable garden	Ornamental garden	Lawn	Greenhouse
Very low	4.8	1.3	1.7	4.3	0.0
Low	6.2	1.3	4.0	8.9	2.6
Rather low	5.6	2.3	5.5	14.1	10.5
Optimal	21.3	5.9	19.0	21.3	18.4
Rather high	34.4	15.5	31.4	30.8	18.4
High	19.7	27.2	27.1	16.8	13.2
Very high	8.0	46.5	11.3	3.8	36.9

Table 9
Distribution (in %) of the sampled gardens, arable land and pasture according to the different soil fertility classes for acidity (pH), carbon content (C) and phosphorus content (P), 2007–2009.

	Garden			Arable land			Pasture		
	pH	C	P	pH	C	P	pH	C	P
Very low	1.9	10.8	3.1	0.7	10.0	0.2	0.7	12.9	1.2
Low	6.1	14.0	5.3	8.9	18.8	0.7	4.5	26.8	5.5
Rather low	8.7	11.3	7.2	30.0	23.5	1.5	13.4	15.8	10.0
Optimal	15.7	31.1	17.4	38.8	37.7	10.7	36.6	31.3	20.1
Rather high	17.3	25.5	28.3	14.8	9.4	33.8	24.0	9.9	39.9
High	24.0	7.1	22.1	5.1	0.6	39.4	15.4	2.2	19.0
Very high	26.3	0.2	16.6	1.7	0.0	13.7	5.4	1.2	4.3

interests. However, the use of fertilisers and the production of organic waste in each of the individual gardens adds up when looking at the garden complex, being the aggregation of individual gardens into a regional wide landscape structure (Dewaelheyns, Bomans, & Gulinck, 2011). The total environmental impact of all garden management actions by individuals will be more clear when looking at domestic gardens as a regional system.

The 36% surveyed garden area with frequent fertiliser and/or soil conditioner usage in 2007 equals to 396 km^2 garden area in Flanders. Combined with an average amount of 67,000 kg of solid fertiliser and/or soil conditioner used per km^2 garden in 2007 (Table 4), this results in an average amount of solid fertiliser and/or soil conditioner of 26.5 million kg used in the Flemish garden complex in 2007. In combination with the soil analyses, these results underpin excessive use of fertilisers. Based on more than 1800 soil samples from domestic and public gardens, the pH, carbon (C) and phosphorus (P) levels are well over the growth optimum. A comparison of the results for gardens with the results for professional agriculture (arable land and pasture, Table 9), shows that domestic garden soils have on average a higher pH. The results from the internet survey already revealed that lime was used in almost 35% of the surveyed gardens. Excessive liming, leading to highly alkaline soils, has a negative effect on the nutrient availability in the soil due to impaired nutrient availability (e.g. due to too high pH) and consequently poor nutrient absorption.

Especially vegetable and ornamental gardens are better supplied with carbon compared to arable land (Table 9). Due to the shallow tillage depth in gardens as compared to conventional arable farming, the carbon content needs to be maintained in a smaller volume. As a small management unit, it is easier to keep the organic matter in individual domestic gardens up to standard through applications of compost, organic fertiliser, manure, green manure or garden waste. The survey results already indicated a frequent (often yearly) incorporation of fertilisers by half of the respondents, with compost and organic fertilisers as the most frequently used products (next to lime). The garden complex has a high potential as carbon sink, but is also capable of processing and storing nitrogen (Groffman, Law, Belt, Band, & Fisher, 2004). This latter however is mortgaged by excessive compost applications, since it contributes significantly to nitrogen fertilization (Tits, Elsen, Bries, & Vandendriessche, 2012). While soils with a low organic matter content (i.e. low carbon content) are known to not function optimally (Oades, 1988; Paul et al., 1997), soils with high carbon content are characterized by a high nitrogen supplying (Tits et al., 2012). In such soils, high amounts of mineral nitrogen are released throughout the year. This will not only result in high mineral nitrogen stocks in spring, but the excess of mineral nitrogen present in the soil will leach to the groundwater after the growing season, especially in vegetable plots and other parts not vegetated during winter. In ornamental gardens and orchards, deep roots may take up the leached mineral N from the deeper soil layers in springtime when the sap flow and nutrient uptake restart.

Hence, a high carbon content of garden soils could have a negative impact on the groundwater quality. The survey clarified that 70% of the used compost is home-made, meaning that there is little to no control and limited knowledge on the composition. The use of home compost is generally seen as a positive act towards the environment and promoted by several government organizations. Compost itself is considered as a valuable fertiliser, not only increasing the carbon content but also supplying nutrients for the plants. Although for most nutrients the processing and usage of home compost in the garden recycles nutrients 'on the spot', we need more detailed information on the practices and carbon and nitrogen contents of applied home compost to broaden the understanding of the complete nutrient cycles in gardens. Such knowledge is essential in making reliable conclusions on the environmental impact of fertilization practices and home compost usage in gardens and to prevent the negative sides of home compost usage.

Finally, the phosphorus content in domestic garden soils and arable land and pastures is equally high. If the phosphorus content is too high, the absorption of microelements, like zinc, is hampered. Phosphorus concentrations that are too high can also cause environmental problems by leaching to the phreatic and surface water. Leaching of phosphates usually occurs in sandy soils, which are poor in iron and aluminium (thus with little sorption capacity) (Elliot, O'Connor, & Brinton, 2002). The high phosphorus concentrations in garden soils strengthens the idea that the intensive fertilization in domestic gardens may have a negative impact on the water quality, but this is so far not supported by research concentrating on gardens.

At the positive side, our survey results indicate that gardens can play a role in the waste recycling process. The 14% surveyed garden area with removal of grass clippings from the garden equals to 154 km^2 garden area in Flanders in which grass clippings were removed in 2007. Combined with an average amount of 2,310,000 l of grass clippings removed per km^2 in 2007 (Table 5), the amount of grass clippings in Flanders exported in 2007 is estimated at nearly 356 million l. Organic garden residue is kept in the garden in 85% of the surveyed gardens, indicating the importance of gardens as recycling units. New ways of valorization of garden waste can be bio-energy production (e.g. Yu, Samani, Hanson, & Smith, 2002). As Refsgaard and Magnussen (2009) state, it is a challenge to reduce the residue flow.

The combination of methods presented here, a regional wide internet survey with detailed soil analyses, has proven its strength in collecting explorative and indicative environmental data on a landscape component that is, for the moment, rather unknown and inaccessible. We succeeded in obtaining a minimum level of representativeness. Both the number of respondents as the number of gardens sampled for soil analyses were sufficient to represent an infinite large population. Based on the bar charts of the degree of passion for gardening as well as of ecological gardening, we assume no bias among the respondents towards more of less passionate nor ecological gardeners.

Although the soil analyses were based on almost 1800 sampled gardens in Flanders, the soil samples were not taken randomly. A bias towards malnutritioned gardens is possible, since a part of the soil analyses was requested by garden owners upon observations of poor plant growth. Moreover, the soil samples of public and private gardens were analyzed together. For the soil fertility analysis, we used agricultural optimal growth standards defined by SSB. Their advantage is twofold: the provision of a clear and interpretable reference and the possibility to make comparisons with agricultural land that is professionally managed. These standards however can also be questioned. In the light of multiple ecosystem services of gardens, the soil fertility state of garden soils could also be interpreted in terms of e.g. nature conservation and potential biodiversity, meaning lower levels of soil fertility for optimal performance. Developing soil fertility classes for a selection of ecosystem services could certainly be a step in specialized research on domestic gardens. A weakness of the presented work however is the fact that the soil samples were not taken in the gardens that were surveyed by means of the internet survey, excluding the possibility to calculate correlations between management practices and soil fertility levels. Soil sampling and analysis along with standardized management diaries in representative case studies can boost future research investigation of the specific interactions between management practice and garden soil fertility.

Although the results of this research should be evaluated for their indicative value, they clarify the need for more detailed environmental research in the garden complex. Reliable data and meaningful indicators are necessary if we want to start thinking about transforming individual gardens into an environment-friendly garden complex. Important determinants of biogeochemical fluxes in gardens are the individual management decisions at the household scale (Kaye et al., 2004), like fertilization levels. Pimentel (1991) already stated that homeowners are more likely to overuse pesticides compared to professionals. Our comparison of soil fertility states between arable land and gardens indicates that similar findings might account for the use of fertilisers and/or soil conditioners in Flanders. While agriculture is extensively monitored and subjected to regulations concerning fertiliser use, garden owners are free to act as they please. As Baker, Hope, Xyu, Edmonds, and Lauver (2001) stated that the most effective nitrogen management strategies are those specifically tailored to individual ecosystems, garden-tailored management plans can be a valuable pathway towards a more environmental-friendly garden complex.

However, an interdisciplinary examination of residential landscapes is needed to understand the feedback and trade-offs of these complex adaptive social-ecological systems as a whole (Cook et al., 2012). Management actions taken at the individual garden level are based in culture, attitudes and beliefs, constrained by institutional and socioeconomic factors (Kaye et al., 2006) and influenced by complex human drivers (Kirkpatrick, Daniels, & Zagorski, 2007; van den Berg & van Winsum-Westra, 2010; Zmyslony & Gagnon, 1998). One of the most important challenges in urban ecology is identifying links between social and ecological processes (Collins et al., 2000; Grimm, Grove, Pickett, & Redman, 2000; Kaye et al., 2004) and, in the case of domestic gardens, motivate individual owners to contribute to collective goals. The 'ecological land-use complementation' concept of Colding (2007) provides an interesting framework of thinking about participatory management approaches in terms of the garden complex.

4. Conclusions

Research on the environmental aspects of individual gardens fits into a broader framework of regional and urban development and planning, sustainability and the relationship between society and natural resources. For the broader land use categories like agriculture, nature and forest, clear information exists about their 'environmental' landscape, thanks to explicit policy and monitoring programs. This allows landscape planners to insert this information in environmental and landscape strategies from local to regional level. The garden complex is underrepresented in such strategies but should surely be put on the agenda of landscape planning worldwide. Current lack of knowledge on the distribution of cover and use characteristics of the garden complex, and the environmental impact of domestic garden management, can be turned in a new frontier of landscape research.

By combining a regional wide internet survey with detailed soil analyses, we succeeded in filling in a first small part of the knowledge gap about the environmental significance of the 8.2% of the Flemish territory taken in by domestic gardens. Excessive and/or improper use of fertilisers, the lack of indicators on over fertilization that are easily measurable and accessible for gardeners, and lack of governmental regulation and control on the amounts of fertilisers used in domestic gardens can be factors that contribute to negative environmental effects of gardens.

The recorded quantities of home composting in Flanders prove the impacts of sensitization campaigns. Sensitization on fertilizer use in gardens is thus certainly realistic. Existing and new sensitization campaigns should be adjusted according to new insights into the environmental impacts of the use of compost and other fertilizers. For instance, most gardeners consider the use of 'natural' products (like compost or stable manure) to be harmless and applicable at all times, but most are not aware about the relative slow breakdown of these products that puts a restriction on frequent applications. A similar reasoning accounts for the use of pesticides. Besides sensitization, monitoring could reach out handles for the development of regulations, as it is the fact for agriculture.

The need for detailed and ongoing monitoring is clear. Currently, it is not sufficiently known which factors determine the nature and amount of the applied and exported products used in gardens. These could be factors like the proportion of lawn area within the garden, but also socio-ecologic and socio-economic factors or other yet undefined factors. Since the fragmentation and heterogeneity in property and management is one of the reasons for the restricted knowledge on gardens, easily accessible and efficient survey techniques are a necessity. The good response of the online survey in this study gives hope for the development of an extended garden monitoring program.

The garden complex should be better acknowledged in policies of environment, agriculture and nature, in spatial and urban planning and design, and in climate change adaptation. Environmental benefits and impacts are just a few aspects of gardens, also other issues like home food production, biodiversity, recreation and wellbeing are related to them. The question is which role the garden complex exactly plays and how it is possible to increase its positive contributions to society and the environment, while decreasing negative impacts. This is plenty of challenge for research.

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Appendix A. Evaluation of pH, C (%) en P in domestic gardens in Flanders

When interpreting the following tables, attention should be paid to the facts that (i) a different assessment framework is used for the three types (a) gardens under construction, vegetable gardens an ornamentals gardens, (b) garden lawns and (c) greenhouses, and that (ii) the assessment classes differ per soil type (Tables A1–A7).

Table A1
Evaluation of pH-KCl in gardens under construction, vegetable gardens and ornamentals gardens.

Evaluation	pH-KCl sand	pH-KCl sandy loam	pH-KCl loam	pH-KCl clay
Very low	<4.0	<4.5	<5.0	<5.5
Low	4.0.–4.5	4.5–5.5	5.0–6.0	5.6–6.4
Rather low	4.6–5.1	5.6–6.1	6.1–6.6	6.5–7.1
Optimal	5.2–5.6	6.2–6.6	6.7–7.3	7.2–7.7
Rather high	5.7–6.2	6.7–6.9	7.4–7.7	7.8–7.9
High	6.3–6.8	7.0–7.4	7.8–8.0	8.0–8.1
Very high	>6.8	>7.4	>8.0	>8.1

Table A2
Evaluation of pH-KCl in lawns.

Evaluation	pH-KCl sand	pH-KCl sandy loam - loam	pH-KCl clay
Very low	<4.4	<4.6	<4.9
Low	4.4–4.7	4.6–5.1	4.9–5.3
Rather low	4.8–5.0	5.2–5.6	5.4–5.6
Optimal	5.1–5.6	5.7–6.2	5.7–6.4
Rather high	5.7–5.9	6.3–6.5	6.5–6.8
High	6.0–6.4	6.6–7.0	6.9–7.2
Very high	>6.4	>7.0	>7.2

Table A3
Evaluation of pH-KCl in green houses.

Evaluation	pH-KCl sand	pH-KCl sandy loam	pH-KCl loam	pH-KCl clay
Very low	<4.2	<4.7	<5.2	<5.7
Low	4.2–4.7	4.7–5.7	5.2–6.2	5.7–6.6
Rather low	4.8–5.3	5.8–6.3	6.3–6.8	6.7–7.3
Optimal	5.4–5.8	6.4–6.8	6.9–7.5	7.4–7.9
Rather high	5.9–6.4	6.9–7.1	7.6–7.9	8.0–8.1
High	6.5–6.9	7.2–7.6	8.0–8.2	8.2–8.3
Very high	>6.9	>7.6	>8.2	>8.3

Table A4
Evaluation of carbon content (C %) in gardens under construction, vegetable gardens and ornamentals gardens.

Evaluation	C% sand	C% sandy loam - loam	C% clay
Very low	<1.2	<0.8	<1.0
Low	1.2–1.4	0.8–0.9	1.0–1.2
Rather low	1.5–1.7	1.0–1.1	1.3–1.5
Optimal	1.8–2.8	1.2–1.6	1.6–2.6
Rather high	2.9–4.5	1.7–3.0	2.7–4.5
High	4.6–10.0	3.1–7.0	4.6–10.0
Very high	>10.0	>7.0	>10.0

Table A5
Evaluation of carbon content (C %) in lawns.

Evaluation	C% all soil textures except loam	C% loam
Very low	<2.0	<1.5
Low	2.0–2.9	1.5–2.0
Rather low	3.0–3.5	2.1–2.5
Optimal	3.6–5.5	2.6–4.2
Rather high	5.6–7.0	4.3–6.5
High	7.1–10.0	6.6–9.0
Very high	>10.0	>9.0

Table A6
Evaluation of carbon content (C %) in greenhouses.

Evaluation	C% all soil textures except sand	C% sand
Very low	<1.3	<1.3
Low	1.3–1.4	1.3–1.6
Rather low	1.5–1.9	1.7–2.4
Optimal	2.0–3.5	2.5–3.9
Rather high	3.6–5.0	4.0–5.0
High	5.1–8.0	5.1–10.0
Very high	>8.0	>10.0

Table A7
Evaluation of phosphorus content (in mg P/100 g dried soil (measured in ammonium lactate extract).

Evaluation	P (mg/100 g dried soil, measured in ammonium lactate extract)		
	Gardens under construction, vegetable and ornamentals gardens	Lawns	Greenhouses
Very low	<5	<8	<12
Low	5–8	8–13	12–20
Rather low	9–11	14–18	21–34
Optimal	12–18	19–25	35–50
Rather high	19–30	26–40	51–60
High	31–50	41–60	61–80
Very high	>50	>60	>80

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