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Environmental Analysis of Sustainable Production Practices Applied to Cyclamen and Zonal Geranium

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Abstract: Italian floriculture is facing structural changes. Possible options to maintain competitiveness of the involved companies include promotion of added values, from local production to environmental sustainability. To quantify value and benefits of cleaner production processes and choices, a holistic view is necessary and could be provided by life cycle assessment (LCA) methodology. Previous studies on ornamental products generally focused on data from one company or a small sample. The aim of this study was a gate-to-gate life cycle assessment of two ornamental species, cyclamen (*Cyclamen persicum* Mill.) and zonal geranium (*Pelargonium* × *hortorum* Bailey), using data from a sample of 20 companies belonging to a floriculture district in the Treviso, Veneto region. We also assessed the potential benefits of the environmental impact of alternative management choices regarding plant protection and reuse of composted waste biomass. Life cycle impact assessment showed higher impact scores for the zonal geranium, mainly as a consequence of greenhouse heating with fossil fuels. This factor, along with higher uniformity of production practices and technological levels of equipment, translated to a lower variability in comparison with cyclamen production, which showed a wider results range, in particular for eutrophication, acidification and human toxicity potential. The application of integrated pest management with cyclamen had significant benefits by reducing acidification and human toxicity, while reducing use of mineral nutrients through amending growing media with compost resulted in a reduction in eutrophication potential. Similar achievable benefits for zonal geranium were not observed because of the dominant contribution of energy inputs.

Keywords: life cycle impact assessment (LCIA); plant protection; compost; sustainable greenhouse production

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1. Introduction

Ornamental plant production is a specialized and intensive agricultural sector that includes a wide range of outputs, such as cut flowers, nursery stock, potted flowering or leafy plants, bulbs and tubers. Europe is the largest consumer market, with Germany, the United Kingdom, France and Italy as leading consumers. Italy is also an important producer, having over 14,000 companies with a GSP of over 1125 million € [1]. This sector has a complex structure, with a few regions having districts specialized in some sections of the production chain.

The Veneto region of Italy is home to some important districts, located in Padova, Treviso, Vicenza and Rovigo provinces. Data from 2016 [2] showed a total of 1490 companies, with a total area of 2730 ha, and a GSP of 206 million €. The overall trend compared to the previous five years highlights how the sector is facing structural changes to cope with the ongoing stagnation in domestic demand as a consequence of the current economic crisis; the number of companies is steadily decreasing, averaging −2% per year, with 4–5% peak losses in some districts (Rovigo, Vicenza). The GSP value of marketable pot plants decreased slightly (−0.5%) until 2016, then the trend started to increase. The nursery production of ornamental, vegetable and orchard plants is stable. Regarding marketing areas, local and regional sales fell (from 34.3% to 29.1% and from 22.6% to 20.2% over five years, respectively), but a slight increasing share of sales to other Italian regions (+3.9% in five years) or EU countries (+4.7% in five years). Indeed, an increased number of companies have obtained the Certificate of Conformity required for sales in EU member countries, to 264 (+18%) in 2018. The changes highlighted by these data are partly related to increased competitiveness from emerging countries [3], and partly to the shift in consumer preferences. Italian companies operating in the northern, high-cost regions are generally small and family-run, and cannot tackle sudden changes in international markets with cost reductions and technological improvements only. Possible options for maintaining competitiveness could focus on the promotion of added value, such as typical/local productions, range and variety of choice, seasonal products and "eco-friendly" choices in production systems. For countries within the EU, sustainable or cleaner production are becoming a requirement rather than an encouraged practice, even the agricultural sector which is often regarded as a polluting activity [4].

Cleaner production is defined by the United Nations Environmental Program [5] as the continuous application of an integrated preventive environmental strategy to processes, products and services, to increase overall efficiency and reduce risks to humans and the environment. Five main components of cleaner production are related to conservation of raw materials, water and energy, eliminating toxic and dangerous emissions and reducing waste. Plastic waste, fertilizer use, peat-based growing media and heating requirements are usually perceived as major contributors to protected crop impacts on environment. Some of the above-mentioned issues have been addressed by researchers, such as integrated or biological crop protection [6–9], use of slow-release fertilizers [10–13], irrigation plans based on crop needs [14], and cultivation of native low energy demanding species [15]. Use of alternative containers such as biodegradable pots for the cultivation of ornamental pot plants were evaluated in various studies [16,17]; also peat substitution with composted materials, or other agro-industrial by-products rich in nutrients, has been widely evaluated in several trials with container grown plants, such as shrubs [18], poinsettia [17], geranium [19–21] and other bedding plants [22–24]. Efficient use of energy in greenhouses has received great focus [25–27]. Many trials aimed at reducing the energy consumption of greenhouses have focused on ventilation processes and the effects of thermal energy and mass transfer [28–31].

To quantify the potential impacts and assess the efficiency of reduction measures on specific crops and production systems, a life cycle methodology should be used. Life cycle assessment (LCA) is a material and energy balance applied to the production of goods or services (ISO 14040 [32]). This methodology has been applied to some ornamental commodities and production systems [33–36]. Previous studies on potted plants under protected cultivation highlighted some of the processes and materials involved in the production of certain emissions, such as energy for heating and artificial lighting, greenhouse frames and covers, plastic containers and peat [35,37–40]. Most assessments, except for a study on nursery production conducted by Lazzerini et al. [39], analyzed data sourced from one representative company and from specific literature or databases.

Objective of the Study

The aim of this study was to assess the environmental aspects of the cultivation of two ornamental species, using data from a sample of nurseries in the Treviso production district. While trying to define average impact results for the most important categories, we analyzed how different management choices and production practices affect final results. In the following sections we present the functional units, data collection processes and the alternative scenarios we chose to assess.

2. Materials and Methods

2.1. Goal and Scope

The goal of this research was to characterize the final cultivation phase of two potted flowering plant species, cyclamen and zonal geranium, from an environmental point of view, defining a range of results representative of the most common practices in the investigated floriculture district. We also assessed the potential environmental benefits achievable with specific practices or management choices that have been adopted by individual growers independently.

Other practices that apply to all the investigated companies, such as collection and recycling of plastic materials, have been implemented in the system models. The scenarios that we investigated concern typical environmental bottlenecks of protected cultivation, such as fertilizer use, plant protection and waste management (biomass).

The scope of our study included production, installation, use and disposal of capital goods (greenhouse frame and cover, as well as heating systems and auxiliary equipment for fertigation) and production, transport, use and disposal of crop inputs. The model system we describe was based on the production practices of a sample of nurseries sited in Treviso province. Since our goal was to describe and assess common practices and average structure and technology, comparison of different company sizes or sale types were outside the scope of this study.

We used open LCA software version 1.5.0 and EcoInvent database version 3.3 to input and model the Life Cycle Inventory data. Life cycle impact assessment (LCIA) was performed with CML-2015 method (CML-Centrum Voor Milieukunde Der Rijksuniversiteit Leiden), first created by the University of Leiden in the Netherlands in 2001. It has been published in a handbook with several authors [41]. The impacts were described using the baseline method impact categories. Acidification potential (AP) measures the increase of the acidity in water and soil systems due to the acidifying effects of anthropogenic emissions nitrogen oxides (NOx) and sulfur oxides (SOx). Acidification potential is expressed using the reference unit, kg SO_2 equivalents. Global warming potential (GWP) measures the alteration of global temperature caused by greenhouse gases released by human activities; characterization of the model was based on factors developed by the UN's Intergovernmental Panel on Climate Change (IPCC). Factors are expressed as global warming potential over the time horizon of 100 years (GWP100), measured in the reference unit kg CO_2 equivalents. Eutrophication is the build-up of a concentration of chemical nutrients in an ecosystem which leads to abnormal productivity. Emissions of ammonia, nitrates, nitrogen oxides and phosphorous to air or water all have an impact on eutrophication. This category is expressed using the reference unit, kg $PO_4{}^{3-}$ equivalents. Direct and indirect impacts of fertilizers are included in the method. The direct impacts are from production of the fertilizers and the indirect ones are calculated using the IPCC method to estimate emissions to water causing eutrophication. Environmental toxicity is measured as two separate impact categories which examine freshwater and terrestrial emission of some substances, such as heavy metals, which can have impacts on the ecosystem. Assessment of toxicity is based on maximum tolerable concentrations in water for ecosystems. The calculation method provides a description of fate, exposure and the effects of toxic substances on the environment. Characterization factors are expressed using the reference unit, kg 1,4-dichlorobenzene equivalents (1,4-DB). The human toxicity potential is a calculated index that reflects the potential harm of a unit of chemical released into the environment, and it is based on both the inherent toxicity of a compound and its potential dose. This impact category is measured in 1,4-DB equivalents. The normalization step is necessary to analyze and describe the relevance of single contributions to an impact category, and to calculate the order of magnitude of the category indicator results relative to a reference information (i.e., total impacts for the selected category in a specific area). LCIA results were normalized with factors for the EU 25 area.

2.2. Data Collection

Data were collected through a survey conducted through questionnaires and interviews with 20 floriculture companies belonging to the Florveneto association, representing ornamental plant growers in Treviso province. The questionnaires were administered in person to the owners, at the company, so that the data collected could be, at least in part, verified. A questionnaire, which had previously been submitted to and validated by two pilot companies, was used to collect information on general production practices, greenhouse structures and equipment. The questionnaire with examples of compilation is available as Supplementary Material questionnaire.

Functional Units and System Boundaries

The functional unit was a single marketable plant in a 14-cm pot. The investigated species, zonal geranium and cyclamen, were chosen for several reasons: First, their economic relevance (they comprise 20% and 22% of the Italian flower market, respectively); second, they represent part of an ideal crop sequence for the average nursery. Lastly, given the seasonality of their production cycles, they are crops with different climate control needs and energy demands. System boundaries include all operations and inputs from transplant to market-ready flowering plants. The plug production phase was also included, even if specific information on seedling or cutting production for the considered species were not collected. This is also motivated by considerable differences concerning the choices of variety and young plant producers found among the surveyed companies.

2.3. System Description: Cyclamen

Cyclamen (*Cyclamen persicum* Mill.) plants are usually grown in structures with a plastic cover (single layer) over a galvanized steel frame. Average plastic cover replacement rate is 6 years, while supporting structure lifetime is 30 years. Potting of young plants occurs from May to mid-July. With an average growing period of 14–16 weeks, early potted plants bloom in September. Optimal temperature in the first period of growth is around 18–20 °C. During flower development normal temperatures should be between 15 and 20 °C. To promote cooler temperatures, shading from 30% to 50% is applied in summer months, together with lateral and roof ventilation. Active cooling systems, like fogging or fan-and-pad are installed and operating in only three nurseries. Cyclamen seedlings are transplanted into 14-cm pots, filled with a substrate composed of white peat with a coarse, porous texture (40% v/v), black peat (45–50% v/v) and expanded perlite (10–15% v/v). Plants are irrigated using overhead spray irrigation (no added fertilizer) for 1–2 weeks, then a fertilizer solution (N:P:K at 1:0.4:1.2) is applied. In some cases, overhead spray irrigation is still preferred at this stage, while most growers (14 out of 20) start fertigation with a spaghetti tube system. Fertilizer solutions applied during the growing period have increasing ratios of potassium to phosphorus to promote flowering and plant resistance to both disease and environmental stress (typical formulations: 17N-3.05P-14.2K; 20N-8.29P–23.3K). Plants are spaced after one month to allow air circulation and canopy growth. Fungal diseases include *Botrytis* and *Fusarium*, anthracnose and powdery mildew. Most are limited by prevention practices and improved breeding, yet between one and three fungicide treatments (classes: Carbamate, thiadiazole, amide, aromatic organic compounds) are reported by most growers. Common cyclamen pests are thrips (*Frankliniella occidentalis*; *Echinotrips americanus*), aphids (*Aphys gossypii*, *Aulacortum circumflexum*), vine weevil (*Otiorhynchus sulcatus*) and mites (*Steneotarsonemus pallidus*, *Tetranichus urticae*). Insecticides (active ingredient classes: Neonicotinoids, organophosphate, pyrethroids or avermectine) are applied from 2 to 5 times during the growing cycle. Growth regulators (chlormequat or daminozide) are applied once or twice to inhibit petiole elongation by 14 growers. See Supplementary Material questionnaire for the complete list of the inputs that were considered.

2.4. System Description: Zonal Geranium

Zonal geranium (*Pelargonium* × *hortorum* Bailey) plants are usually grown in structures with a plastic cover (double layer, air inflated) and galvanized steel frame, or in glasshouses with a steel frame. Average replacement rate of a plastic cover is 6 years while glass and supporting structures lifetime often exceeds 30 years which was the value assumed for calculations. The most widely used heating system consists of diesel-powered fan-burners generating hot air while only two companies use gas boilers and a network of polypropylene pipes to deliver hot water under cultivation benches. In the first 10–15 days after seedling transplant, optimal temperature is around 18 °C in the daytime and 16 °C at night. After this phase, diurnal temperatures are kept around 16 °C and night temperatures around 14 °C. No artificial lighting is applied during this growth phase. Growing media are usually comprised of peat moss (80–85% v/v) blended with porous materials such as perlite or expanded clay (10–15% v/v). Plants are fertigated using overhead spray irrigation for a period ranging from 6 days to 3 weeks, depending on the individual choices made by growers. After this period, until marketable size is attained, plants are placed on benches and fertigated with ebb-and-flow or with spaghetti-tubing irrigation systems. Fertilizer solutions applied during the first period have a N:P:K ratio of 1:0.5:1. To promote flower quality, potassium concentration is increased during the final growth phase (N:P:K at 0.8:0.3:1.2). Common diseases are *Xanthomonas campestris* pv. *pelargonii* (wilt and spots), *Ralstonia* (wilt), *Pythium*, and *Botrytis*. Bacterial diseases are best fought with prevention practices and early detection, and soil-borne fungal diseases can be prevented by avoiding excessive air and substrate humidity, facilitating canopy air movement and raising night temperatures. Besides prevention practices, plants are usually treated one to three times with fungicides (active ingredient classes: Dichlorophenyl dicarboximide, aromatic organic compounds, amide). As a typical spring crop, zonal geranium is very sensitive to thrips; aphids (*Acyrthosiphon malvae*) can also be a problem and cause small, distorted leaves and black sooty mold. Insecticides are applied preventively in 40% of cases; most common active ingredients belong to the carbamate, organochlorine and pyrethroid classes. Along with other ornamentals such as petunias (*Petunia* spp.) and calibrachoas (*Calibrachoa* spp.), pelargoniums can be affected by budworms (*Geraniums bronze*, *Cacyreus marshalli*) during the last growth stages. These worms can devastate geraniums by tunneling into young buds and destroying the flower. Neonicotenoid or pyrethroid insecticides are applied to control this pest. See Supplementary Material questionnaire for the complete list of the inputs that were considered.

2.5. Assumptions

Data for background processes such as material manufacturing and disposal activities were sourced from the Ecoinvent 3.3 database, and modeled with OpenLCA ver. 1.5.0. Direct emissions were calculated by using estimation models, which are flexible and allow for an estimation of mitigating options. For fertilizer use, we estimated nitrate (NO_3^-) emissions with the Swiss agricultural life cycle assessment (SALCA) method, assuming a draining fraction of 25% for open-loop systems, which is a common leaching value applied to prevent root zone salinization. Phosphate (PO_4^{3-}) emissions were calculated according to SALCA-P emission model [42]. Plant protection products applied were modeled as emissions to agricultural soil.

2.6. Description of Alternative Practices

As mentioned earlier, during the data collection it was noticed that, even if close similarities were recorded in most of the interviewed nurseries regarding structure types, technological level of growing equipment, management decisions and cultivation inputs for the studied crops, the choices made by some growers led to significant differences in the reported input levels. Management decisions could in turn lead to different emission patterns and levels. These practices mainly included plant protection practices, fertigation management and recycling of waste biomass.

2.6.1. Integrated Pest Management and Biological Plant Protection

Monitoring of insect presence (with chromotropic traps or visual inspection) is a known, yet not very widespread practice. Objective assessment of infestation and potential damage is also very difficult for crops with aesthetic value as their main feature. Despite this, the application of integrated pest management (IPM) and biological control agents is receiving growing attention, also because many active ingredients registered for use on ornamental species have recently been revoked or are no more available [43].

Due to the greater effort required, and uncertainties linked to these practices, most growers are delaying their application and still rely heavily on chemical control.

Based on information from four growers using IPM strategies, we assessed the potential impact of less chemical input and use (manufacturing of raw materials and soil emissions) as compared to an average production scenario. For cyclamen production, we considered that prevention practices at the transplant phase, with inoculation of a biological antagonist to *F. oxysporum* in the growth medium, can the reduce need for fungicide treatment to 1 per crop cycle, while improved insect scouting and monitoring reduces insecticide sprays to 2 per crop cycle. Zonal geranium benefits from biological prevention and control both at the transplant phase and in the first stages with *T. harzianum* and *B. subtilis* strains, while preventive insecticide spraying is integrated with antifeedant treatments (Azadirachtin); for this scenario we considered no fungicide treatment and a reduction of 40% in insecticide use (active substance).

2.6.2. Management and Reuse of Waste Biomass

Protected soilless crops generate a significant amount of waste, due to material requirements for growing media, containers, benches, irrigation pipes and plug trays. These materials need to be disposed of at their end-of-life and several options are available from incineration to landfilling, or composting, depending on material segregation practices, regulations and grower's choices. Recycling of plastic material is a common and well-established practice among the interviewed growers, thanks to good awareness and coordinated efforts by the Florveneto association. Management of biowaste differs between growers. The amount of non-yield biomass in ornamental containerized crops is lower than in other protected crops, yet a certain amount of unsold or discarded plants are produced and must be disposed of confined windrow composting and reuse in situ could be an option, and one grower reported to have adopted this practice. However, in this case chemical and physical properties as well as direct emissions are probably highly variable and difficult to measure, and we therefore chose to model an alternative option, where compost is produced from miscellaneous green waste in a composting facility and used in growth media preparation as a substitute for peat. The considered rate of compost addition to the growth medium is 20% (v/v); this was chosen in accordance with growth trials of containerized plants on compost amended substrates reported in several studies [19,44,45]. For different plant species, supporting effects on growth with compost rates up to 20% were reported in these studies, but different effects were found for higher substitution rates. An analysis from a local composting plant shows the chemical composition and nutrient content of composted garden waste (Table 1). Two options are considered for the offset of mineral fertilizers: NPK content of compost does not replace fertilizers (option 1); NPK content replaces part of the mineral fertilizers applied through fertigation (option 2). The following rates of nutrient content available for the crop were considered: 20% for N, 50% for P and 50% for K. These values were taken from Boldrin et al. [46], and were reduced to account for the limited length of the growing period for the considered species.

Table 1. Chemical and physical properties of the garden waste compost considered for the evaluation of the impacts.

Compost Characteristic	Value
Bulk density (kg m^{-3} dry weight)	404
Water holding capacity (v/v)	64.8
Dry matter (%)	66.5
Organic matter (%)	38.7
pH	8.70
Electrical conductivity (Sd m^{-1})	3.78
NO_3^- (mg L^{-1})	108
PO_4^{3-} (mg L^{-1})	40.6
Na^+ (mg L^{-1})	200
NH_4^+ (mg L^{-1})	19.7
K^+ (mg L^{-1})	603
Mg^{2+} (mg L^{-1})	22.8
Ca^{2+} (mg L^{-1})	115

3. Results and Discussion

The considered inputs (Supplementary Material questionnaire) were grouped into six main categories, which include production, use and end-of-life phases: Greenhouse structures and covering materials, fertilizers, plant protection products, pots (including only the containers used in the cultivation phase), growing media and heating. Looking at absolute values (Table 2) for the assessed impact categories, we can note how the heated crop (zonal geranium) scored higher results for all indicators, even by several orders of magnitude for AP and GWP categories. As highlighted in the analysis of relative contributions (Figures 1 and 2), heating with fossil fuels contributed the greatest to the inputs of production. This factor, together with the greater uniformity found for some management choices in zonal geranium, also influenced the variability, which showed minor fluctuations around average values compared to cyclamen. For geranium, to better highlight the contribution of the main groups of input to the different impact categories we excluded the most impacting one (heat) even if this is beyond both the scope of the work and the meaning of the LCA analysis. With the exclusion of heating, the categories with the greatest weight were the greenhouse structure and coverage that contributed over 60% in the fresh water aquatic ecotoxicity (FWAE), human toxicity (HT) and terrestrial ecotoxicity (TE) categories, the pot that contributed over 51% in the acidification potential (AP) and 64% in the GWP categories, the substrate accounted for about 20% in three categories (AP, GWP and HT), and the fertilizers which contributed 75% in the Eutrophication potential (EP) category.

Table 2. Absolute values and standard deviation (in percentage) for the assessed impact categories for flowering potted plants of cyclamen (*Cyclamen persicum* Mill.) and zonal geranium (*Pelargonium* × *hortorum* Bailey).

Impact Category	Reference Unit	Cyclamen		Zonal Geranium	
	Equivalents	Mean	St.Dev. (%)	Mean	St.Dev. (%)
Acidification potential (AP)	kg SO_2	0.00036	11.63	0.00175	1.28
Global warming potential (GWP)	kg CO_2	0.07459	3.32	0.77210	1.29
Eutrophication potential (EP)	kg PO_4^{3-}	0.00027	23.01	0.00042	11.02
Fresh water aquatic ecotoxicity (FWAE)	kg 1,4-DB [z]	0.01934	4.35	0.03490	3.48
Human toxicity (HT)	kg 1,4-DB	0.04410	15.60	0.10200	1.03
Terrestrial ecotoxicity (TE)	kg 1,4-DB	0.00066	4.63	0.00144	0.79

[z] 1,4-dichlorobenzene (DB).

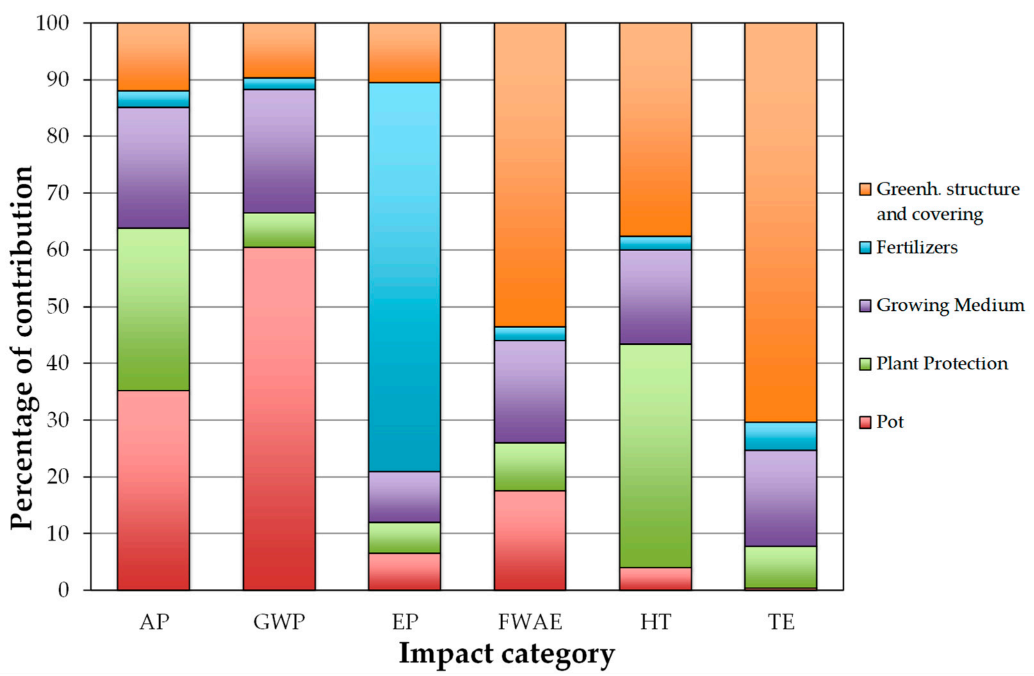

Figure 1. Relative contribution of different inputs for cyclamen potted plant production. The impact categories assessed are: Acidification potential (AP), global warming potential (time horizon of 100 years) (GWP), eutrophication potential (EP), fresh water aquatic ecotoxicity (FWAE), human toxicity (HT) and terrestrial ecotoxicity (TE).

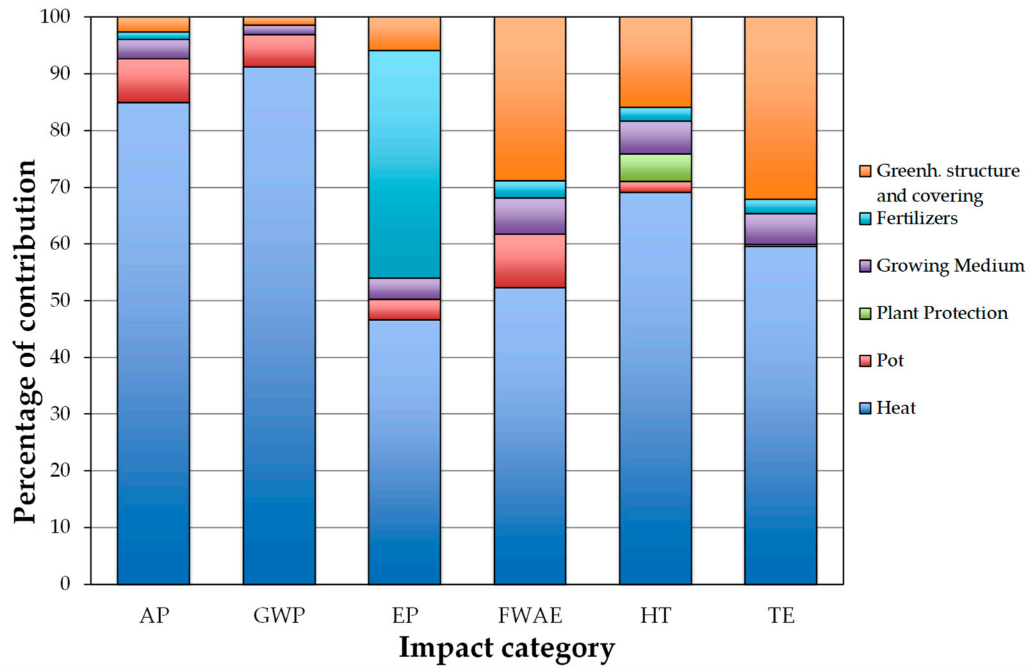

Figure 2. Relative contribution of different inputs for zonal geranium potted plant production. The impact categories assessed are: AP, GWP, EP, FWAE, HT and TE.

Relative contributions in the impact categories are depicted graphically in Figures 1 and 2. The reported percentages refer to average sample values. The contribution of some materials or structures showed little variation, given the relative uniformity of supply chain and input choices among the growers. Other inputs with less standardization showed significant differences in their contribution to impact categories, which will be discussed in the following paragraphs.

3.1. Cyclamen

Plastic containers were the major contributor (60.5%) for the GWP category, but also accounted for a significant share of impacts in AP (35.2%) and FWAE (17.6%) (Figure 1). All burdens were associated with material production, since no emissions were considered for use and end-of-life phases. Growing media components had an important share of impacts in the AP (21.3%), GWP (21.6%), FWAE (18%), HT (16.5%) and TE (17%) categories. Expanded perlite production and disposal was an important source of emissions for HT, TE and FWAE; emissions related to peat roadway transport from Baltic countries contributed mainly to GWP and AP categories (Figure 1). Greenhouse structure shared major burdens in FWAE (53.5%), HT (37.6%) and TE (70.4%) categories, mostly linked to production and disposal of steel frame and electricity consumption. Emissions related to production and use of plant protection products mainly influenced HT (39.4%) and AP (28.6%) categories; depending on chemical products type and frequency of treatments their contribution varied between 35.6% and 22.7% for AP, and between 43.8% and 32.5% for HT (Figure 1). Emissions related to fertilizer and water use contributed mainly (68.5%) to EP category results. The release of nitrate and phosphate in ground and surface water was directly linked to fertigation method and discharge mode and rate of nutrient solutions; the overall contribution of this phase varied between 44.6% for closed systems with no overhead application to 72% for open systems with frequent overhead applications (Figure 1). Fertigation management of cyclamen plants with the latter method was prevalent among the interviewed growers. Most studies on the environmental impact of potted plants have focused mainly on climate change (GWP) [38,39], while few studies conducted complete LCIA including other impact categories [34,37]. In accordance with our results, when referring to unheated crops with no artificial lighting, factors influencing GWP are mainly linked to manufacturing of plastic materials (containers and greenhouse cover) and growing media components (peat and expanded perlite). Fertilizer contribution to the EP category on the overall production process of cyclamen potted plants was also highlighted by Russo and De Lucia Zeller [37]. Their finding is in line with our results, suggesting that management practices aimed at reducing fertilizer use and leaching have the best chances for impact reduction in this category. The significant contribution of greenhouse structures to TE and FWAE categories is in line with similar studies on ornamental productions [34].

3.2. Zonal Geranium

Emissions deriving from production and use of diesel fuel burned to heat the greenhouse contributed a major share of impacts in all considered categories, accounting for over 91.3% of overall emissions in GWP and 84.7% in AP (Figure 2). Production and disposal of greenhouse frames contributed significantly to FWAE (28.7%), HT (17.9%) and TE (32.1%) categories (Figure 2). Fertilizer and water use contributed 40% of the impacts in the EP category. Since zonal geranium is often fertigated with ebb and flow systems, which allow for a reduction of direct emissions of both water and fertilizers, the contribution of this step was less variable than in cyclamen and ranged from 36.4% to 43.9% (Figure 2). Plastic pot contribution averaged 9.7% for FWAE, 7.7% for AP and 5.65% for GWP categories. The share of environmental burden from application of plant protection products and fertigation was not relevant for the selected impact categories, except for HT (4.8%) (Figure 2). These results are in line with other studies on protected crops that require energy inputs to actively control the greenhouse environment (light, temperature) or for preservation purposes [40]; the overall impact dramatically increases [34] and is almost entirely attributable to energy demand, as in the case of zonal geranium.

3.3. Effect of Alternative Practices on Cyclamen and Zonal Geranium Impact Assessment Results

Sensitivity analysis is a tool for studying the variability of LCIA results to input parameters and data. In the following sections we use it to assess the effects of different scenarios (management choices) on the environmental profile of our functional units. Since the chosen unit was a single potted plant, absolute impact values and variations observed in the analysis were extremely small. For this reason, the relevant differences are expressed in percentage on the impact potential.

Table 3 shows the results for the chosen categories of average production practices and for the alternative scenarios for cyclamen plants, highlighting the achievable impact. The reduction in chemical inputs attained through the application of integrated pest and pathogen management programs for cyclamen plants resulted in an overall reduction of potential impacts, which is relevant in particular for HT (−25%) and AP (−16.3%) categories (IPM in Table 3 vs. actual scenario in Table 2). For HT, this result was due primarily to reduction of soil emissions and manufacturing of active ingredients with fungicide activity, achieved through application of biological control agents and careful fertigation management.

Table 3. Sensitivity analysis for one cyclamen plant subjected to alternative practices. In relation to garden waste compost addition to the growing medium in option 1, NPK content of compost does not replace fertilizers and in option 2 NPK content replaces part of the mineral fertilizers applied through fertigation. IPM = integrated pest management.

Impact Category	Reference Unit	Compost		
	Equivalents	Option 1	Option 2	IPM
Acidification potential (AP)	kg SO_2	0.00035	0.00034	0.00030
Global warming potential (GWP)	kg CO_2	0.06980	0.06910	0.07260
Eutrophication potential (EP)	kg $PO_4{}^{3-}$	0.00027	0.00022	0.00027
Fresh water aquatic ecotoxicity (FWAE)	kg 1,4-DB [z]	0.01810	0.01780	0.01850
Human toxicity (HT)	kg 1,4-DB	0.04180	0.04100	0.03290
Terrestrial ecotoxicity (TE)	kg 1,4-DB	0.00063	0.00063	0.00064

[z] 1,4-dichlorobenzene (DB).

Use of compost as growing media component without changes in fertilizer application rate (option 1) showed relatively small further reduction potential compared to the option in which fertilization was also considered (option 2), linked mostly to reduced peat extraction and transport. Another study in which the environmental aspects of compost substitution was assessed [46] reported lower impact values for different categories, including climate change (another expression used for GWP), acidification potential, eutrophication potential and photochemical ozone formation. In this study, leaching tests for soil application suggested a potential higher impact of composts when considering potential impacts on human toxicity via water and soil, because of high release rates of heavy metals. These considerations partly support our results, since application of compost, that substitutes a 20% volume of peat in the growth medium, results in a slight reduction of several indicators, including GWP, that was reduced by only 7.4% and 6.4% in options 2 and 1, respectively. However, the reduction achieved by this practice had a limited relevance on the overall impact of the functional units. This can be explained by the small amount of peat replaced, the relative importance of growing media components in the assessed categories, and finally because of the impacts related to the compost production process. When considering also nutrient release from the compost amendment and subsequent reduction of fertigation needs, a significant reduction for the EP category (−19.6%) was observed, which can be explained both by reduction of fertilizer production and decreased leaching. We highlight that the minimum value of EP observed for cyclamen was very similar to that obtained for this scenario. This result is justified by data on cultivation with closed-loop fertigation systems with nutrient solution recirculation. To maximize impact reduction from nutrient production and leaching to surface and groundwater, a combination of fertigation management and use of nutrient-rich amendments in the growth medium could be a useful indication for best management practices.

Table 4 shows the impact of average production practices and the alternative scenarios for zonal geranium plants. We highlight how the potential for impact reduction was strongly limited by the major burdens linked to heating in all impact categories. Application of IPM programs achieved a moderate reduction of results for HT (−2.4%) category. Use of compost, not considering nutrient supply, achieved a reduction exceeding 1% of impact results for only FWAE (1.08%), TE (1.11%) and HT (1.63%) categories.

Table 4. Sensitivity analysis for one zonal geranium plant subjected to alternative practices. In relation to garden waste compost addition to the growing medium in option 1, NPK content of compost does not replace fertilizers and in option 2 NPK content replaces part of the mineral fertilizers applied through fertigation.

Impact Category	Reference Unit	Compost		
	Equivalents	Option 1	Option 2	IPM
Acidification potential (AP)	kg SO_2	0.00035	0.00034	0.00030
Global warming potential (GWP)	kg CO_2	0.77110	0.77090	0.77190
Eutrophication potential (EP)	kg PO_4^{3-}	0.00042	0.00036	0.00042
Fresh water aquatic ecotoxicity (FWAE)	kg 1,4-DB [z]	0.03450	0.03410	0.03510
Human toxicity (HT)	kg 1,4-DB	0.09990	0.09930	0.09910
Terrestrial ecotoxicity (TE)	kg 1,4-DB	0.00142	0.00139	0.00142

[z] 1,4-dichlorobenzene (DB).

When considering mineral fertilizing offsets, the differences increased, in particular for EP that shows a 14% reduction in the final result. This value was lower than the observed minimum, highlighting the higher uniformity and technological level adopted for zonal geranium fertigation. In a trial on geranium bedding plants [20], compost from selected materials had a supporting effect on growth of geranium plants, providing an increased nutrient budget in the growing media and an increased uptake and nutrient content in plant tissues. The use of peat-free substrate increases production risk and requires expertise, and often alternative substrates cannot be adopted [36]; however, the addition of compost to growing media for geranium growth may be increased to 40%, providing a large part of its nutrient requirements, as evidenced by Perner et al. [44] in growth trials conducted with potted geranium. The adoption of this practice therefore shows a potential for impact reduction in the EP category, if mineral fertilizer inputs are accordingly reduced. The alternative practice we investigated falls among the priorities in pollution prevention listed as Best Agricultural Practices for protected crops in Mediterranean Climates [47], yet their improvement potential differs greatly depending on the set of impact categories and technological level, material and energy requirements of the investigated production system. For low energy-input crops such as cyclamen, the decrease in fertilizer and pesticide use can result in a significant impact reduction for most of the selected categories. The potential benefit resulting from combined application was 32% for HT, 20% for AP and EP, 12.5% for FWAE and 10% for GWP.

For zonal geranium, we highlight how reduction of energy input is the first priority for soilless heated crops, since best practices for other highly impacting materials (plastic containers and cover) have already been adopted. The reduced amount of fertilizer and plant protection product translates to a relatively irrelevant contribution, except for the EP category.

4. Conclusions

In this study we investigated the environmental impact aspects of the cultivation of cyclamen and zonal geranium starting from data coming from different greenhouse farms located in the Treviso province of Italy. Given the fragmented structure of the production chain for floriculture products in this region, the definition of common practices and their characterization should be linked to a variability measure in order to include the complexity and plurality of structures and management choices in the final results. In the case of cyclamen production, technological level and management choices can greatly affect the values obtained for different environmental indicators, in particular with regard to fertigation management and use of plant protection products. The results of the analysis also highlighted how the efficiency of reduction measures should always be checked with a life cycle study on the production or process to address (e.g., potted ornamental plants).

While “sustainable” choices such as composting and reuse of waste biomass and reduction of chemical treatments have a significant benefit when applied to crops grown in a passive greenhouse, energy saving and changes in fuel type should be the main concern when aiming to reduce the impacts for crops requiring active control of the growth environment, as in the case of zonal geranium.

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