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URBAN COMMUNITY GARDENS AS NATURE-BASED SOLUTIONS FOR WATER RESILIENCE IN CO-PRODUCTION. THE CASE OF BOLOGNA

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Abstract

In the context of increasing water scarcity, Urban Community Gardens (UCGs) are emerging as hotspots of the built environment, where efficient and sustainable water management practices can be tested and implemented. The paper's objective is to describe UCGs as examples of co-production in Nature-Based Solutions (NBS), focusing on the design and development of circular strategies for water reuse. The study explores six experimental case studies located in the metropolitan city of Bologna (Italy), a context where urban horticulture has long served as local welfare and is now evolving to host innovative solutions supporting environmental resilience. In addition, the paper highlights the implementation of social innovation pathways, community building, and citizen engagement. These co-production dynamics were enabled through co-design activities using open innovation approaches, particularly Urban Living Labs (ULLs), which facilitated the development and experimentation of locally adapted, do-it-yourself solutions. The analysis of the results reveals that the implemented solutions had a significant social and economic impact, demonstrating the effectiveness of UCGs as NBS in strengthening communities, contributing to the achievement of the 2030 Agenda SDGs for more sustainable and resilient cities, and validating the positive outcomes of a participatory, co-production-based approach.

Key words: circular water management, co-production, nature-based solutions, urban community gardens, urban living lab

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1. Introduction

The increasingly frequent extreme weather events, hydrogeological instability, and, on the other hand, drought and desertification phenomena are all closely related to climate change affecting the whole globe (Naderi et al., 2024). It is necessary to adapt to these changes, which can no longer be considered calamities, by trying to adopt strategies to obtain benefits for the environment and the community.

The protection and sustainable management of water resources is, of course, one of the priorities of intervention as precious and indispensable resources to meet basic human needs, ensure health, and economic development, promote food and energy security, and protect the integrity of ecosystems

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(UNESCO, 2019).

The effects of these changes are particularly evident in nature and among people in an urban context. Cities can be considered as real microcosms in which more than 66.6% of the world's population lives, the rapid urbanization, along with climate change-related hazards from the increased frequency, intensity, and severity of extreme weather events pose significant challenges to cities worldwide to allow suitable economic development while remaining ecologically viable and socially impartial (Cabral et al., 2017; Su et al., 2024). In an urban context, the research and application of sustainable development practices are essential for allowing adaptation to climate change, to the water crisis, and to protecting water resources. Actions can be taken on several fronts, through wide-ranging strategies, involving not only political decision-makers and the scientific community, but also and especially the citizenry (Qu and Day, 2025).

One way to cope with hydrogeological vulnerability in cities is certainly through the adoption of Nature-Based Solutions (NBS) defined as "*solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions"* (EC, 2015a). The NBS approach to urban development emphasizes the inclusion of diverse stakeholders in planning and decision-making processes (EC, 2015b; Pauleit et al., 2017). According to Basnou et al. (2020) and Buijs et al. (2016), co-production is recognized as an approach to involve citizens not only in the initial planning but also in the subsequent implementation and maintenance phases of NBS. Several cities have implemented co-production in the NBS process (Chan et al., 2018; Frantzeskaki, 2019). This co-creation approach ensures that NBS are tailored to local needs, enhance community ownership, and ultimately lead to greater acceptance and sustainability of the solutions (Van Rompaey et al., 2023).

Shared urban contexts such as Urban Community Gardens (UCGs) represent co-production solutions aimed at growing vegetables, fruit or raising small animals (Huq and Deacon, 2025). Their application in urban areas allows the active involvement of the community. In recent years, urban gardens and UCGs have received much interest from urban citizens and administrators as tools to promote inclusive and sustainable urban development. UCGs are recognised as able to enhance the resilience of social-ecological systems on an urban scale. Usually, a resilient social–ecological system is defined as able to absorb, self-organize, learning, and adapt itself to some disturbances without altering its own functioning (Berkes, 2017), and more in general, it is possible to define resilience as the capacity of a system to absorb and overcome any disturbance (Walker and Salt, 2006). Moreover, Cumming (2011) explains in its theory of spatial resilience that spatial variations both influence and are influenced by the resilience of social-ecological systems. From that perspective, UCGs could play an important role in urban planning and urban development.

There are no standardised definitions of UCG in literature, but generally, the term refers to open spaces which are managed and operated by members of the local community where food or flowers are cultivated (Holland, 2004). In this paper, we adopt this broad definition able to consider almost any type of UCG; however, it is important to highlight that UCG is similar to, but not synonymous with, Urban and Peri-Urban Agriculture (UPA). UPA, according to the Food and Agriculture Organization (FAO) of the United Nations, can be defined as the growing of plants or animals within and around cities, and associated activities (FAO, 2011).

The increased demand for UCGs is related to urban health (i) by facilitating healthy food consumption and strengthening the communities (Alaimo, 2016, Grewal and Grewal, 2012); (ii) by creating a healthy environment (i.e., by more physical activity, and stress reduction) (Hartig et al., 2014); (iii) by supporting climate resilience and ecosystem maintenance (i.e., by improved air and water quality, reduced urban heat island, etc.) (Artmann and Sartison, 2018).

Following this latter interpretation, UCGs can be considered as NBS. The concept of NBS is linked to ecosystem services and green infrastructure, where nature is used to manage social, environmental, and economic issues from a multifunctional perspective (Nesshöver et al., 2017). The scientific literature highlights the contributions of horticulture and co-production to both social and ecological sustainability, providing important ecosystem services (Wolch et al., 2014; Speak et al., 2015). In fact, this type of garden supporting "productivity" and "food security" contribute to provisioning services (Eigenbrod and Gruda, 2015), while covering the role of "environmental restoration" by mitigating climatic conditions and pollution contribute to regulating services (Bowler et al., 2010), and with regards to "environmental education and sociability" as natural place of aggregation contribute to cultural services (Orsini et al., 2013; Turner et al., 2011).

The paper's objective is to describe UCGs as examples of co-production in NBS to experiment with the adoption of sustainable and strategic management of water resources in a circular way. Specifically, six experimental case studies of UCGs developed in the metropolitan city of Bologna (Italy) are presented.

These experimental case studies were designed for the circular water management such as the recovery of rainwater and its subsequent reuse, thus integrating self-constructed tanks and soilless cultivation. Furthermore, the paper shows the implementation of social innovation paths, community creation, and citizen involvement for the circular water management. The methodology adopted for the stakeholder engagement is the Living Labs, which have emerged as a long-term, collaborative approach to addressing complex societal challenges, such as sustainable land and water management and climate change adaptation (Bhatta et al., 2025). In particular, Urban Living Labs (ULLs) can be defined as experimental environments within cities that offer a dynamic platform to test and refine sustainable solutions (Bulkeley et al., 2016). ULLs also represent a crucial element for the development of long-term innovative policies, enabling the exploration of new products, platforms, and solutions with a significant impact on the future of cities (Prisco et al., 2024). According to Innella et al. (2024), ULLs offer an approach to promote the "circular" transition at a local level, providing the methodology for the co-creation of project proposals on circular economy activities to be implemented in an urban area.

According to the systematic review of Nguyen et al. (2024), there are gaps in ULL-UCG linkages; only one case of green space for growing food adopted a Living Lab approach. Adopting an ULLs approach, the paper describes how the involvement of citizens and some students was developed in co-production NBS such as UCGs.

2. Material and methods

In recent years, Bologna has been affected by an increase in the frequency of extreme rainfall events, with flooding episodes alternating with periods of drought, with consequences on the quality and quantity of available water. Urban horticulture and community gardens management have long promoted well-being, and in the current climate-critical context, it also serves as a testing ground for innovative solutions in water resource reuse and citizen engagement.

In the framework of the Interreg Central Europe project NiCE (From Niche to Centre - City Centres as Places of Circular Lifestyles), a mapping of circular water management good practices was carried out in Bologna, resulting in the identification of some inspiring case studies aimed at favoring a sustainability transition to a circular economy of urban areas and communities with special attention to conscious lifestyles (Szabo et al., 2024). Among these, the six case studies (Fig. 1)specifically examined in this paper represent urban NBS closely aligned with the research objective.

2.1. Aqua in circolo pilot project

"Acqua in circolo" is the pilot project for the metropolitan city of Bologna, developed as part of the Interreg Central Europe NiCE project that aims to implement circular water solutions and business models, and consumption on a pilot scale in seven European cities. The goal of the Pilot of the Metropolitan City of Bologna was to increase good practices of reuse and saving of water resources at the urban level, promoting the transition to conscious lifestyles and consumption, from a circular economy view.

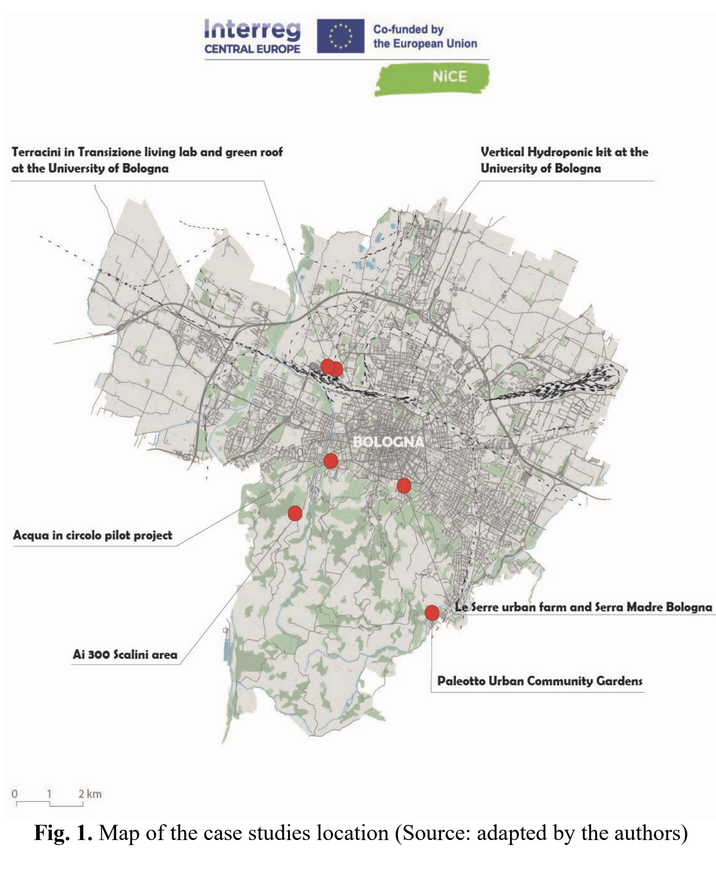

Fig. 1. Map of the case studies location (Source: adapted by the authors)

Through a participatory and citizen science approach, a cycle of three ULLs took place, during which experts from ENEA and Aquaponic Design srl and facilitators involved citizens and local stakeholders in the co-design and self-construction of "do-it-yourself" solutions for the collection and reuse of rainwater to be used in homes and private gardens, but also in urban green areas such as UCGs. The ULLs were divided into a first exploratory phase (understanding and awareness of the project information, exploration of possible applicability scenarios), a co-design phase (choice of operational contexts, evaluation and drafting of ideas and practical solutions to be applied), and a final experimental phase that led to the demonstration of some examples of small water collection systems.

A relevant result achieved in the pilot project is the realization, assembly and use in urban areas of prototypes by stakeholders. Among the proposed solutions, the wicking bed system (Fig. 2) built at the "Orti di Saragozza" gardens, green spaces located near to the city center and dedicated to urban agriculture maintained by citizens. Wicking beds are raised garden beds with a built-in sub-irrigation system that uses capillary action to draw water upward, keeping the soil consistently moist while minimizing waste. The water stored at the bottom of the substrate is supplemented by rainwater collection from a roof placed at the top of the garden, which also provides shade. These gardens not only improve access to fresh produce but also serve as spaces for community gathering, learning, and collective stewardship of public green areas.

2.2. Paleotto urban community gardens

The Paleotto horticultural area has a surface of 11700m^2 and is divided into 134 UCGs. It lends itself to experiments in the dissemination of agriculture in its historical context between nature and culture, proposing sustainable living models for the self-production of food and as a social practice capable of fostering aggregation and integration, education, and improvement of situations of hardship and exclusion. The Area Ortiva Paleotto Association, active since 1997, and supported by the Municipality of Bologna, has given rise to wellness and health initiatives, combined with organic farming practices, artistic decorum, and seeking innovative architectural solutions.

Among the activities promoting sustainability within the Paleotto UCGs, the renovation of a previously unsafe mowing collection tank and the construction of a second tank for the production of compost from the mowing were carried out, precisely to practice the circular economy and make waste become resources, through a participatory process in collaboration with the municipality of Bologna. In fact, enhancing participation allows the achievement of more sustainable results in the direction of waste management, environmental preservation, and sustainability (Rizzo et al., 2017).

Fig. 2. Wicking bed system at "Orti di Saragozza" gardens. Source: picture taken by the authors

At the same time, to optimize and exploit the water resource, since 2022 the collection of rainwater from the roofs of the tool sheds was perfected by setting up a network of rainwater collection downspouts, with the installation of 24 rainwater collection tanks, each with dimensions DIAM.70cm and H 97cm for a volume of about 510L each, and a total water storage capacity of 510Lx24, or 12240L. Since 2022, within the Paleotto UCGs, awareness campaigns have been promoted for the use of rainwater collected in the cisterns and for their correct maintenance, for example through the installation of mosquito nets to avoid the proliferation of larvae in the water of the containers, along with campaigns to teach users how to self-read their water meters, especially during the summer, in order to self-assess excessive consumption from the water network.

Synergistic agricultural practices are already in place in the horticultural area, with mulching, drip irrigation, organic production, the promotion of different crops, and interaction between the different knowledge of horticulturists.

Mulching techniques derived from self-produced compost are promoted to create an environment favorable to the proliferation of beneficial soil microorganisms. The intention is to use biodegradable material such as straw, cellulose, sawdust, pruning waste, or other plant elements to obtain greater protection of the soil from frost in winter and excessive solar radiation in summer, maintain constant humidity, create an environment favorable to the proliferation of beneficial soil microorganisms, a modified number of weeds and a lower spread of pathogens.

2.3. Ai 300 Scalini area

In 2014, the association for social promotion “Teatro dei Mignoli” regenerated and settled in an abandoned portion of San Pellegrino Park, in the peri-urban area of the Porto-Saragozza district in Bologna, launching a culture-based regeneration project titled “Ai 300 Scalini”. Currently, the space hosts a community vegetable garden, a restored greenhouse, beehives, and a food court that is a fixed wooden kiosk with a very low environmental impact.

The area dedicated to the vegetable garden covers about 200m² and is co-managed by the members of the association, who plan the harvesting process and the working hours. The shared principle is to follow natural cultivation practices, without using chemical additives or GMO seeds. The installed irrigation system consists of a drip irrigation system fed by the public water provider for an average daily consumption of about $1m^3$, approximately from March to November. In fact, during the winter period, the area is closed to the public, and the vegetable garden is not exploited due to the lack of adequate fencing to avoid local fauna access.

Since May 25th 2024, the water supply source for the vegetable garden has changed, thanks to the installation of a rainwater collection tank near the kiosk of the food court. The stormwater collection system (Fig. 3*)* consists of gutters surrounding the entire perimeter of the structure (useful rainwater collection surface of $15m^2$), a first filter to block coarse materials such as leaves, branches, fruits etc., and a final mechanical filter in which the water flows through expanded clay, allowing pollutants removal. The water finally reaches a collection tank with a capacity of $1m^3$, connected to the drip irrigation system installed in the vegetable garden through a piping system.

2.4. Terracini in Transizione living lab and green roof at the University of Bologna

“Terracini in Transizione” represents a relevant case of co-design and participatory implementation of a Nature-Based Solution through the ULLs methodology. Developed around ten years ago at the University of Bologna’s new Engineering and Architecture campus, the initiative fostered collaboration among students, faculty, and staff in rethinking the institutional site as a living laboratory for sustainability. This process enabled new opportunities and useful initiatives for research, teaching, and sustainable management of university buildings, with an inclusive and “bottom-up” approach. The promoted activities included seminars, conferences, workshops, and film clubs, aiming at spreading awareness on ecological transition and resilient urban environments. One of the most relevant initiatives was the involvement of students in educational workshops during some teaching courses (Rizzo et al., 2015) dedicated to energy and water savings, urban and electronic waste management, single-use plastic ban from the cafeteria, mains drinking water use, low ecological footprint construction materials, and alternative private and public mobility.

Among the various interventions, the installation of a green roof on the DICAM department laboratories stands out as a multifunctional NBS, combining environmental, educational, and social benefits (Vourdoubas, 2024). Equipped with specific instruments for collecting weather and climate data and for environmental monitoring, the green roof was implemented to improve the thermal performance of the roof and for better integration of the plant cover with the surrounding semi-natural environment and, above all, for scientific purposes to be able to investigate the effects of green infrastructures on the flow of rainwater.

Basically, a green roof acts like a sponge capable of absorbing large amounts of water related to concentrated rainfall events. In comparison with a traditional waterproof roof, which instantly releases the entire flow of rain, a green roof guarantees a slow release over time, also during many hours, avoiding rapid runoff phenomena and the risk of flooding (Basu et al., 2022).

Fig. 3. Rainwater collection system installed at “Ai 300 Scalini”, Bologna.
Source: Pictures taken by the authors

In urban contexts where ground-level space is scarce or unavailable, integrating water storage systems with green roofs provides a valid solution to implement space-optimized urban horticulture. Proper soil depth, irrigation systems, and plant selection contribute to unexploited space transformation into productive green areas and community empowerment in dense city environments.

2.5. Vertical hydroponic kit at the University of Bologna

The collaboration between the Terracini in Transizione group and the Interreg Central Europe project NiCE led to the installation of a vertical hydroponic vegetable garden at the School of Engineering and Architecture of the University of Bologna - via Terracini.

The vertical hydroponic kit (Fig. 4) is 120cm tall and consists of 25 compartments to host the plants, a 40L pot equipped with wheels and a floating measurement system, an irrigation system complete with a pump, the water-soluble nutrients, and a digital probe to measure pH and EC. The installed system works according to the principles of hydroponic cultivation, whereby plant roots are directly immersed in the nutrient solution of water and substances, namely salts, minerals, and other elements (Niu and Masabni, 2022). Soil is only used as a small anchoring substrate for the roots of the plants.

Fig. 4. Vertical hydroponic vegetable garden at the Faculty of Engineering and Architecture, Bologna. Source: Pictures taken by the authors

Given the vertical layout of the installed solution, it was preferred to plant green leafy salads, aromatic herbs, and ornamental plants, which can survive easily indoors and in settings where exposure to solar radiation is not always guaranteed. Weekly monitoring activity collects Ph, electroconductivity (μS/cm,) and temperature (°C) values of the water-nutrient solution, in addition to room temperature, resources replenishment, and leaves appearance.

2.6. Le Serre urban farm and Serra Madre Bologna

With the growing demand for fresh, locally sourced food and the urgent need to reduce the environmental impact associated with traditional agriculture, aquaponics systems represent a promising innovation. The urban agriculture initiative developed at "Le Serre – Kilowatt" combines sustainable innovation with social engagement, offering a model that promotes local food production while strengthening community bonds. At the heart of the project is an aquaponics system that integrates the cultivation of vegetables and strawberries with the raising of ornamental fish, such as carp and goldfish, within a closed-loop, self-sustaining ecosystem (Settanni et al., 2020).

The system located within the "Le Serre – Kilowatt" area comprises both indoor and outdoor installations. The outdoor structure is composed of a vertical system for growing plants, a large tank for fish, and an advanced biofiltration and water recirculation system. Specifically, the vertical growing system is capable of producing up to 400kg of vegetables per year, which are primarily used by the on-site vegetarian and vegan restaurant, contributing to a short and sustainable food supply chain. This method is particularly advantageous because it allows for significant soil saving, allowing for the cultivation of up to 275 plants in just 4m^2, thanks to the use of patented vertical towers (Deep Water Tower). The tank, with a capacity of 10000L, is home to ornamental fish and automatically collects about 6,7m^3 of rainwater per year, taking advantage of the average annual rainfall in Bologna (670mm/year). The biofiltration and water recirculation system is also fundamental for the sustainability of the project. It consists of a 1m^3 underground tank that acts as a primary biofilter and 500 bio carriers that transform fish waste into nutrients useful for plants. The system is equipped with advanced sensors that monitor pH, nitrate, and ammonia in real time, guaranteeing water quality through a mobile application.

The indoor system is developed inside the so called "Serra Madre" building. "Serra Madre" is a cultural production center that combines art, science, and environmental sustainability. Through an interdisciplinary approach, the project aims to raise awareness in the local community about the need to adopt sustainable practices in urban food production and to reach building carbon neutrality through the implementation of aquaponics and hydroponics systems. An urban greenhouse of about 660m^2 has been built inside, hosting a tank for the cultivation of Spirulina with a capacity of 40000L. The water used comes from the automatic collection of precipitation (rainwater and snow), allowing for an estimated collection of approximately 442000L of water per year.

3. Results and discussion

The development of sustainable UPA is among the priority goals of the 2030 Agenda for Sustainable Development, drafted by the UN in 2015, and is to be achieved by 2030 (UN, 2015). The creation of UCGs could be viewed as a segment of UPA, to encourage and form widespread creativity practices with the aim of strengthening and creating solid forms of citizenship.

In each of the six case studies illustrated, benefits are considerable, and the social ones have a high relevance, with the projects serving a strong educational purpose by promoting circular design and integrating principles of sustainable farming, collaboration, and collective intelligence.

3.1. Results for Acqua in circolo pilot project

The implemented solutions enabled the collection and reuse of rainwater in micro-cultivation plants, saving drinkable water from the grid. Specifically, the wicking bed installed at “Orti di Saragozza” garden collected approximately 160L of rainwater over a three-month period of monitoring, which is the same amount of drinking water that would have been used in a traditional vegetable garden for cultivation during the same period. Considering that this cultivation system is estimated to reduce water requirements by 40% for the same surface area compared to a traditional garden, the estimated consumption of the wicking bed drops to less than 100L.

3.2. Results for Paleotto Urban Community Gardens

Before the installation of rainwater collection tanks in 2022, the water supply system of Paleotto UCGs was based exclusively on the use of water from the municipal water supply network, through a tap installed in each garden. Currently, the use of water from the municipal water supply network is supplemented by rainwater collection. The water consumption data from the municipal water network are recorded directly on-site through a meter installed in each garden. The available data refers to six years from 2019 to 2024 and demonstrate an average annual reduction of 500m^3 of water from the grid starting from 2022, referring to the previous period 2019-2020, as shown in Fig. 5, which equates to an economic saves of 835€/year considering the fixed price of 1,67€/m^3 for public water supply in Emilia-Romagna. The year 2021 was not taken into account due to excessive consumption caused by a leak in the water network.

3.3. Results for Ai 300 Scalini area

Preliminary analysis of consumption data from the “Ai 300 Scalini” area, collected after the installation of the rainwater harvesting system, indicates potential economic benefits, as evidenced by reductions observed in water bills. In 2023, the yearly water consumption was 290m^3, approximately equivalent to 500€, only considering the fixed price of 1,67€/m^3 for public water supply in Emilia-Romagna. As a matter of fact, from the data collected from January 2024 to January 2025, the annual water consumption decreased to 263m^3, providing, given the same price per unit, a 45€ reduction of the total costs.

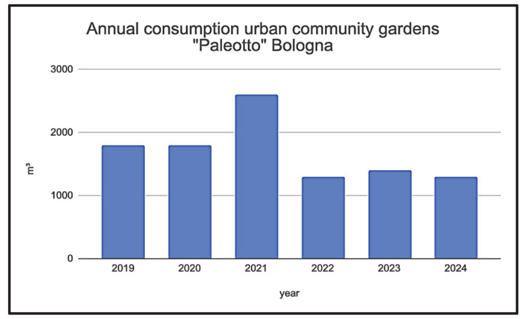

Fig. 5. Annual consumption of the Paleotto Urban Community Gardens, Bologna (Source: created by the authors)

3.4. Results for Terracini in Transizione living lab and green roof at the University of Bologna

The pilot green roof of the University of Bologna was planted with Sedum over an experimental area of approximately 50m². The latter was monitored and compared with another impermeable portion of the roof covered with a conventional bituminous membrane during a rainfall event in August. The results provided by Bonoli et al. (2013) are reported in Fig. 6 and clearly highlight the effect of the green roof in reducing the peak intensity of the natural event and regulating the runoff discharge towards the drainage infrastructure. Runoff recovery and reuse is undoubtedly a practical and effective approach to reduce the reliance on mains drinking water.

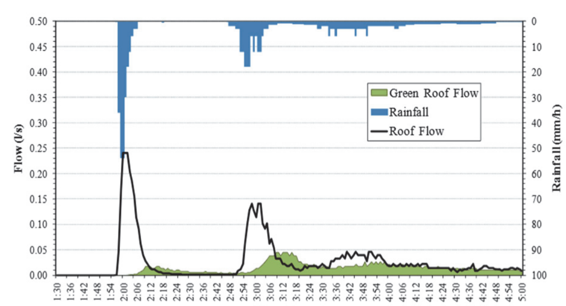

Fig. 6. Monitoring results for the rainfall event collected on 20/08/2013. Source: (Bonoli et al., 2013)

3.5. Results for Vertical Hydroponic kit at the University of Bologna

A preliminary analysis of the data collected from the hydroponic installation at the University of Bologna suggests that pH (8,3 average value) and electroconductivity (1800μS/cm average value) are influenced by the non-direct solar radiation and the absence of acidifying substances, yet fully compliant with the national regulation (Decree 31, 2001). The weekly water demand for irrigation is around 5L of water and 20mL of nutrients, mainly due to slightly high air temperature (22°C average value), which increases the evapotranspiration of the plants (Katul et al., 2012).

Generally, considering the national relevance of protected crops areas and family vegetable gardens, requiring 4.7% of the total irrigation volumes used (ISTAT, 2014), and evaluating the whole water demand for kit activation (30L) and weekly replenishment of 5L, the water consumption associated to the vertical hydroponic solution installed in Bologna is significantly lower than the average consumption required for traditional soil cultivation, which, based on the crop type, varies between 18,2L/m^2 per week and 81,9L/m^2 per week (Sanyé-Mengual et al., 2015).

3.6. Results for Le Serre urban farm and Serra Madre Bologna

During the six-month trial period, the outdoor aquaponic system showed remarkable productivity and resilience. In particular, considering that the system produces about 400kg of vegetables per year, it has been estimated that compared to traditional cultivation methods, this system allows a saving of about 80-90% of water, which translates into about 16000L saved per year.

Moreover, the amount of water recovered in “Serra Madre” is adequate to fully satisfy the irrigation demands of a conventional 500m² soil-based vegetable garden, thereby demonstrating the system's significant contribution to water conservation. In fact, by using collected rainwater, “Serra Madre” saves about 442000L of drinking water per year, significantly reducing the withdrawal from local water resources. This water is then used for growing Spirulina, which in turn is used to produce a natural fertilizer for both hydroponic and aquaponic systems, as well as for traditional vegetable gardening. This virtuous cycle allows for a further reduction in the use of chemical fertilizers, significantly decreasing the overall environmental impact.

3.7. Social impact

Managing and maintaining vegetable gardens plays a vital role in community engagement. The awareness of belonging to one neighborhood, of being a community in UCG, as in the case of the Paleotto Park in Bologna (Italy), and the aspiration to live it as active participants, restores to citizens the material and symbolic meaning of being a community.

As seen in the “Ai 300 Scalini” case study, variations in participation and the time required to make the soil suitable for cultivation present ongoing difficulties in ensuring consistent use. However, interest in water reuse solutions stems not only from a desire to reduce reliance on drinking water for irrigation, but also from the need to lower water consumption costs. As evidence, the case study of Paleotto proves economic gains and substantially reduced water consumption thanks to the installation of storage systems.

As a matter of fact, the growing impact of urbanization favors gray areas at the expense of green spaces (Garcia-Nieto et al., 2018), thus reducing the possibilities for citizens to cultivate vegetable gardens and produce their food. Exploiting roofs, as in the case study of the green roof created under the project Terracini in Transizione, can contribute to transforming the urban landscape and provide citizens with fertile and available soil, while fostering self-sufficiency (Lucertini and Di Giustino, 2021). Furthermore, promoting vertical and aquaponics cultivation also offers urban dwellers such opportunities, while reducing waste and overconsumption of water resources (Van Gerrewey et al., 2022).

Hydroponic solutions such as the one proposed for the case study at DICAM and at “Le Serre” area, ensure flexible and adaptable layout, and the possibility to integrate solar panels for renewable energy supply, transforms the whole system into self-sustained and less impactant installation.. Additionally, hydroponic farming saves up to 90% of water (Dhandapani et al., 2025), while still ensuring a harvest even in small spaces. Several plants can be grown exploiting such techniques, i.e., salads, herbs, strawberries, and tomatoes, depending on the species to grow, different structure configurations are developed in order to handle even large root systems and long growing cycles.

The integration of the rainwater collection system eases the impact of the vegetable garden on water supply, leading to economic savings and environmental benefits while fostering social engagement, as clearly visible for “Serra Madre” installations and for the wicking bed installed as part of the “Acqua in circolo” pilot project. In that sense, to be able to assess and evaluate the real impacts of these systems in UCGs becomes a relevant issue. In fact, many such experiences, if not well managed and projected, could produce negative effects in terms of resource uses and urban regeneration (Ferris et al., 2001).

The activities carried out within the ULLs of the NiCE project have also allowed the active involvement of citizens in the design, co-creation, and live-testing phase to address the challenge of water recovery and reuse to facilitate local sustainability transitions. In fact, the whole “Le Serre” project recorded more than 100 people participating in workshops, educational activities, and guided tours. Of those, about 80% went on to develop their own home-based cultivation systems, demonstrating a strong educational and inspirational impact. Indeed, the devices selected and co-developed from case studies can be integrated into urban, community, and small home gardens and be used by stakeholders, allowing a real contribution to a more sustainable management of water resources. Such aspect is confirmed by the results of the questionnaire shared after the installation of the vertical hydroponic kit at the University of Bologna to ensure public engagement and to collect feedback from the students. Questions included whether they liked or disliked the structure, and 94,4% of respondents confirmed their appreciation of the kit. Another important finding was the willingness of 100% of respondents to install that same, or similar, solution within their own houses.

Although in recent years, there has been much talk of ULL (Bulkeley et al., 2016), in the literature, there are not many experiences that show a connection between ULL and UCG. However, existing experiences tell us that co-production activities are able to foster productive long-term relations between communities and other involved partners.

Co-design methods are generative in this environment, supporting action on the ground and developing situated responses to local needs (Belfield and Petrescu, 2024). Participation in the laboratories was also an important moment of community education by experts, enabling citizens to acquire skills and raise awareness on the sensitive issue of water saving.

Finally, ULLs proved to be a moment of cultural integration and exchange of views, demonstrating how teamwork can lead to better results than individual ones.

4. Conclusions

The paper stems from the realization that the current climate and environmental crisis have us all participating in preparing actions to mitigate, combat, and adapt. UCGs show their ability to create co-production in NBS and resilient communities capable of coping with the current climate change, to achieve healthy nutrition through zero-mile food with the system of self-production, to experiment with innovative cultivation techniques in close contact with nature, to establish balance and cooperation between soil, plants, microfauna present in and surrounding the fields, and human beings who operate on the cultivated soil.

The case studies proposed demonstrate that a bottom-up approach with the right technique can increase the resilience of the place and reduce the impact of human activities. However, governments, urbanists, and practitioners should include these practices and spaces in their plans and projects to improve the resilience of cities and citizens. Local initiatives must be connected with urban planning so that resilient and good practices can be implemented strategically in the city's vision. Finally, the involvement of citizens in projects for the co-design of solutions for water reuse in urban contexts through ULLs has enabled the transfer of scientific knowledge and expertise that can be exploited to undertake projects for more resilient cities.

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