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# IMPROVING WATER USE EFFICIENCY OF VEGETABLE AS PART OF INTEGRATED SUSTAINABLE AGRICULTURE MANAGEMENT FOR SMALLHOLDERS AND LANDLESS IN THE TROPICS.

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## Summary

Water is an essential natural resource for agricultural production and food security of the world population. In the coming decades, a growing number of regions will face increasing water scarcity. Considering that about 70% of global freshwater withdrawals are currently used in agriculture, accurate management of agricultural water resources to increase crop water use efficiency (WUE) is one of the main targets in research on plant-soil-water relations. Different strategies are available to predict soil water availability for plants and maximize crop WUE. However, innovative irrigation technologies need to be adapted to local environmental conditions and available technical solutions, particularly in simplified growing systems generally found in developing countries.

Other aspects to consider are the constant increase in the world population, which is expected to reach more than 9 billion people by 2050, and the fact that the urban population has currently outnumbered the population living in rural areas. As a consequence, the demand for food is expected to surge by more than 50%. Regarding the population inhabiting urban centers, it is larger than the rural one. On May 23, 2007, the urban population got 3.303.992.253 people and overtook the rural community that amounted to 3.303.866.404. Moreover, according to most current data, 55% of people live in an urban setting, and it is expected that within the next 25 years, the world population should have a dramatic increase of about 4 billion in the number of people in cities, mainly in the towns located in Asia.

Furthermore, the pandemic's current situation due to COVID19 affects global agro-food systems, damaging agricultural value chains at the regional level, generating risks to ensure food and nutritional security for many families. In many parts of the world, the pandemic has highlighted the fragility of the food supply system. In many countries, e.g., Latin America, the monoculture has colonized the agricultural production system. It has contributed to eradicating the culture of crop diversification and family production, making a large part of the population dependent on the national and international markets to purchase even staple food. Therefore, the role of "proximity agriculture" with the promotion of sustainable management of home gardening in remote rural areas and individual or communities’ urban gardens for vegetable production will be central in the short term to improve vulnerable families' resilience living in rural and urban areas ensuring adequate access to fresh food.

The three aspects mentioned above (climate change and water scarcity; population increase, and constant increase of people living in urban areas; and people food insecurity also due to covid19 emergency) require that more resilient food systems are implemented, natural resource use efficiency are increased, and local food production and supply are reinforced. Nevertheless, it must be done responsibly to ensure the proper crop and local production management and guarantee natural resources' sustainability starting from accurate soil and water resources management. The latter will be the principal thematic in-depth studied in this dissertation.

This doctoral thesis aims at identifying simplified irrigation strategies for vegetable production addressed to small-scale farmers practicing local agriculture in urban and rural areas of several countries worldwide (focusing mainly on tropical regions).

The following main specific objectives have been pursued:

**Objective 1:** Assess the awareness on natural resources management in the urban vegetable gardens with particular reference to irrigation water management and WUE.

**Objective 2:** Identify the appropriate substrate and nutrient solution strategies for vegetable transplant production in Tropical areas.

**Objective 3:** Identify the appropriate water management strategies for vegetable production in semi-arid climate characterized by severe water scarcity.

**Objective 4:** Assess the viability of simplified soilless culture (SSC) system for lettuce production compared to traditional soil cultivation techniques in tropical environments, considering yield, water use efficiency, and the overall physiological plant response.

In addition, it is intended to evaluate, on the one hand, the response of hybrid and open-pollinated varieties grown under water stress conditions taking into account that hybrid varieties are not always readily available in vulnerable contexts. On the other hand, introducing simplified soilless culture (SSC) systems aim at grown ornamental plants could increase the family's income of growers working in urban areas of big cities. In this regard, two specific objectives were added:

**Objective 5:** Assess drought stress affects yield, water use efficiency and quality parameters in hybrid and open-pollinated lines of tomato *(Solanum lycopersicum L.)* under different levels of irrigation water deficit.

**Objective 6:** Assess simplified soilless systems to improve ornamental plants' cultivation, targeting the identification of appropriate cropping systems to optimal commercial production and maximization of the WUE.

Different experiments have been carried out in tropical and Mediterranean areas to achieve the mentioned objectives. In all cases, the studies have been based on experimental fieldwork.

The first objective was achieved by studying the awareness on management of natural resources by small farmers involved in urban production activities. The case study describes the results obtained from a survey carried out among farmers involved in the communities' urban gardens of Teresina City. Teresina, capital of Piauì State of Brazil, accounted for an estimated population in 2019 of about 860'000 inhabitants and suffered a considerable impact on the flow of immigration in the state, influencing the process of establishment of slums and determining the increase of request for education, housing, health, and income generation activities. In this context, the Community Urban Gardens (CUG) establishment was promoted in urban peri-urban areas of Teresina by the Municipality to generate work and income and improve families' livelihood in urban and peri-urban areas. Teresina currently counts 43 community gardens located in the urban and peri-urban and some also in rural areas, totalizing 115,4 hectares and employing 2454 people. This work utilized the results of a survey conducted during summer 2019 in five community gardens (UC Garden) located in Teresina City; four are located in urban areas and one in the rural area. Ninety-two questionnaires have been applied, representing 40% of the total number of gardeners working in the community gardens covered by the survey. The main results showed that despite in some urban gardens the production could be considered satisfactory (reaching, for example, 2.7 ± 0,22 kg $m^2$ of lettuce), the water use efficiency (WUE) was very low (average of 6.9 ±0.4 g FW $L^{-1}$ $H_2O$). The survey pointed out that innovative diagnostic tools to reduce water consumption and tailored training for the growers on more efficient use of natural resources are needed to contribute to a better and more sustainable production.

The second research is about vegetable nursery management and aimed to evaluate the effects of different substrates and different nutrient solution concentrations on the Lettuce and Chinese cabbage transplant production in a tropical area. It was deemed necessary to develop this research because, based on personal experience in the field, it is clear that the achievement of satisfactory vegetable yield depends on the starting point: high-quality seedlings. Two experiments were conducted at the Soil and Water Research Station at Yezin Agriculture University, Myanmar. In one experiment has been tested the adaptability of lettuce seedling on two substrates. One was made of 50% mature cattle manure, and 50% carbonized rice husk, and the second one was composed of 70% local soil, 20% burned rice husk, and 10% fresh cattle manure. Two different concentrations of nutrient solutions' salinity were also tested. Lettuce seedlings have been used for the experiment. In the second experiment, two species (Lettuce and Chinese Cabbage) were growing and tested separately. For both crops, a total of 4 different concentrations of mineral fertilizer (15-15-15) were adopted, and the quantitative and qualitative results obtained were compared. In this experiment, the substrate adopted was composed of 50% mature cattle manure and 50% carbonized rice husk, which had better performance in the first experiment.  The results of this research showed that the adoption of different substrates and the application of different nutrient solutions significantly affected both quantitative parameters (fresh weight and leaf morphology) and physiological parameters (stomatal conductance, leaf temperature, SPAD values) of Lettuce and Chinese Cabbage seedling grown in Central Dry Zone, Myanmar.  The experiments pointed out that identifying proper growing media and nutrient solution concentration is crucial to get good quality lettuce and Chinese cabbage seedling.

Objectives three and four were achieved by identifying appropriate irrigation strategies to maximize the efficiency of water use of leafy vegetables grown in tropical areas.  The irrigation strategies applied in the experiments included soil-based cultivation systems equipped with the drip irrigation system (Chapter 4-5 and simplified soilless systems for vegetable and ornamental plant production (Chapter 5). Besides, irrigation strategies were combined with other factors: different $ET_o$ estimation equations and the adoption of organic soil mulching.

The fourth research aims at identifying sustainable irrigation water management strategies for the lettuce crop in a semi-arid climate. Three independent experiments were carried out on a commercial variety of lettuce (*Lactuca sativa* L.) during the dry season in Central Dry Zone, Myanmar. Different irrigation levels based on crop evapotranspiration ($ET_c$) were applied. ETo has been estimated through both Hargreaves-Samani and Penman-Monteith equations. In the first experiment, one treatment was also guided by soil moisture sensors. A factorial combination was used in the second and third experiments, combining the different irrigation levels with two soil mulching treatments, namely soil without mulch and soil mulched with dried rice straw residues. The research showed that different irrigation levels (restoring 25%, 50%, 75%,100%, and 125% of $Et_o$) significantly affected plant growth, yield, and physiology. Both the adoption of sensors for guiding irrigation and the application of mulching with straw promoted satisfactory yield. As the irrigation water level was reduced, the WUE increased. WUE was also increased by covering the soil with mulch. The experiments pointed out that accurate irrigation water management using drip irrigation system associated with soil mulching increases yield and improves the WUE of lettuce crop in Central Dry Zone, Myanmar.

In the fifth research, four independent experiments were conducted to assess the applicability of Simplified Soilless Culture systems (SSC) in Northeast of Brazil (NE-Brazil) and Central Dry Zone of Myanmar (CDZ-Myanmar). In the first two experiments, the potentiality for lettuce crop production and water use efficiency (WUE) in a SSC system against traditional on-soil cultivation was addressed. Then, the definition of how main crop features (cultivar, nutrient solution concentration, system orientation, and crop position) within the SSC system affects productivity was evidenced. The adoption of SSC improved yield (+35% and +72%, in NE-Brazil and CDZ-Myanmar) and WUE (7.7 and 2.7 times higher, in NE-Brazil and CDZ-Myanmar) as compared to traditional on-soil cultivation. In NE-Brazil, an eastern orientation of the system enabled to achieve higher yield for some selected lettuce cultivars. Furthermore, in both the considered contexts, a lower concentration of the nutrient solution (1.2 vs. 1.8 dS $m^{-1}$) and an upper plant position within the SSC system enabled higher yield and WUE. The experiments validate the applicability of SSC technologies for lettuce cultivation in tropical areas.

The sixth research aims to elucidate drought-tolerant productivity performance in open-pollinated tomato cultivars compared to the commercial hybrid. The work's central hypothesis is to ensure good tomato production despite water-stressed treatments that do not meet 100% of the water plants' needs. The experiments were conducted during the spring-summer seasons of years 2017 and 2018 in open field conditions at Cadriano Farm of Agriculture Science and Technology Department (DISTAL) of Bologna University. Two independent experiments were carried out on eight genotypes of tomato (*Solanum lycopersicum* L): 4 Open Pollinated varieties and 4 Hybrids. Three different irrigation levels based on crop evapotranspiration (ETc) were applied, respectively restoring 25%, 50 %, and 100% of crop $ET_c$. $ET_o$ has been estimated using the Hargreaves-Samani equation (HS). The study pointed out that water was not a limiting factor in determining yield in most studied cultivars and that accurate irrigation management associated with selected tomato varieties increases yield and improves the WUE of tomato production. This research showed that the irrigation management returning 50% of $ET_c$ combined with the hybrid variety named Kirill and the black Cherry, open-pollinated variety, resulted in efficient water use and satisfactory yields.

The last experiment focuses on the adaptability of different simplified soilless systems for the production of ornamental plants. It was considered necessary to develop this research as ornamental plants could play an important role in urban agriculture. The introduction of ornamental plants into production activities could raise income and increase biodiversity within the gardens. The study evaluates simplified hydroponics' feasibility for the growth of rooted cuttings of geranium (*Pelargonium zonale*) for commercial purposes. Three systems were tested and compared: 1) traditional open-cycle farm system where plants grow in plastic pots filled with peat and irrigation is made manually by watering can; 2) an open-cycle drip system similar to the previous one, but irrigation is carried out by drip irrigation system; and 3) a Nutrient Film Technique system (closed – cycle). The results showed that the soilless systems typology significantly affected plants' growth, commercial features, and WUE. Adopting the open-cycle drip system resulted in a significant improvement of all the commercial crop characteristics compared with other treatments, making plants more attractive for the market.

The dissertation contributes to identified simplified irrigation strategies for vegetable growers and useful tools that small-scale farmers could adopt to enhance water resource management both at urban and rural levels.

An interdisciplinary approach and appropriate dissemination activities of the strategies and knowledge will be essential to guarantee that improved water management methodology and technology for agriculture will be applied adequately by local institutions and farmers. Besides, simplified soilless systems could become an efficient strategy for contributing to sustainably feeding the world's growing population, especially in challenging areas, such as the North East of Brazil and the Central Dry Zone of Myanmar.

## Preface

The present doctoral thesis was elaborated from November 2017 to October 2020 in compliance with the XXXIII Cycle of the PhD program of Agriculture and Food Sciences of Bologna University; thematic: Agronomy, Herbaceous and Horticultural Systems, Agricultural Genetics, and Chemistry.

The thesis analyzes the use of natural resources for vegetable production. It is based on improving water resources management in vegetable cultivation both in rural and urban environments. Currently, urban agriculture is increasingly widespread and consolidated, and for this reason, users must also apply agricultural technologies to maximize the efficiency of natural resources contributing to environmental sustainability.

Improving water use efficiency in horticulture is a key issue in ensuring its environmental sustainability in rural and urban environments. Moreover, the selection of drought-resistant varieties and crop diversification also play an essential role in obtaining in a sustainable way the production necessary to meet the world's population's growing food requirements.

This dissertation's scenario adopts innovative and rational irrigation strategies to increase water use efficiency on both on-soil and simplified soilless systems in different urban and rural environments, mainly in Tropical contexts.

This dissertation is based on the following five articles published in peer-reviewed indexed journals.

- **Michelon, N.**; Pennisi, G.; Myint, N.O.; Orsini, F.; Gianquinto, G. Optimization of Substrate and Nutrient Solution Strength for Lettuce and Chinese Cabbage Seedling Production in the Semi-Arid Environment of Central Myanmar. *Horticulturae* 2021, 7, 64. https:// doi.org/10.3390/horticulturae7040064
- Orsini, F., Pennisi, G., **Michelon, N.**, Minelli, A., Bazzocchi, G., Sanyé-Mengual, E., Gianquinto, G. (2020). Features and functions of multifunctional urban agriculture in the Global North: a review. *Frontiers in Sustainable Food Systems, 4, 562513. doi:* https://doi.org/10.3389/fsufs.2020.562513.
- **Michelon, N.**; Pennisi, G.; Myint, N.O.; Dall'Olio, G.; Batista, L.P.; Salviano, A.A.C.; Gruda, N.S.; Orsini, F.; Gianquinto, G. Strategies for Improved Yield and Water Use Efficiency of Lettuce (*Lactuca sativa* L.) through Simplified Soilless Cultivation under Semi-Arid Climate. *Agronomy*, 2020, 10, 1379. https://doi.org/10.3390/agronomy10091379
- **Michelon, N.**; Pennisi, G.; Myint, N.O.; Orsini, F.; Gianquinto, G. Strategies for Improved Water Use Efficiency (WUE) of Field-Grown Lettuce (Lactuca sativa L.) under a Semi-Arid Climate. *Agronomy*, 2020, 10, 668. https://doi.org/10.3390/agronomy10050668
- Brentari, L., **Michelon, N**., Gianquinto, G., Orsini, F., Zamboni, F., & Porro, D. (2020). Comparative Study of Three Low-Tech Soilless Systems for the Cultivation of Geranium (Pelargonium zonale): A Commercial Quality Assessment. *Agronomy*, 10(9), 1430. https://doi.org/10.3390/agronomy10091430

Moreover, the following seven posters and oral communication were presented in scientific congress and/or technical/project events as part of the doctoral thesis:

- **N. Michelon**, G. Gianquinto. Simplified Soilless system worldwide case –study. The experience of Rescue-AB of Bologna University. Workshop on "Hydroponics in the development and humanitarian context". October 14-15-22, **2020.**
- **N. Michelon**, G. Pennisi, S. Bona, L. Pacheco Batista, F. Orsini, G. Gianquinto. Teresina Urban community gardens. The producer's perception of natural resources management. FoodE, Food Systems in European Cities. Virtual workshop within SPPS PhD Conference, September 2, **2020**.
- **N. Michelon**, G. Pennisi, Nang Ohn Myint, F. Orsini, G. Gianquinto **(2019)**. Uso de solução nutritiva para a produção de mudas de alface e couve-chinesa em ambiente semiárido da região central do Mianmar.

*Anais de conferência V Jornada Cientifica – Embrapa Meio Norte "AG Tech Meio-Norte Innovaçao para o Agro , 3-5 Set 2019 Teresina -Piauì-Brasil*

- **N. Michelon**, G. Pennisi, Nang Ohn Myint, F. Orsini, G. Gianquinto Water use efficiency in drought stressed lettuce (*Lactuca sativa*) in the central dry zone of Myanmar, **(2019)**. *Atti del XXII Convegno Nazionale di Agrometeorologia Ricerca ed innovazione per la gestione del rischio meteo-climatico in agricoltura*. Napoli, 11-13 Giugno 2019. DOI 10.6092/unibo/amsacta/6175
- **N. Michelon**, G. Pennisi, Nang Ohn Myint, F. Orsini, G. Gianquinto **(2019)**. Water use efficiency in drought-stressed lettuce (*Lactuca sativa*) in the central dry zone of Myanmar. *I Convegno AISSA#UNDER40 San Donà di Piave (VE) 16-17 May 2019".*
- **Michelon**, **N.**, Pennisi, G., Vastola, F., Padula, R., Orsini, F., Gianquinto, G. **(2018)**. Drought stress affects yield, water use efficiency and quality parameters in hybrid and open-pollinated lines of tomato *(Solanum Lycopersicum L.). VII International Conference on Landscape and Urban Horticulture. Istanbul, August 12, 2018.*
- G. Pennisi, F. Magrefi, **N. Michelon**, G. Bazzocchi, E. Sanyé-Mengual, F. Orsini, G. Gianquinto, **(2018)**. Promoting education and training in urban agriculture building on international projects at the Research Centre on Urban Environment for Agriculture and Biodiversity. *VII International Conference on Landscape and Urban Horticulture.* Istanbul, August 12, 2018.

Participation as a co-author in three articles and one book chapter, either published or under review in peer-reviewed indexed journals:

- Sanyé-Mengual, E., Gasperi, D., **Michelon, N.**, Orsini, F., Ponchia, G., & Gianquinto, G. **(2018)**. Eco-Efficiency Assessment and Food Security Potential of Home Gardening: A Case Study in Padua, Italy. *Sustainability, 10(7), 1-25.*Doi: 10.3390/su10072124
- Centrone Stefani, M., Orsini, F., Magrefi, F., Sanyé-Mengual, E., Pennisi, G., **Michelon, N**., Bazzocchi, G., Gianquinto, G. **(2018)**. Toward the Creation of Urban Foodscapes: Case Studies of Successful Urban Agriculture Projects for Income Generation, Food Security, and Social Cohesion. In *Urban Horticulture,* Springer, Cham. 91-106. Doi: 10.1007/978-3-319-67017-1_5.
- E. Appolloni, F. Orsini, **N. Michelon**, A. Pistillo, I. Paucek, G. Pennisi, G. Bazzocchi, G. Gianquinto. From microgarden technologies to vertical farms: innovative growing solutions for multifunctional urban agriculture. In I International Symposium on Botanical Gardens and Landscapes, *Acta Hort.* **2019**, 1298 (pp. 59-70).

Participation as a correlator in several bachelor's and master's degrees' thesis related to PhD topic. The titles of the main thesis were:

- Urban Gardens: Evolution in history and towards self-sufficiency;
- Analysis of the effects of the increase in world population and the reduction of available agricultural land on food security
- Relationship between the Urban garden and sustainable use of natural resources - A case study of Teresina's urban community's gardens;
- The economic and productive potential of urban gardens;
- Introduction to a rational model of urban agriculture: EtaBeta case study
- Current situation and development prospects of shared urban gardens in the municipality of bologna
- Response to water stress in traditional cultivars of lettuce raised in open field and above ground
- Response to water stress in traditional and commercial cultivars of table tomatoes bred in the open field

Furthermore, additional training and knowledge were obtained through collaborations in other studies related to the dissertation's goals, such as the project Garden to Grow (GtG). GtG is an ERASMUS PLUS – Capacity building project financed by the EU (GtG, 2020). GtG project aimed to provide Early Childhood Education and Care (ECEC) teaching with an innovative methodology, tools, and materials to foster inclusive attitudes and key competencies acquisition from a very early childhood development (0-6) through horticulture (GtG, 2020).

The experiment results and technical guidelines to manage small-scale gardens within the schools have been shared through seven transnational meetings, two learning and teaching activities, several communication activities, and educational content provided in an open-source format in the learning platform Explora Education. Around 1800 people have been reached worldwide (Italy, Spain, UK, and Bulgary) during the project through the training physically carried out by me and through the free online platform (Codazzi, 2020). Experiments' results have been shared, and the technologies were also adopted for implementing the educational and practical activities within the mentioned project. To promote knowledge diffusion and replication, technical guidelines on how to build and manage the school – urban gardens have been developed (https://www.exploraedu.it/gardens-to-learn/).

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## Structure of the dissertation

This thesis is composed of three main part and ten chapters, as illustrated in the following figure:

**Part 1 Introduction and methodology**

**Chapter 1** Introduction and objectives

**Part 2 Analysing water use efficiency in vegetable crops**

**Chapter 2:** Teresina Urban community gardens. The producer's perception of natural resources management.

**Chapter 3:** Use of different substrates and nutrient solution concentration for the production of Lettuce and Chinese cabbage seedlings in a semi-arid environment in central Myanmar.

**Chapter 4:** Strategies for Improved Water Use Efficiency (WUE) of Field-Grown Lettuce (*Lactuca sativa* L.) under a Semi-Arid Climate.

**Chapter 5:** Strategies for improved yield and Water Use Efficiency (WUE) of lettuce (*Lactuca sativa*) through simplified soilless cultivation under semi-arid climate.

**Chapter 6:** Drought stress affects yield, water use efficiency and quality parameters in hybrid and open-pollinated lines of tomato *(Solanum lycopersicum L.).*

**Chapter 7:** Comparative Study of Three Low-Tech Soilless Systems for Geranium's Cultivation (*Pelargonium zonale*): A Commercial Quality Assessment.

**Part 3 Conclusions and further research**

**Chapter 8:** General Discussion and Conclusions

**Chapter 9:** Suggestion for further research

## CHAPTER 1 – Introduction and objectives

This section presents the general framework of the thesis, which focuses on different irrigation strategies in order to contribute in improving water use efficiency (WUE) with a particular emphasis on vegetable production in the global north and south of the world, in the urban and rural area, adopting both on the soil-based system and simplified soilless culture system (SSC).

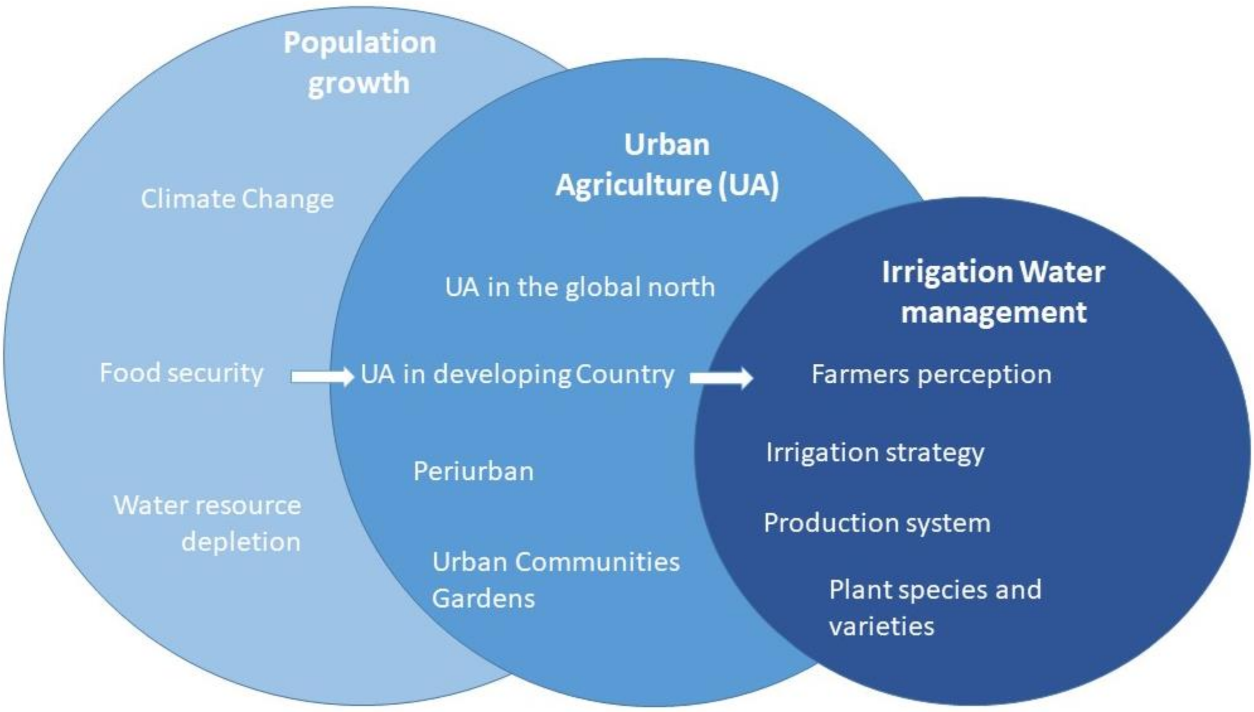


Figure 1-1 General Overview of the framework of the dissertation

### 1.1 Population growth

The population growth (in 2050 we will be about a third more than today) combined with the even more marked increase in consumption, especially in the emerging countries, will mean that in the next thirty years, we should produce 70% more food to keep pace with demand (FAO, 2013). In contrast to the trend, arable land is being reduced by cementing, desertification, erosion, salinization, change of use, and marginal land abandonment. The above evidence is also manifested in the consequent significant increase in food costs (FAO 2014). Therefore, the collaboration between researchers, farmers, politicians, and all the agro-food sector stakeholders will be fundamental to deal with this situation. Therefore, the main challenge will be to produce more but in a more sustainable way. Twenty-six percent of the world's agricultural area is cultivated under irrigation, mainly “cash” crops such as fruit and vegetables that produce 40% of food requirements (Perniola *et al*., 1994). The average production recorded in irrigated areas has reached 80% of the maximum potential yield in recent years (World Bank, 2008). Consequently, little remains for a further increase in production under irrigation. The remaining 74% of the world's agricultural area is cultivated under dry conditions, generally in semi-arid environments; in these contexts, 60% of the necessary raw materials for human and animal feed, such as cereals and fodder crops, are produced (Biradar *et al*., 2009).
Unlike what happens in irrigated areas, the average unit production in semi-arid areas is lower than that potentially obtainable in the same environmental contexts (Passiura and Angus, 2010).
In semi-arid environments, productivity is often limited by water scarcity and other factors that interact and could substantially affect production capacity (Angus and Van Hearwardeen, 2001). The planting period, competition from spontaneous flora, pathogenic attacks, nutritional deficiencies, soil abnormalities, high and

low temperatures could be considered. Applying technologies to maximize yield and high efficiency and sustainable use of resources is very relevant (Perniola *et al*. 1994).

Among these, there are the so-called "Water Saving Technologies" (including also soilless systems) or techniques that allow maximizing the irrigation water use efficiency (Michelon *et al*., 2006, 2020a, 2020b). It is possible to refer to techniques, for example, that aim to accumulate water in the soil, reduce water losses by evaporation, and reduce water surface runoff. Moreover, species/varieties to be cultivated with the increased ability to exploit the water of rainfall and irrigation and implemented methods that allow rational management of water resources based on soil/climate characteristics and physiological/productive needs of crops (Ceccon *et al*., 2017).

Modern irrigation technologies will need to be adapted to local environmental conditions and available technical solutions with particular reference to the adaptation of simplified cultivation practices and systems (Berihun *et al*., 2011). Appropriate water management for irrigation can be beneficial for farmers as it allows both an improvement and a stabilization of physiological yields of crops grown mainly in areas characterized by water scarcity (Dagdelen, 2009).

However, although technological innovation is making significant progress, many farmers still irrigate using methods based on their experience, without any rational criteria that allow them to follow the crop grown's real needs and conditions (Michelon *et al*., 2020b). Often, irrigation water is supplied in excess or at the wrong moment, without responding to the crop's real needs. In the same way, there may be a risk of creating deficits and causing water stress, with negative consequences on the crop's production performance (Michelon *et al*., 2020a, b).

Maximizing the water use efficiency through the rational use of irrigation is one of the fundamental factors contributing to sustainable agriculture (Capra, 2016). Not only because it allows the farmers to obtain high quality and high production, but mostly because it makes possible greater flexibility in the choice of production systems by farmers, relieving them from the scarcity and uncertainty of water supplies resulting from rainfall (Michelon *et al*., 2020b).

In recent years, the modernization of the irrigation systems, both on a consortium and farm scale, has allowed increasing the water use efficiency in agriculture through a better control in the monitoring and quantification of the volumes supplied to the crops determining the reduction of water losses (Nino *et al*. 2015).

However, the rapidly intensifying water request, both for agriculture and civil sectors, in the context of climate change, could intensify the problems of water scarcity and irrigation needs in regions characterized by drought. In contrast, for areas traditionally not affected by water scarcity, a review of management policies adopted so far could be raised. An accurate assessment of water resource requirements for irrigation (and other uses) is a fundamental requirement for more rational water management (Maton *et al.*, 2005).

The requirement for a more conscious and rational use of water resources has also prompted the European Commission to outline guidelines, first through the Water Directive 2000/60/EC, and then in the definition of the Common Agricultural Policies (CAP) towards 2020 (European Commission, 2011), to combine the competitiveness of the agricultural system with more accurate protection of environmental resources. The recent communications on water scarcity and drought (European Commission, 2007), as well as the document "Blueprint" for the protection of European water resources (European Commission, 2012), have led to an extension of the conditionality criteria of aid to encourage water saving in agriculture.

The management of irrigation should be considered in a broader context. In addition to the irrigation system's operational needs, environmental issues with a view to the "sustainability" of irrigation must be considered. In this context, the development of new technologies, together with a better understanding of the physical processes characterizing the irrigation systems, allows the development tools to support the decisions that water resource managers should make. With regard to aspects related to irrigation management, there has also been the development and diffusion of irrigation consulting services at the international level (Martín de Santa Olalla *et al*., 2003) that can offer tools to generate information on the most efficient use of water and communication mechanisms (SMS, MMS, internet, ...) to transmit information quickly and effectively to end-users (managers and farmers).

This development has been further facilitated by the spread of the Internet and the possibility of real-time access to geo-referenced databases (satellite images, agro-meteorological data, statistical data on crop distribution, cadastral maps). Currently, many technologies and tools are available to maximize water use efficiency in agriculture. There are more and less sophisticated technologies to manage the irrigation water properly, and most of them aim at a "precision" activity, and this requires an accurate estimate of the real water needs of the crop and the accurate application of a determined volume of water at the right time (Misra *et al*., 2005). Nowadays, proper irrigation must meet crop needs promptly and as effectively and uniformly as possible. All this involves soil analysis to determine the hydrological parameters (Field capacity, wilting point, etc.) of the cultivated soil; the control of the irrigation distribution, so only the necessary amount of water is applied (high volumetric efficiency); the irrigation system's design so that each plant or area of the field receives the same quantity (high spatial uniformity) (Michelon *et al*., 2020b).

### 1.2 Urban Agriculture (UA)

The concepts discussed in the previous paragraph must be taken into account for rural agriculture activities and the urban ones since the urban agriculture concept is rapidly consolidating both in the global north and global south of the world. Indeed, on May 23, 2007, for the first time in human history, the rate of the population inhabiting urban centers overhauled the rural one: both the North Carolina and Georgia Universities have estimated that in that day, the urban population reached 3.303.992.253 people, while rural population amounted at 3.303.866.4040 (ScienceDaily, 2007; Orsini *et al*., 2013).
The urban population expansion is further evident in developing countries as the result of rural-to-urban migration and natural population growth (FAO 2007; City Farmer 2011; FAO-FCIT 2011). Forecasts indicated that by 2020, 55 % of the world population is living in the urban centers, and the percentage will increase to 60 and 70 % in 2030 and 2050, respectively (Orsini *et al*., 2013), generating an unprecedented requirement for sustainable food production (Martellozzo, 2014). The Food and Agriculture Organization (FAO) assessed that urban agriculture is currently practiced by approximately 800 million people worldwide (Goldstein *et al*., 2016). Representative case studies of urban gardens are found in many cities worldwide, both on the global north and south. Still, it is fundamental to note that the urbanization process's trend and dynamics are not the same the world over – there are significant differences among the continents (Drescher, 2002). The following paragraphs reported an overview of UA case studies in both the north and south of the world.

#### 1.2.1 Urban gardens in the global north

In recent years, urban agriculture (UA) experiences are finding large applications in the developed economies of the so-called Global North with a stronger multifunctional connotation, resulting in multiple combinations of farming purposes and business models (Orsini *et al*., 2020). Orsini et al. identified and classified 470 urban garden activities distributed across different world regions of the so-called Global North, according to their primary business models, farming purposes, and surface covered. The review observed that a large share of UA projects operates on a small surface (<1000 $m^2$). With a size above 10 ha, larger farms represent 50% of Europe's cases and 3-4% in America and Oceania. In Europe, North America, and Oceania, the UA projects are mainly focused on share economy business models in which citizens move from the concept of consumers and become “prosumers” capable of influencing the structure and overall sustainability of their food systems (Orsini *et al*., 2020).
Moreover, many urban garden activities identified in the review also have a social and educational purpose. The review highlights that in recent years, also in northern global areas, urban gardening is considered a strategy to contribute to food security and city environmental sustainability (Taylor and Taylor Lovell, 2014), and they are mainly organized in allotment gardens, extensive peri-urban farms and community gardens. The main case studies related to the three categories of urban gardening mentioned above will be reported in the next paragraphs[1].

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[1] The following information is taken from the review Orsini *et al*., 2020 and are the ones directly taken from my contribution within the review. Reference: Orsini, F., Pennisi, G., Michelon, N., Minelli, A., Bazzocchi, G., Sanyé-Mengual, E., Gianquinto, G. (2020). Features and functions of multifunctional urban agriculture in the Global North: a review. Frontiers in Sustainable Food Systems, 4, 562513. doi: https://doi.org/10.3389/fsufs.2020.562513

**Allotment gardens:** Private and public urban gardens for vegetable production are widespread all over the world and include experiences such as the *"kleingärten"* in Austria, Switzerland, and Germany, the *"Ogròdek dzialkòwy"* in Poland, the *"Rodinnà Zahradka"* in the Czech Republic, the *"kiskertek"* in Hungary, the *"volkstuin"* in Holland and Belgium, the *'jardins ouvriers'* or *'jardins familiaux'* in France and Belgium, the *'kolonihave'* in Denmark, the *'kolonihage'* in Norway, the *'kolonitraetgard'* in Sweden, the *'siirtolapuutarhat*' in Finland, the *'shimin-noen'* in Japan, the *'community gardens'* and the *'allotment gardens'* in the Anglo-Saxon countries (Bell *et al*., 2016). Historically, allotment gardens were set up with the primary goal to mitigate poverty by providing fresh food among factory workers during the industrial revolution or later during wars and depression times (Barthel *et al*., 2013). Their relevance was dramatically increased during the first half of the 20th century, during the two World Wars, when agricultural products could not easily reach the city markets and were sold at elevating prices or on the black market. Consequently, the production of foodstuffs, especially fruit and vegetables, became essential for the survival of cities' inhabitants. As a result, in those years, the number of vegetable gardens rose dramatically in almost all cities touched by the war where not only family and urban gardens but also public parks and roadways' edges were cultivated (often under the names of "war gardens" or "victory gardens"). During the conflict, areas destroyed by air raids were also used for growing crops. After the war, reconstruction activities began: jobs, industries, cities were growing, the price of building land was raised, and urban gardens' phenomenon significantly decreased. However, the gardens did not disappear; they moved from the city center to the suburbs and frequently reappeared as squatting. Since the 1980s, a "renaissance" of UA has been noticed. Urban gardens aimed initially at ensuring food security evolved, addressing other vital roles (ecological-environmental, aesthetic-recreational, social-educational, therapeutic) concerning the changed economic and socio-cultural conditions (Crouch, 2000; Hynes and Howe, 2004; Tei *et al*., 2009; Meneghello *et al*., 2016; Righetto *et al*., 2016). During the last 50 years, the local municipalities promoted urban gardens by providing the land, establishing a water system, and eventually fencing the area. In most cases, urban allotment gardens are organized in associations or committees for decision-making (Bell *et al*., 2016). Allotment gardeners are generally requested to pay a small rent for the plot and attend specific association duties. Production is intended exclusively for self-consumption or limited to donation, as in most cases, the sale is not allowed by municipal regulations (Barthel *et al*., 2013). Today food production is not anymore the only primary purpose, but also other functionalities are acknowledged, including aesthetic-recreational and educational (Wells, 2000), social (Tei *et al*., 2009) or therapeutic (Crouch, 2000). In Italy, these gardens have evolved in their form in the last decades (La Malfa, 1997). For instance, in Bologna (Italy), the urban regulation of allotment gardens was promulgated around the 1980s (Mancarella *et al*., 2016), and today the city accounts for more than 20 areas hosting allotment gardens and covering a surface of 17.5 hectares for a total of over 2.750 plots (Gasperi *et al*., 2012), each covering a surface of 25 to 40 m$^2$. All gardeners are members of the Italian association for recreation, culture, and gardens (Associazione Nazionale dei Centri Sociali Ricreativi Culturali ed Orti - ANCeSCAO), providing them with administrative and insurance support (Gianquinto *et al*., 2019). ANCeSCAO currently is widespread throughout the country and has more than 360'000 members, and manages 1'400 social centers and 22'000 vegetable gardens. Similar organizations are found in Germany, such as Kleingaerten, and Schrebergaerten allotment gardens (Drescher, 2001), Real Food Wythenshawe, Manchester in the UK (Bell *et al*., 2016); "Gezonde Gronden allotment gardens" in the Netherlands (Jan Willem van der Schans, 2010); Pispala allotment, Tampere in Finland (Bell *et al*., 2016) and ROD Obroncow Pokoju, Warsaw in Poland (Bell *et al*., 2016) and have proven to be a useful means for learning democratic rules as well (Gianquinto *et al*., 2019).

**Extensive peri-urban farms:** In recent years, the relevance of urban and periurban farming in terms of food production in cities and their contribution to food security has been a matter of extensive research. Whether or not to include periurban farms as a part of UA has been discussed in several ways, with most authors suggesting their inclusion and adopting the more general definition of Urban and Periurban Agriculture (UPA) (Van der Schans and Wiskerke 2012) or urban agriculture (Heimlich, 1989), both synonyms of the more general concept of UA adopted in the present manuscript. While UA's primary purpose is still meeting food needs mainly at the household level, extensive peri-urban agriculture can provide more substantial quantities and has broader distribution pathways, allowing for significant contributions in terms of food supply at the city level in the Global North. Extensive peri-urban agriculture farms provide goods and services both for the local and global markets (Opitz *et al*., 2016). These farms emerge within the "transition area" between urban and rural environments, characterized by lower population density with lesser infrastructures and buildings, while concurrently featuring a more limited land availability for agriculture use than rural areas (Allen 2003; Piorr *et al*. 2011). In extensive periurban farms, multifunctionality at the farm level appears, with farms providing agricultural goods and food and services to the community and available functionalities (Le *et al*., 2018). Representative cases studies of peri-urban farms are found within metropolitan areas in several cities of the Global North. In Bologna (Italy), *Spazio Battirame* (https://www.etabeta.coop/spaziobattirame/), is a place of socio-recreational and educational activities created and developed as an urban regeneration project by the social cooperative Eta Beta (Gasperi *et al*., 2016). In *Spazio Battirame*, cultural events, handicraft laboratories, and concerts are organized, while organic vegetables are produced over 4 hectares of open-fields and marketed through solidarity buying groups and participation in weekly farmer's markets. A professional kitchen serves a bar-restaurant and hosts cooking courses and food-related activities. The project has a strong social connotation, and functions include inclusive job creation, education and training, urban regeneration, and sustainable growth (Cavallo and Rainieri, 2018). In the fringes of the city of Angers (France), proximity agriculture tale place at *Le jardin de l'avenir* (The future garden, https://www.jardindelavenir.fr/). The farm, extended over almost 9 hectares, operates on a pick-your-own scheme, where residents may accede the farm and harvest fruits and vegetables based on their needs and then weigh and pay them at the counter. The farm is managed following organic farming principles and permaculture principles, while environmental sustainability is also targeted through the co-generation of electricity for the farm needs and the local energy supplier. The farm Hof Mertin (Germany) adopts a similar scheme, placed in the Ruhr's densely urbanized and industrial region (Pölling *et al*., 2017). The farm (https://hof-mertin.de/) extends over around 120 hectares, out of which 40 are devoted to strawberry cultivation and integrated into a pick-your-own scheme or used for educational/recreational workshops. In Ontario (Canada), a survey involving 21 peri-urban farmers highlighted that, while proximity to the city may open up new marketing opportunities, the overall sustainability of the sector strongly depends on the existence of infrastructural and policy measures to link UPA with the local market (Akimowicz *et al*., 2016). It appears that while UPA actors may benefit from the nearly rural conditions of their environment, a set of diversified and adaptive strategies must be integrated in order to attract local citizens and involve them in alternative food networks, as also evidenced in a recent study in the city of Barcelona (Spain) (Paül and McKenzie, 2013).

**Urban community gardens:** The term 'community garden' refers to 'open spaces which are managed and operated by members of the local community in which food or flowers are cultivated' (Holland, 2004; Pudup, 2008). Nowadays, community gardens are growing in popularity in response to the shift towards cooperative forms of spatial design and land-use, and reflect the shift from government to governance, including changing roles, responsibilities, and impact of government agencies and local citizens (Rosol, 2010). They are growing in popularity and can involve a wide range of groups such as schools, prisons, youth, the elderly, hospitals, and residents of neighbourhoods (Pudup, 2008; Teig *et al*., 2009). Different studies emphasized that community gardens are a source of food and provide other benefits, such as community building, education, and promoting health (Turner, 2011). Indeed, the most common motivation to take part in a community garden by the citizen is: to consume fresh foods, social development or cohesion such as community building and culture exchange, to improve health among members, and to make or save money by eating from the garden or selling the produce (Guitart *et al*., 2012). It was recently estimated that 86% of community gardens in the USA were used to grow food, flowers, and native vegetation. The same study also revealed that 82% of community gardens were operated by non-profit organizations, including cultural and neighbourhood groups (Guitart *et al*., 2012).

Further researches confirm that community garden members are rather heterogeneous in terms of education, age, gender, and financial aspect and usually lack previous gardening experience (Bell *et al*., 2016). Community gardens can also be classified based on their government structures (Fox-Kämper, 2018). Nettle observes that community gardens can be classified as either top-down or bottom-up governance structures depending on who initiated them (Nettle 2016). McGlone *et al*. (1999) noted the difference between gardens that were managed by external professionals (top-down) and those that were managed (bottom-up) by community members, including professionals. Top-down community gardens are implemented with the help of enabling legislation passed by local or central government (Nettle, 2016), and external /private officials carry out the garden management to meet government-set outcomes (McGlone *et al*., 1999).

On the other hand, bottom-up community gardens build upon a direct involvement of the local community. In the latter case, the community garden is planned and devised through collaboration by community groups (Okvat and Zautra, 2014) and the implementation to enable legislation passed by local or central government (Nettle, 2016). The community also collaborates to devise a management scheme for the garden (McGlone et al., 1999). Among the most famous cases of community gardening in the Global North may be found several initiatives in the city of Berlin (Germany), including the Allmende Kontor (https://www.allmende-kontor.de/) in the former Tempelhof airport, the Ton Steine Garten (http://gaerten-am-mariannenplatz.blogspot.com/) in the Kreuzberg area or the more experiences of community entrepreneurship found in both Prinzessinengarten (https://prinzessinnengarten.net/) and Himmelbeet (https://himmelbeet.de/) (Wunder, 2013; Bradley and Hedrén, 2014). In Italy, remarkable is the case study of Bologna. The city has 21 municipal community urban gardens **(Figure 1-1)** totaling 20 ha, and approximately 4000 families are currently involved.


**Figure 1-1.** Communities urban gardens allocated in urban areas of Bologna city
Source: Cerasola Vito.

### 1.2.2 Urban gardens in developing countries

For many years, agriculture in developing countries was exclusively associated with the rural context, and countryside agricultural production itself was considered, for a long time, to be sufficient to feed the urban population (Orsini *et al*., 2013). Most developing countries located in tropical areas are also vulnerable to climate change due to their dependence on rain-fed agriculture, widespread poverty, limited access to innovative technologies, and improved agricultural practices (Dowuona nii nortey *et al*., 2014). An evident interdependence between climate change, economic vulnerability, and migrations exists (Barbieri *et al*., 2010). Accordingly, climate change is also resulting in a growing rate of migration toward urban and peri-urban areas of large cities. However, adaptation mechanisms are not yet in place or are not strong enough to mitigate the economic vulnerability of the most impoverished strata of the population (Barbieri *et al*., 2010). Moreover,

in the tropical areas of Latin America and South-East Asia, health concerns are related to different forms of malnutrition frequently associated with a lack of micronutrients and vitamins in the population diet and low dietary diversification of vulnerable people living in urban and peri-urban areas of big cities (Orsini *et al*., 2013).
The constraints mentioned above could be considered the leading causes of the urbanization process (Barbieri *et al*., 2010). While poverty was mainly concentrated in rural areas, urban poverty has increased considerably in developing Countries (Piel G., 1997). Urban poor people are certainly the least resilient and most vulnerable to food access and food price volatility (Zezza, 2008), making them the most exposed to food insecurity, but also to violence and crime (Orsini *et al*., 2013; Attiani, 2012). This adverse scenario has stimulated food production systems in the city, whose fresh food production becomes complementary with food production from the countryside (Van Veenhuizen, 2006). Nowadays, the benefits of urban agriculture are also currently valorized by many municipalities located in developing countries. Indeed, it is widely demonstrated that urban agriculture contributes actively to food security because it ensures greater access to food for vulnerable people (Maxwell, 1998). A close association between urban agriculture, diet diversification, and household income rise is also evident (Zezza and Tasciotti, 2010) in most UA experiences in developing countries. Moreover, the urban agriculture role is not only relegated to the food supply. It is also well-documented that UA can contribute to other aspects such as local economic development, biodiversity and landscape, urban waste disposal, urban heat island mitigation, education, social inclusion, and physical and mental rehabilitation (Paltrinieri, 2012; Orsini *et al*., 2010).
According to Orsini *et al*., 2013, the growing role of urban horticulture in society can be confirmed. Indeed, proofs of the increasing role of urban agriculture are available for several cities located in tropical areas: more than 21,000 ha in Cagayan de Oro City (Philippines) is occupied by urban agriculture activities (Potutan *et al*. 2000); in Havana-Cuba, about 12 % of urban land is dedicated to agriculture (Cruz and Medina 2003); and more than 11,000 ha are used for agricultural production in Jakarta (Indonesia) (Purnomohadi, 2000). The production seems to be significantly diversified, and it includes corn, vegetables, flowers, and livestock production within the city of Harare (Zimbabwe) (Ghosh, 2004). About 100,000 tons of fresh foods are produced in Dar es Salaam (Tanzania) yearly (Ratta and Nasr, 1996); 100%of milk and 90% of eggs consumed in Shanghai (China) are produced within the city boundaries (Yi-Zhang and Zhangen, 2000).

According to Mougeot, the increased relevance in the urban texture from a socio-economic and ecological perspective is considered an essential feature of urban agriculture (Mougeot, 2000).

The rate of urban population involved in agriculture has been estimated at 50 % in Accra, Ghana, 80 % in Brazzaville (Congo), 68 % in the five most prominent cities of Tanzania, 45 % in Lusaka (Zambia), 37 % in Maputo (Mozambique), 36 % in Ouagadougou (Burkina Faso), and 35%in Yaoundé (Cameroon) (Orsini *et al*., 2013). In Kenyan cities, about 29% of the families are employed in urban farming (Ghosh, 2004). From a study of Zezza and Tasciotti (2010)—using survey data from fifteen countries across the four principal development regions, i.e., Asia (Bangladesh, Indonesia, Nepal, Pakistan, and Vietnam), Africa (Ghana, Madagascar, Malawi, and Nigeria), Eastern Europe (Albania and Bulgaria), and Latin America (Ecuador, Guatemala, Nicaragua, and Panama)—the shares of urban households that earn income from agriculture vary from 11 % in Indonesia to almost 70 % in Vietnam and Nicaragua. In 11 of the 15 countries in the dataset, households' share is over 30 %. (Orsini *et al*., 2013).

In many countries, local governments are promoting and encouraging the development of urban agricultural activities and production. For example, Argentina, Brazil, and Cuba have developed national policies and programs that promote urban horticulture (Van Veenhuizen, 2006). 23.3% of the urban families in Brazil are still suffering from food and nutrition insecurity. Therefore, urban and peri-urban agricultural initiatives are stimulated and supported by local communities, universities, the private sector, and three government levels (federal, state, and municipal) (Santandreu, 2018). According to a survey carried out by Sant'Anna de Medeiros *et al*., 2020, urban and peri-urban food production occurs in all Brazil regions, and over 600 initiatives for both self-consumption and commercial purposes have been identified. The urban gardens' size at city level in Brazil varies from a little more than 1000 $m^2$ (Sant'Anna de Medeiros *et al*., 2020) up to 115 ha, as in Teresina's

case urban gardens (Michelon *et al*., 2020a). Teresina is the capital of Piauì, located in the northeast of Brazil. The city's urban gardens occupy 115 hectares, directly involving more than 5000 people who have obtained employment through the urban gardens, considerably improving their daily diet and family income. Nowadays, the socio-economic importance of urban gardens and their role in developing local territory is widely recognized. It is also included in the governmental public policies that enabled producers' income generation, increasing the region's supply and food security.
Moreover, due to the current pandemic situation caused by Covid 19, the potential of urban/family gardens to ensure easy access to food for the families was very clear (Laborde *et al*., 2020), and, likely, UA will further spread and strengthen it worldwide. Indeed, urban horticulture activities have been further boosted during the pandemic emergency (Lal, 2020). UA's concept also refers to proximity farming, i.e., proximity to production, the market, and proximity to home (e.g., family gardens). The mentioned concept can be used for urban context and marginal rural areas such as small villages located in remote areas where access to many services (health, market, etc.) is minimal. Therefore, the promotion and strengthening of proximity agriculture in urban and remote rural areas will play an essential role in ensuring more straightforward access to fresh food.

UA projects are considered essential to contribute to food and economic resilience, mainly addressed to families with vulnerable socio-economic situations with low resilience (Béné, 2020). Pandemic's current situation affects global agri-food systems, damaging agricultural value chains at the regional level, generating risks to ensure food and nutritional security for many families (Laborde *et al.*, 2020). Many food security projects in rural and urban areas will probably be encouraged and implemented in the coming years by international agencies. In confirmation of the above, it is important to mention two projects implemented during the pandemic period and respond to it. The projects are called "FoodLand" and "Huerta familiar y seguridad alimentaria." In both projects, the DISTAL of the University of Bologna is involved in managing and implementing project activities. FoodLand project aims to develop, implement, and validate innovative, scalable, sustainable technologies to support local food systems' nutrition performance in urban areas of different cities of Africa while strengthening agro-biodiversity and food diversity merged with the diversity of diets. The total number of beneficiaries involved in urban agriculture will be about 500 families covering around 10 ha of cultivated urban land. The project "Huerta Familiar y Seguridad alimentaria" is taking place in Colombia since September 2020. The initiative, which will benefit 630 families in the Huila department (southwest of Colombia), aims to implement a sustainable model to guarantee food sovereignty, generating food and income for local families. The first phase of the project will involve a growing area of approximately 20 ha.

### 1.2.3 Strengths and weaknesses of urban agriculture

Urban agriculture contributes to the city's transversal development, including social, environmental, and economic impacts (Fleury and Ba, 2005), and positively contributes to many of the problems affecting the urban environment. At the same time, when using poor practices, it can harm human health and the environment.

The main strengths and weaknesses of urban agriculture may be synthesized as follows:

**Strengths of UA:**

- UA allows more access to **safe and nutritious food** (mainly fresh products), helps improve the urban poor's health conditions (Orsini *et al*., 2013; Drescher, 2004; Ghosh, 2004; Van Veenhuizen, 2006).
- Research carried out by Aquino and Assis (2007), Hirata (2010), Leme and Pimentel (2011), and Istan *et al*. (2015) point out the potential **economic returns** that urban activities could generate for the families involved. From the economic point of view, the small production contributes to the family income by reducing food and health expenses, exchange networks, and, eventually, the transformation and commercialization of production surpluses (Aquino and Assis; 2007; Hirata, 2010). Likewise, the growing awareness of healthy food and fewer agrochemicals could create a new market

niche, adding value and strengthening the food market generated from ecologically-based agriculture (Leme and Pimentel, 2011; Istan *et al*., 2015).

- Urban activities are improving the **local communities' integration and sociability**. According to Hirata *et al*. (2010), Serafim and Dias (2013), public and idle land remains with scrubland and is still used for waste disposal in many regions (Hirata, 2010; Serafin, 2013). With the implementation of urban community gardens on these lands, the places are illuminated and well managed (Leme and Pimentel, 2011).
- From a psychosocial point of view, several studies observed that, since most of the beneficiaries of urban community gardens are retired people and mostly started to engage in the urban activities as a hobby and to obtain a complementary income, the new occupation contributes to the strengthening of the identity and improvement of self-confidence (Orsini *et al*., 2008; Calbino *et al*., 2017).
- Especially in tropical areas, characterized, during the rainy season, by heavy downpours and weighty rains, the valorization and creation of urban green areas favor the better infiltration of rainwater and makes waste recycling feasible, indicating the importance of public policies for the increase of agricultural activity in the urban area and the consequent increase of its social and environmental benefits (Calbino *et al*., 2017; Orsini *et al*., 2013).

**Weaknesses of UA**

Despite the advances in policies to encourage urban community gardens, there are also some limits and challenges to be overcome. Agricultural production, not adequately managed and grown in the polluted area, which may pose a severe threat to public health. Therefore, the best technologies and good agricultural practices used in cultivation in rural areas must also be put into practice in the urban environment. This aspect remains almost unexplored (Birley and Lock, 2000; Danso *et al*. 2003), but should not be ignored, and therein, regulation and prevention measures should be reinforced. Assessments carried out in different context around the world on urban horticulture projects/ activities such as Teresina, Brazil by Michelon *et al*. (2020a), Sete Lagoas, Brazil by Calbino *et al*. (2017), Nairobi, Kenya by Karanja *et al*. (2010), highlight the following limitation:

- **Contamination by pathogens** that determine**:** (a) from irrigation with polluted water, (b) inappropriate use of organic fertilizer (e.g., fresh animal dejections or non-composted urban wastes that are in direct contact with edible parts of the plants), and (c) poor hygienic practices during post-harvest and handling activities (viz., transport, transformation, and marketing) (Orsini *et al*., 2013);
- Contamination as a consequence of the **inappropriate use of pesticides** (Orsini *et al*., 2013; Calbino *et al*., 2017; Karanja *et al*., 2010);
- Contamination of soil and products with **heavy metals** as a consequence of agricultural production along roads with high traffic or near industrial discharges (Pennisi *et al*., 2017; Karanja *et al*., 2010);
- Improper management of available natural resources by the UA beneficiaries determines a **limited agricultural production** (Michelon *et al*., 2020a; Calbino *et al*., 2017). The survey carried out in a city of Brazil named Sete Lagoas by Calbino et al., points out that 49% of the producers registered significant losses in their production, due mainly to the following issues: lack of proper commercialization (32%); water availability (29%); pest and diseases (25%); other reasons (14%) (Calbino *et al*., 2020).
- High occurrence of **insects-disease vectors** (e.g., mosquitoes) attracted by the agricultural production (Klinkenberg *et al*. 2008).
- Related to the two above last issues, it is also important to highlight as a constraint, the **limited technical knowledge** of part of producers to deal, for example, with appropriate use of irrigation water, the improvement of the marketing methods of the products, and with pest and diseases management (Hirata *et al*., 2010; Pimentel 2011; Michelon *et al*., 2020a). Furthermore, these limitations do not be overcome in many cases due to the **inadequate technical assistance** carried out by local agencies (Castelo Branco and Alcantra, 2011; Michelon *et al*., 2020a).
- Serafim e Dias (2013) points out the problem related to urban areas' use destined for urban agriculture activities. Generally, because government programs are involved, the land used for the implementations of gardens are seen as transitory spaces, ceded to the program. This **uncertainty** about the permanence and durability of a garden unit causes instability as to its continuity.

Consequently, since the garden participants do not own the land, they often cannot apply for certain aids to access funding programs (Serafim and Dias, 2013).

It is clear that in general, about agricultural activities carried out in the urban environment, more significant support from local agencies is needed to deal with the producers' technical expertise, also encouraging more supportive interpersonal relationships. Therefore, specific issues must be considered to ensure urban gardens' sustainability regarding institutional – public policy and agronomical technical issues. Consequently, the promotion of urban agriculture public policies through community gardens must be implemented and considered a strategic incentive mechanism for local economies and strengthening both the technical skills of farmers and agricultural technology applied to urban agriculture activities (Michelon *et al*., 2020a; Calbino *et al*., 2020). Accordingly, guidelines on appropriate urban and peri-urban agricultural practices are required and even urgent, which can be adequately understood and followed only with a higher awareness of the UA beneficiaries and a better education. Moreover, all risks usually encountered in traditional rural farming should be carefully considered in urban agriculture activities.

**1.3 Irrigation Water Management**

To promote the sustainability of water resources and food production in towns and remote rural villages, accurate implementation of irrigation water management is necessary.
Various research has demonstrated the technical viability (Cerón-Palma *et al*., 2012; Nadal *et al*., 2017; Orsini *et al*., 2014), qualifying also the environmental impact through the Life Cycle Assessment (LCA) approach (Sanyé-Mengual *et al*., 2015) of producing food on urban areas. The research's main topics mentioned above are enhancing the system's design and finding an alternative use for waste (Gianquinto *et al*., 2007; Lorach Massana, 2017; Sanjuan Delmas, 2017). Despite it, irrigation water resource management is still a big issue at the urban and small scale farmer level, confirmed by high water consumption of urban gardens in the cities and therefore by very low values of WUE usually obtained compared to the ones that could be achieved with accurate resource management (Cerasola, 2018; Michelon *et al*., 2020a; Calbino *et al*., 2020). The two main reasons for it could be accomplished on limited technical assistance provided to small-scale farmers and the practicers' limited agricultural knowledge (Michelon *et al*., 2020a; Orsini *et al*., 2013; Castelo Branco and Alcantra, 2011).

Nowadays, innovative and more or less sophisticated technologies are available to manage water for irrigation to growing vegetables properly.

Under the category of sophisticated irrigation management technologies, it could include the following technologies:

- Tecnologies that adopt satellite remote sensing applications for irrigation needs assessment (D'Urso, 2010). These technologies are based on the acquisition and analysis of electromagnetic energy emission measurements, reflected or transmitted from the Earth's surface, to identify, directly or indirectly, qualitative and quantitative information that characterize it (Brivio *et al*., 2006).
- Various studies have led to a linear correlation between Kc and the Ndvi green index; this has led to the definition of evapotranspiration maps.
- Global Position Systems (GPS) have become global today, and this accessibility is enabled precision agriculture and is now finding its way into irrigation. In the field, geolocation of management of zones, utilization of variable rate irrigation, and understanding data from soil moisture probes all rely on GPS technology.
- Modern information technology also makes it possible to create systems capable of detecting soil moisture at different points and different depths, making it possible to map the volumetric water content accurately and optimally manage irrigation strategies.

Above have been reported only some of the sophisticated technologies that enable precise irrigation planning in agriculture. However, currently, farmers worldwide seem somewhat reluctant to invest in automatic or semi-automatic technology, although they are often very interested in the new technology. This scepticism could probably be due to inappropriate knowledge of these technologies and the high initial cost (Serafim *et al*., 2003).
This thesis will focus mainly on managing irrigation water resources to produce vegetables adopting technologies and methodologies that could facilitate the adoption of accurate irrigation practices by the small-scale farmers in rural and urban areas and could be a preparatory step for introducing more sophisticated precision irrigation technologies. Nevertheless, as much for sophisticated technology as for less sophisticated technology, it will be important that local institutions in developed and developing countries adopt an interdisciplinary approach to ensure that farmers properly apply water management technologies (Michelon *et al*., 2020a).

In the experiments carried out within this PhD thesis, the soil-based system's irrigation strategy was based mainly on the estimation of crop evapotranspiration ($ET_c$), and as irrigation system has been adopted the drip irrigation system. Other simple technologies have also been tested to facilitate accurate irrigation management for horticultural production, such as soil moisture sensors and simplified soilless systems. Details on the irrigation strategies adopted under this thesis can be found in the "Material and Methods" sessions of chapters 4-5-6-7.

### 1.4 Objectives of the dissertation

The present dissertation's main objectives are to identify simplified irrigation strategies for vegetable production in the Tropical areas by analyzing different factors that can affect the water use efficiency.

To do so, the following specific objectives were studied in detail:

**Objective 1:** Assess the management of natural resources in the urban vegetable gardens with particular reference to irrigation water management and WUE.

**Objective 2:** Identify the appropriate water management strategies for vegetable production in semi-arid climate characterized by severe water scarcity.

**Objective 3:** Assess the viability of a simplified soilless culture (SSC) system for the production of lettuce compared to traditional on soil cultivation techniques in tropical environments, considering yield, water use efficiency, and the overall physiological plant response.

**Objective 4:** Assess drought stress affects yield, water use efficiency and quality parameters in hybrid and open-pollinated lines of tomato *(Solanum lycopersicum L.)* under different levels of irrigation water deficit.

**Objective 5:** Assess simplified soilless systems to improve ornamental plants' cultivation, targeting the identification of appropriate cropping systems to optimal commercial production and maximization of the WUE.

The present dissertation focused on six tailored studies that deeply impact different aspects of WUE to analyze the mentioned above objectives.

1) Teresina Urban community gardens. The producer's perception of natural resources management. – **Chapter 2**.

2) Use of different substrates and nutrient solution concentration for the production of Lettuce and Chinese cabbage seedlings in a semi-arid environment in central Myanmar. - **Chapter 3**.
3) Strategies for Improved Water Use Efficiency (WUE) of Field-Grown Lettuce (*Lactuca sativa* L.) under a Semi-Arid Climate. **– Chapter 4**.
4) Strategies for improved yield and Water Use Efficiency (WUE) of lettuce (*Lactuca sativa* L.) through simplified soilless cultivation under semi-arid climate. - **Chapter 5**.
5) Drought stress affects yield, water use efficiency and quality parameters in hybrid and open-pollinated lines of tomato *(Solanum lycopersicum L.). -* **Chapter 6**.
6) Comparative Study of Three Low-Tech Soilless Systems for Geranium's Cultivation (*Pelargonium zonale*): A Commercial Quality Assessment. - **Chapter 7**.

## CHAPTER 2 – Teresina Urban community gardens. The producer's perception of natural resources management.

**Abstract.** The urban and peri-urban areas of the main cities of developing countries are characterized by spread poverty and a high unemployment rate. The promotion of urban community gardens allows the production of fresh vegetables to improve people's diets and create job opportunities. This study was conducted to characterize the urban and peri-urban community gardens of Teresina city (Piauì State in north-est of Brazil), determine their role in peri-urban agriculture production, and assess potential risks regarding natural resources management. This work utilized the results of a survey conducted during the summer of 2019. The users of 5 urban communities garden of Teresina city have been interviewed. A total of ninety-five questionnaires have been applied. The complete questionnaire used 25 both open and closed questions. It was structured into two sections, including general information (for instance, age, gender, level of education, etc…) and technical and production information (for example, cropping system adopted by the horticulturists, production, irrigation water consumption etc…). The most growers were female, over 45 years old, most of the growers had incomplete elementary education and a weak agricultural background. Almost all the growers (95%) did not know their soil and water quality. The majority of production was focused on Coriander, Green onion, and Lettuce. There were significant differences in terms of production (kg $m^{-2}$) among the urban community gardens. Although in some urban gardens, the production (kg $m^{-2}$) could be considered satisfactory, reaching 2.7 ± 0,22 kg $m^2$ of lettuce, the water use efficiency (WUE) values obtained were very low (average of 6.9 ±0.4 g FW $L^{-1}$ $H_2O$). The highest WUE values were found in the urban gardens where the micro-sprinkler irrigation system was adopted. The survey pointed out that tailored training for the growers on more efficient use of natural resources is needed to contribute a better and more sustainable management of urban and peri-urban garden production of Teresina city.

### 2.1 Introduction

On May 23, 2007, the rate of the population inhabiting urban centers overtook the rural one: both the North Carolina and Georgia Universities have estimated that on that day, the urban population got 3.303.992.253 people, whereas rural community amounted to 3.303.866.404 (Orsini *et al*., 2013). Furthermore, it is expected that within the next 25 years, the world population should have a dramatic increase of about 4 billion in the number of people in cities, mainly in the towns located in Asia, some on the American Continent, and in Africa (UNCHS, 2007). The trend and the dynamics of the urbanization process are not the same worldwide, and there are vast differences among the continents (Drescher *et al*., 2002). The urban population expansion is more pronounced in developing countries as the result of rural-to-urban migration and natural population growth (FAO-FCIT, 2011). This last aspect mentioned is also occurred in Piaùi, located in the Northeast of Brazil. The rural exodus that has characterized Northeast of Brazil and, therefore, Piaùi State, during the previous 30 years and throughout Brazil, has led people to look for alternative occupations in the capital, which is Teresina (Stefani *et al*. 2018). Often, these people are not absorbed in the city labor market, and they usually end up in poverty and are characterized by low access to food and severe food insecurity (Gianquinto *et al*., 2007). Food insecurity is frequently associated with overweight, obesity, hypovitaminosis A and anemia (Orsini *et al*., 2013). Indeed, iron deficiency is widespread in the region resulting in a high percentage of anemia. Carvalho *et al*. (2010), pointed out that 92.4% of under-five children analyzed in the area were affected by anemia (Hb <110g / L), and 28.9% by moderate/severe anemia (Hb <90g / L). With regards to obesity, it is correlated with increased consumption of meat and industrialized foods with high levels of saturated and hydrogenated fats, sugar and soft drinks, and a reduction in the use of fruits, vegetables, and essential traditional foods such as beans, tubers, and rice (Camara Inter *et al*., 2011).

Within NE-Brazil, the capital of the Piaui state Teresina (5°05' S, 42°48' W) accounts for an estimated population in 2019 of about 860'000 inhabitants (Junior *et al*., 2020). This Municipality suffered a substantial impact on the flow of immigration in the state, and several slums were established. As a matter of fact, in 1991 Teresina counted 56 towns and slums, and in 1993, there was a further increase of 169.6% in these locations (Montero *et al*., 2006). Moreover, between 1990 and 2000, Teresina presented a new progressive process of urbanization with an increase in city population of 10.30% and a consequent decrease in rural population of 5,42%. This determined an increasing request for education, housing, health, and income generation activities (IBGE, 2010). Therefore, to reverse the detrimental effect of high population growth rates, the field-city migration flow, and the low job offer and food insecurity, an implementation of public policy was claimed (Ambiente, 2005). To promote policies and programs toward sustainable food security, elaborating the meaning of food and nutrition security in its full complexity is required. While results such as improving food diversity or reducing food insecurity, or increasing agricultural production may be explicit goals, one way to look at sustainability is to focus on the myriad ways in which different urban populations benefit socially from growing food as an explicitly social activity, with social effects in addition to food and nutrition outcomes (Orsini *et al*., 2013). In this context, fascinating is the case study of Community Urban Garden (CUG) established in Teresina by the Municipality to generate work and income and improve the food security of families living in urban and suburban areas of the town. Another aim is to increase the local market's vegetable supply since there is still a high dependency on imported vegetables from other states (Da Silva, 2018). The Teresina Community Gardens were established in 1987 with the primary aim of integrating children's and teenagers' marginality. With the development of the garden activity, a large number of family members took part in the project, due to the high unemployment rate (71,16% of the population was jobless) that was characterizing the capital of the Piaùi in the late 1990s (Montero *et al*.,2006).

For this reason, the Urban Community Garden (UCG) program changed focus, involving the vulnerable families in the urban and sub-urban areas of the city. The Dirceu Arcoverde neighbourhood was the area chosen to establish the first urban community garden of Teresina city with the double aim of improving the family diet and increasing their income-earning capacity. Teresina currently counts 43 community gardens located in the urban area, totalizing 115,4 hectares, and employing 2454 people (PMT-SDR, 2019). The technical management of UCGs is carried out by growers that cope with their growing plot. Technical assistance is carried out by the Rural Development Secretary (SDR) professional staff that assists the beneficiaries in some technical advice, equipment maintenance, and logistic expenses to guarantee the proper functioning of the

UCG (Da Silva, 2018). Currently, UCG beneficiaries are recognized as rural workers, and they benefit from rural worker rights. They can also reach the retirement pension at 55 years old for the women and 60 years old for the man demonstrating that they were working in the UCG for at least 15 years (PMT-SDR, 2019). All beneficiaries are members of several Gardeners Association, one for each UCG, ensuring the growers to access public policy programs promoted by Federal governments. The more impacting program is the Brazilian School Feeding Program (PNAE) developed within the Zero Hunger Strategy during Lula's Presidency. The PNAE involves all public and community schools of the primary education system, from kindergarten, elementary, and high school. It has the main objective of strengthening local family farming and, at the same time, promoting access to equilibrate and healthy diets in all public schools (Sidaner *et al*., 2013). In Brazil, the number of people in food insecurity and poverty decreased due to the committed public policies in such an extent that the percentage of households living in food insecurity fell from 34.8% in 2004 to 30.5% in 2009 (IBGE, 2010), and extreme poverty from 17.4% in 2001 to less than 9% 2008 (De Lima *et al*., 2014). The beneficiaries of Urban Communities Garden of Teresina are benefiting from these programs as one of the PNAE's demands is that at least 30% of the fruit and vegetables supplied to the school must come from local communities (Sidaner *et al*., 2013). It is an excellent opportunity for the beneficiary to raise their family income, and some of them are making fair use of this opportunity. Still, for many growers, the UCG guarantees only complementary family income, and it is not yet representing the primary family income source, despite various commercial opportunities currently available in the region (PMT-SDR, 2019). According to Da Silva *et al*. (2018) and Monteiro *et al*. (2006), the limited production capacity of part of the gardeners is due mainly to the low level of education, the low crop diversification, the precarious forms of post-harvest management, the low qualification and the inappropriate use of natural resources available for the vegetable production, with specific reference to irrigation water use and land use. According to Michelon *et al*. (2020a), irrigation management in the UCG is carried out based on the growers' traditional local habit using manual irrigation. Water is distributed by 12 L watering bucket. The amount of water distributed in the garden is based on growers' experience without considering any agronomic approaches. Consequently, the water use efficiency is often low-performing, around 5,6 g of FW per $L^{-1}$ $H_2O$ (Michelon *et al*., 2020b). The introduction of innovative agricultural technologies that allow vegetable production even in urban and peri-urban areas while fostering water-saving techniques to improve crop water use efficiency (WUE) is crucial (Gianquinto *et al*., 2007).
This study aims to assess the agronomic viability of urban communities' gardens of Teresina City to produce vegetables, focusing mainly on quantitative parameters such as main crop yield and water use efficiency. The assumption is that water management for vegetable production within the urban garden is inaccurate, and gardeners still need training and technical assistance to maximize natural resources. The study's main findings will be shared with the Rural Development Secretary (SDR), and training session, and targeted intervention strategies to improve the ecological sustainability of the urban community gardens of Teresina city will be implemented.

## 2.2 Material and Methods

### 2.2.1 The study area

The surveys were carried out in 2019 in Teresina, Capital of the State of Piauì (NE-Brazil; 5°05'41.64 "S 42°48'15.12 "W). The study was carried out in five community gardens (UC Garden) located in Teresina City. Four of them are located in urban areas and one in the rural area.
The UC Gardens were the following **(Figure 2-1)**:

- → UC garden Carlos Feitosa located in the north zone of the city (5°03'48 "S 42°50'12 "W), with 42 families registered;
- → UC garden Tabuleta: situated in the south zone of the city (5°06'22 "S 42°44'59 "W), with 39 families registered;
- → UC garden Parque Ideal: located in the southeast area of the city (5°07'35 "S 42°47'46 "W), with 93 families registered;
- → UC garden Vila Nova II: located in the east zone of the city (5°00'50 "S 42°47'08 "W), with 30 families registered;

→ UC garden Soinho: garden located in a rural area (4°59'53''S 42°42'50''W) in the city's east zone), with 37 families registered.

In **table 2-1,** are reported more details on surveyed community gardens.

| sn | UC garden name | Start Year | Area (ha) | Nº of Garden Parcel |
|---|---|---|---|---|
| **1** | Carlos Feitosa | 1999 | 3.0 | 68 |
| **2** | Tabuleta | 1997 | 5.5 | 126 |
| **3** | Parque Ideal | 1994 | 8.0 | 126 |
| **4** | Vila Nova II | 1995 | 3.0 | 60 |
| **5** | Soinho | 2018 | 4.0 | 78 |

**Table 2-1:** Information on Community garden starting year, on size (ha) and number of the cultivable.

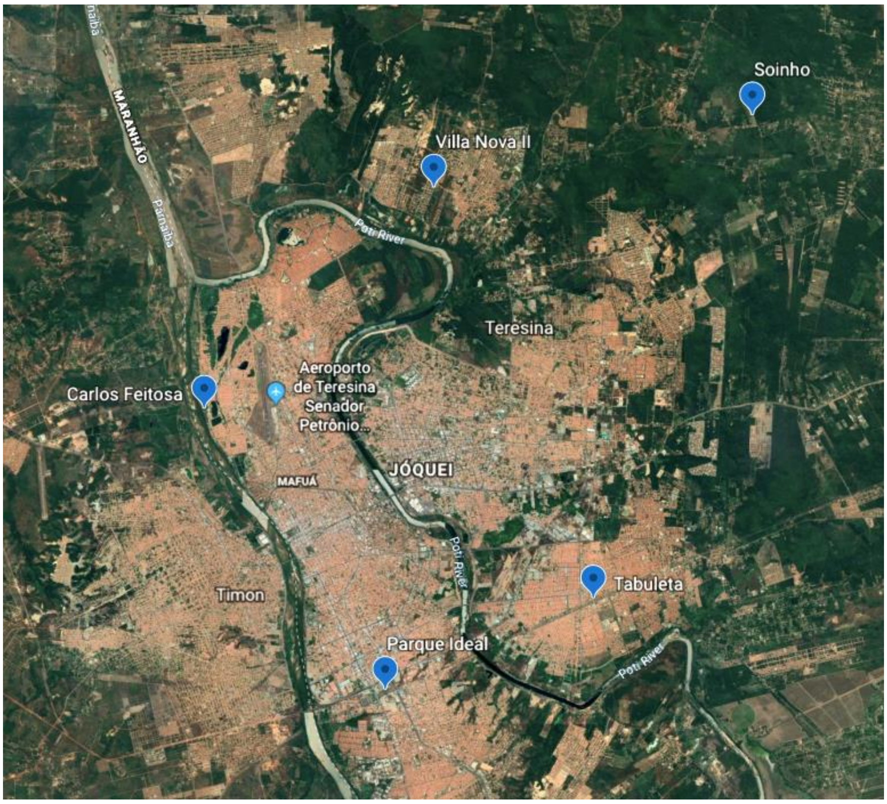



**Figure 2-1.** Disposition of the urban gardens surveyed in the city of Teresina

According to Köppen's classification, the local climate is Aw type, which is tropical rainy with dry summer and rainy season concentrated between January and May.
Based on a study carried out by Barboza *et al*., 2020, concerning the climatic conditions of the city of Teresina, the following considerations can be made: the average monthly temperature in Teresina ranged between 26.9 ºC and 30.1ºC, and average annual temperature was 28.1ºC. The yearly maximum temperature is 33.8 ºC, with monthly swings 31.8 ºC to 37.1°C, the minimum annual temperature is around 22.4°C and its monthly variations range from 20.7 ºC to 23.8 ºC. The relative air humidity in the urban area ranges from 75 to 83%. The local climate has a yearly average air temperature of around 29.6°C and relative air humidity of 67.7% (Barboza *et al*., 2020). The average annual precipitation is 1,378 mm, and the yearly average evaporation is 2,149 mm, and the annual insolation average of 3,194 hours, with the driest months being more sunlight (Lima *et al*., 2011). Five community gardens with different distances from the urban center were selected **(Fig. 2-1)** and surveyed. All assessed gardens presented soils classified as ferralic arenosols (IUSS, 2014).

### 2.2.2 Climate data collection and soil sampling

Meteorological data and soil analysis allowed to assess whether the natural resource management and technologies adopted by local gardeners were agronomically adequate. Such information, combined with the results obtained by the questionnaire applied, could allow us to develop some technical advice to share with SDR professional staff to improve the efficient use of natural resources and maximize the production potential of the community gardens of Teresina City.

Local climate data (2017, 2018 and 2019) have been taken from the database made available online by the Embrapa (Empresa Brasileira de Pesquisa Agropecuária): https://www.infoteca.cnptia.embrapa.br/. The meteorological data has been used for the determination of the reference evapotranspiration. The $ET_o$ estimated by the Penman–Monteith (PM) equation was obtained using the FAO CropWat 8.0 software.

Each UCG was divided in four uniform areas, in which soil samples at 0–20 cm depth were collected. Each soil sample were obtained by mixing and homogenising six sub-samples collected using a soil probe. The soil samples were analysed for physical and chemical characteristics in the laboratory of EMBRAPA "Meio Norte" located in Teresina City.

The soil samples have been dried in a ventilated oven, and then the chemical-physical analyses were carried out. The pH was determined on a sample of 10 grams of soil sieved at 2 mm with distilled water 1:2,5 w/v and measured with a pH-meter after shaking the sample for 2 hours.

The texture (Sand, Lime, and Clay) was obtained with a sedimentation cylinder after the sample's dispersion with a sodium hexametaphosphate solution (Gee & Bauder, 1986).

Total carbonates ($CaCO_3$) were quantified by the volumetric method with a Dietrich-Fruhling calcimeter. The total organic matter was determined by weight loss after muffle combustion.

The available phosphorus was extracted in Mehlich (HCl 0,05 mol $L^{-1}$ e $H_2SO_4$ 0,0125 mol $L^{-1}$) (Teixeira *et al.*, 2017).

The total amount of Ca, Fe, Mg, K, Mn, Na, P, and S were determined utilizing inductively coupled optical emission plasma spectrometer (ICP - OES, Ametek, Spectro Arcos, Germany) after the water extraction (Vittori Antisari *et al.*, 2014). For the measurement, 0.25 g of the ground and dried soil samples were treated with a mixture of HCl and $HNO_3$ over pure (3:1 v:v) in a microwave oven (Milestone, 1200). After cooling, the digests were filtered and diluted with distilled water up to 20 mL, and the concentrations of the elements were measured using ICP-OES.

### 2.2.3 Survey design

The complete survey included 25 both open and closed questions and was structured into three sections. The survey was conducted under appropriate ethics and protocols following the urban community garden's relevant guidelines and regulations. On July 25, 2019, the survey methodology was approved by the local Ethics Committee (https://www.uespi.br/site/?page_id=107158).

Additionally, we received consent and permission from the growers to perform research within their community gardens, and written consent was obtained from each gardener as part of their participation in the project and for the use of soil and water data for the analysis. There is no identifying information for any of the participants in the manuscript or corresponding data files (available upon request).

The first section (general information) included questions regarding the participants' profile, name, age, gender, education level, and garden size **(Table 2-2)**.

The second section (agronomic aspects of garden management) consisted of closed questions that analysed the different technical aspects of garden management. The aspects examined in this section are the following: crop system adopted, crop cultivated, yield, irrigation system, irrigation management, and soil and water quality awareness by the growers. A Likert-type scale was used in this section for rating some parameters (Bernard, 2017). This scale is a psychometric response scale primarily used in questionnaires to assess the subject's perception and usually comprises a 5-point range (ordinal data), assigning numeric values to each level (Wadgave and Khairnar, 2016). For example, the question "In general, how do you evaluate the quality of the water you use for irrigation?" had five options: "very good", "good", "acceptable", "bad," and "very bad".

The third section (awarness of natural resources and propensity's sustainability and propensity to change some technical cropping aspects by the growers) encompassed closed and open questions. The main topics were regarding, for example, the willingness of the gardeners to change the cropping system, if the grower will request soil and water analyses, and whether he wants to improve irrigation water management

**2.2.4 Questionnaire survey sampling**

The target population was over 18 years old growers working in the selected urban community garden of Teresina City.

A meeting with the gardeners was carried out in each community garden before the questionnaire application to explain the research methodology and objective and present the team members responsible for collecting the information. The meetings have been organized and authorized by the SDR of Teresina.

A total of 95 growers have been interviewed. Participation was voluntary, and consent was obtained. The respect of gender has been ensured by involving both male and female beneficiaries equally.

Some specifications regarding some questions are needed, regarding how some data were treated.

**Individual garden size:** Most gardeners were giving information on their garden size differently using some traditional manner. For example, some growers measured the area using the number of 10 $m^2$ plots named locally "canteiros," other ones were using the total available area called "Lote". One Lote is corresponding to an area of 400 $m^{2,}$ whose only 200 cultivable.  The information obtained by the gardeners was converted into square meters.

**Water use information:** Each interviewed was asked to indicate the amount of irrigation water used for the specific crop. In this case, gardeners were also adopting different measurement units, such as the number of 10 liters watering can day$^{-1}$"*canteiro*"$^{-1}$; the other one answered using the irrigation times (when the irrigation system was available and adopted). Then the conversion has allowed getting the data in l $m^{-2}$ $day^{-1}$.

**Water use efficiency:** Water use efficiency (WUE) was determined as the ratio between the production informed by the growers (fresh weight) and the volume of water used and expressed as g FW $L^{-1}$ $H_2O$, as generally done for leaves vegetable crops (Michelon *et al*., 2020a).

**2.2.5 Data analysis**

The experiment design was completely randomized with five treatments (represented by the five community gardens) and 19 replications (represented by the individual grower).

Data were collected on 5 community gardens of Teresina city involving 95 growers. Data were analyzed using one-way ANOVA. Means were separated using the Tukey HSD test at $p \leq 0.05$. Before the analysis, all data were checked for normality and homogeneity of variance. Averages and standard errors (SE) were calculated. Statistical analysis was carried out using R statistical software (version 3.3.2, package "emmeans" and "car").

**2.3. Results**

*2.3.1 Meteorological data*

Considering the last three years (2017, 2018 and 2019), the average climate data were the following.  Daily maximum air temperatures ranged between 27.5 and 40.2 °C, with an average of 34.8 °C. Daily minimum temperatures ranged between 16.9 and 26.6 °C, with an average of 23.1 °C. Daily relative humidity (RH) ranged between a minimum of 37% and a maximum of 92%.  The average wind speed is 1.16 m $s^{-1,}$ with the windiest month in November with 1.57 m $s^{-1}$. The average annual rainfall is 1192 mm, and rain occurred between December to May. According to the FAO Penman-Monteith formula, the average yearly ETo calculated is 4.64 mm $day^{-1}$ with the highest value in October and lower one in February with 6.0 and 3.9 mm $day^{-1,}$ respectively.

*2.3.2 Chemical and physical Soil analysis results*

Chemical and physical soil analysis of the surveyed sites has been carried out. An additional soil sampling has been collected in the native area (area never cultivated and characterized by original vegetation) close to Soinho Community garden.

The sites used for the survey obtain the following chemical-physical characteristics:
- **Community Garden Soinho**: the soil presented a Sandy loam texture with 57% of sand, 13,4% of Clay, and 29.5 of silt; a wilting point of 15,1% v:v; and field capacity of 29,8% v:v. The soil chemical characteristics in the 0–0.20 m layer were as follows: pH ($H_2O$) 6.89; EC 399 µs $cm^{-1}$; 3.02% organic matter; 187.08 mg $dm^{-3}$ of available P; 0.71 cmolc/$dm^3$ of exchangeable K; 0.12 cmolc/$dm^3$ of Sodium; 8.79 cmolc/$dm^3$ of Calcium; 1.96 cmolc/$dm^3$ of Magnesium; 12.04 cmolc/$dm^3$ of Cation-Exchange Capacity (CEC) and 96.09% of Base saturation (%BS).
- **Community Garden Carlos Feitosa**: the soil presented a loam texture with 50.5% of sand, 12,6% of Clay, and 36.9 of silt; a wilting point of 14,1% v:v; and field capacity of 29 % v:v. The soil chemical characteristics in the 0–0.20 m layer were as follows: pH ($H_2O$) 7.78; EC 370 µs $cm^{-1}$; 2.53% organic matter; 248.08 mg $dm^{-3}$ of available P; 0.71 cmolc/$dm^3$ of exchangeable K; 0.18 cmolc/$dm^3$ of Sodium; 13.14 cmolc/$dm^3$ of Calcium; 2.43 cmolc/$dm^3$ of Magnesium; 16.97 cmolc/$dm^3$ of Cation-Exchange Capacity (CEC) and 96.97% of Base saturation (%BS).
- **Community Garden Vila Nova**: the soil presented a sandy loam texture with 58.8% of sand, 14,3% of Clay, and 26.9 of silt, a wilting point of 15,2% v:v; and field capacity of 29,4 % v:v. The soil chemical characteristics in the 0–0.20 m layer were as follows: pH ($H_2O$) 7.35; EC 433 µs $cm^{-1}$; 2.89% organic matter; 378.49 mg $dm^{-3}$ of available P; 0.4 cmolc/$dm^3$ of exchangeable K; 0.45 cmolc/$dm^3$ of Sodium; 9.55 cmolc/$dm^3$ of Calcium; 1.88 cmolc/$dm^3$ of Magnesium; 13.14 cmolc/$dm^3$ of Cation-Exchange Capacity (CEC) and 93.42% of Base saturation (%BS).
- **Community Garden Tabuleta**: the soil presented a sandy loam texture with 67.2% of sand, 16.6% of Clay, and 16.2 of silt, a wilting point of 13,9% v:v; and field capacity of 25,1 % v:v. The soil chemical characteristics in the 0–0.20 m layer were as follows: pH ($H_2O$) 6.02; EC 339 µs $cm^{-1}$; 2.51% organic matter; 126 mg $dm^{-3}$ of available P; 0.4 cmolc/$dm^3$ of exchangeable K; 0.18 cmolc/$dm^3$ of Sodium; 4.27 cmolc/$dm^3$ of Calcium; 1.26 cmolc/$dm^3$ of Magnesium; 8.96 cmolc/$dm^3$ of Cation-Exchange Capacity (CEC) and 73.7% of Base saturation (%BS).
- **Community Parque Ideal**: the soil presented a sandy loam texture with 70.7% of sand, 12,8% of Clay, and 16.5 of silt; a wilting point of 13,2% v:v; and field capacity of 24,6 % v:v. The soil chemical characteristics in the 0–0.20 m layer were as follows: pH ($H_2O$) 7.11; EC 274 µs $cm^{-1}$; 2.46% organic matter; 276 mg $dm^{-3}$ of available P; 0.26 cmolc/$dm^3$ of exchangeable K; 0.33 cmolc/$dm^3$ of Sodium; 9.45 cmolc/$dm^3$ of Calcium; 1.59 cmolc/$dm^3$ of Magnesium; 12.3 cmolc/$dm^3$ of Cation-Exchange Capacity (CEC) and 94.7% of Base saturation (%BS).

The chemical and physical values of the native area are the following:

- **Native Area**: the soil presented a sandy loam texture with 72.0% of sand, 16,8% of Clay, and 11.3 silt. The soil chemical characteristics in the 0–0.20 m layer were as follows: pH ($H_2O$) 4.5; 1.56% organic matter; 3.9 mg $dm^{-3}$ of available P; 0.11 cmolc/$dm^3$ of exchangeable K; 0.03 cmolc/$dm^3$ of Sodium; 1.44 cmolc/$dm^3$ of Calcium; 0.82 cmolc/$dm^3$ of Magnesium; 6.07 cmolc/$dm^3$ of Cation-Exchange Capacity (CEC) and 39.6% of Base saturation (%BS).

*2.3.3 Questionnaire results*

**Section 1**

The studied sample (N=97) consisted of people between 25 and 77 years old, 51% of whom were women. Regarding education, 54% of respondents completed at least primary school, and 23% achieved secondary diploma, and the remaining respondents have not reached any school level.

The average size of the individual garden area (including both cultivated and service area) for each family is 404 $m^2$.

**Table 2:** General information on the individual beneficiary.

| Aspect Characteristic | Category | Answer (%) |
|---|---|---|
| Sex | Female | 51% |
| | Male | 49% |
| Age | 18-24 | 6% |
| | 25-34 | 13% |
| | 35-44 | 28% |
| | 45-54 | 27% |
| | 55-64 | 21% |
| | 65-74 | 5% |
| | >74 | 6% |
| Educational Level | Master | 0% |
| | Bachelor | 0% |
| | Secondary school | 23% |
| | Primary school | 54% |
| | None of the above options | 23% |
| Size of own garden parcel ($m^2$ of cultivated soil) | <99 | 9% |
| | 100-299 | 47% |
| | 300-499 | 26% |
| | 500-699 | 14% |
| | >700 | 5% |

**Section 2**

*Production system*

According to the orientation of the SDR office, three production systems were possible to identify among community gardens:

1. *Conventional system*: it is the traditional cropping system adopted by the majority of garden beneficiaries. Gardeners are not adopting a clear methodology regarding fertilizer and pest and disease management. In addition to organic fertilizer, they are adopting the mineral one. Concerning pest management, chemical insecticide and fungicides are sometimes used. The technical decision (how much water, how much fertilizer) is based on their own experience, and growers mainly focus on lettuce, coriander, and green onion production.
2. *Integrated system*: The gardeners adopting such cropping systems are diversifying crop management, increasing biodiversity, including in the garden new species of vegetables and flowers and aromatic plants. Regarding pest and disease management, they adopt the integrated pest management utilizing organic control and chemical pesticides only under a technical recommendation made by the technicians from the SDR of Teresina city.
3. *Organic system*: The gardeners adopting it are following all the guidelines suggested by the organic cropping system. Growers are using their compost as fertilizer and are adopting organic strategies to manage pests and diseases. High biodiversity is also promoted inside the gardens. It is important to mention that the organic system adopted by some growers is not yet certified. The SDR is working to obtain the certification.

Generally, in a single garden there is not an unique cropping system and it is possible to identify different cultivation approaches accordingly to the initiative and knowledge of each grower. An average of 36% of growers are still adopting a conventional cropping system, 25% are adopting an integrated system, and 39% of growers started to adopt the organic approach. Nevertheless, only growers from the Soinho community garden adopt 100% of the organic cultivation system **(Table 3)**.

**Table 2-3:** Cropping system adopted by the beneficiaries

| Description | % of growers adopting cropping system | | | | |
|---|---|---|---|---|---|
| **Production system** | **Soinho** | **Vila Nova** | **Tabuleta** | **P. Ideal** | **C. Feitosa** |
| Conventional system | 0% | 54% | 40% | 29% | 57% |
| Integrated system | 0% | 31% | 30% | 33% | 33% |
| Organic system | 100% | 15% | 30% | 38% | 10% |

*Irrigation strategy*

Two irrigation strategies were observed in the community gardens. Mostly, irrigation management was carried out based on the gardeners' traditional local habit using manual irrigation. Water is distributed across cultivated plots through manual labor, and usually, a 10 L watering bucket is used. The amount of water distributed in the cultivated plot is based on growers' experience. Some community gardens are adopting a micro-sprinkler irrigation system, usually provided by the SDR of Teresina City.

The micro-sprinkler system is adopting only in the Soinho Community garden, Tabuleta, and Parque Ideal UCG. However, all gardeners are integrating the irrigation also with manual intervention. A water committee (constituted inside the garden) manages the micro-sprinkler system, and the irrigation time is according to technical advice. Nevertheless, all growers interviewed consider the irrigation water distributed by the system not enough; thus, they integrate with the manual irrigation system. Vila Nova and Carlos Feitosa Community garden adopt 100% manual irrigation because they are not equipped with a micro-sprinkler irrigation system. It should be noted that until three years ago, both gardens were equipped with the Drip Irrigation System (Carlos Feitosa) and Sprinkler (Vilanova). Currently, both systems are not working because they are considered by growers challenging to use and manage. The irrigation system is provided by the SDR that selected some community gardens to test it and allow the gardenersto gain experience in irrigation system management. Only 7% of growers interviewed would be willing to finance the installation of the irrigation system themselves.

*Irrigation Water and Soil quality*

Most of the gardeners consider the water quality used in the garden, has good features from visual and taste points of view (figure 13). Only 8% of growers interviewed (from Soinho Community garden) affirm that they know the chemical properties of water used for irrigation, but they do not know how to interpret it.

A similar trend is also observed regarding the knowledge by the gardeners of chemical and physical soil property. Only 23% of total growers interviewed at Soinho community garden growers affirmed to be aware of soil property. All other gardeners interviewed affirmed that they do not know soil property. Despite it, the soil used for gardening is considered good quality and suitable for many gardeners' growing vegetables.

*Productive Parameters*

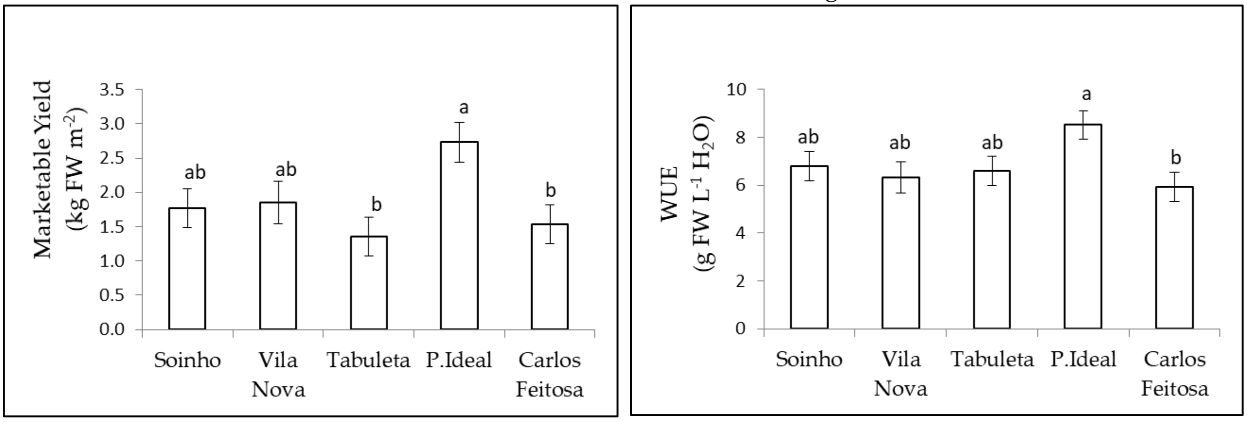
In all the surveyed gardens, the main crops cultivated are Lettuce (*Lactuca sativa*), Coriander (*Coriandrum sativum*), and Green onion (*Allium schoenoprasum*) mainly due to their high marketable potential in the local market. Besides the mentioned cash crops, gardeners also produce tomatoes, peppers, sweet potatoes, and aromatic plants, mainly for their family consumption.

*Marketable yield and WUE*

**Lettuce**

Significant differences among community gardens at $p \leq 0.005$ were noticed for marketable yield and WUE. The highest fresh weight was obtained in the Community garden of P. Ideal with 2.73 kg of FW $m^{-2}$. No significant difference was observed with Soinho and Vila Nova's results. The lowest yield was noted in Carlos Feitosa and Tabuleta UCG, respectively, 1.53 and 1.35 kg of FW $m^{-2}$ **(Figure 2-2)**. Regarding WUE, no significant difference was observed among

P. Ideal, Tabuleta, Soinho and Vila Nova Community garden with an average of WUE of 7,05 g FW l-1 $H_2O$. The lowest value of WUE has been observed in the Carlos Feitosa UG a value of 5,92 g FW l-1 $H_2O$.

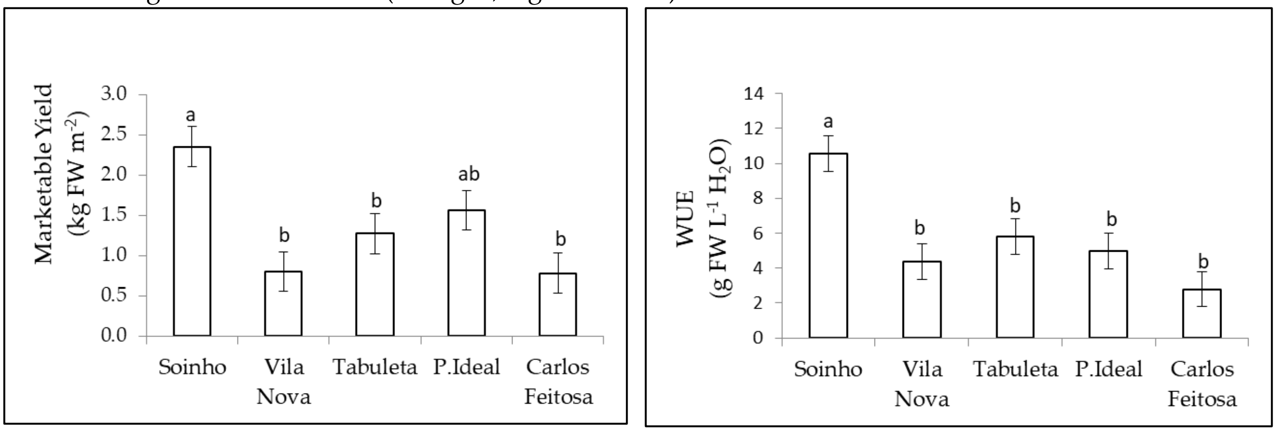



**(a)** **(b)**

**Figure 2-2.** Lettuce Marketable Yield (**a**) and Water Use Efficiency (WUE, **b**). Vertical bars represent standard errors. Different letters indicate significant differences with P≤0.05.

**Coriander**

The significant difference among community gardens at $p \leq 0.001$ was also observed for marketable yield and WUE in coriander species. The highest value of fresh weight was shown in the Community garden of Soinho with 2.35 kg of FW $m^{-2}$ **(Figure 2-3)**. No significant difference was observed in P. Ideal gardens while the others showed the lower production **(Figure 2-3)** with an average marketable yield of 0,95 kg of FW $m^{-2}$ **(data not shown)**. Similar trend was also observed for the WUE, with the highest value obtained at Soinho CG (10.5 g FW $L^{-1}$ $H_2O$) while the others treatments showed the significant lower results (average 4,48 g FW $L^{-1}$ $H_2O$).

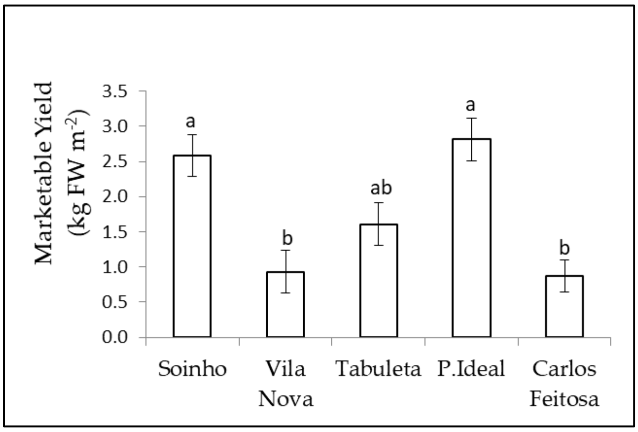



**(a)** **(b)**

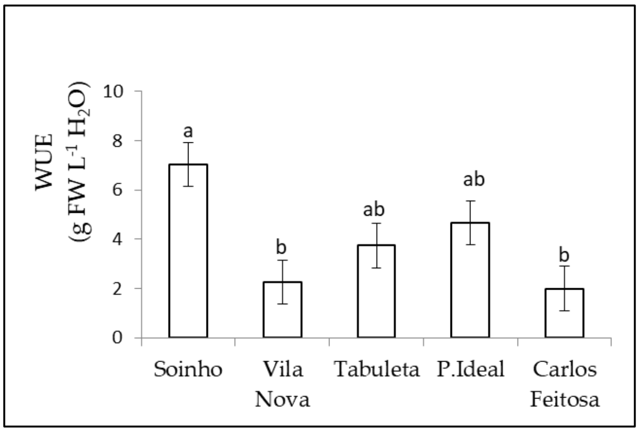
**Figure 2-3.** Coriander Marketable Yield (**a**) and Water Use Efficiency (WUE, **b**). Vertical bars represent standard errors. Different letters indicate significant differences with P≤0.05.

**Green onion**

Significant differences among community gardens at $p \leq 0.001$ were also observed for marketable yield and WUE. The highest value of fresh weight was shown in the Community garden of P. Ideal and Soinho with 2.81 and 2.58 kg of FW $m^{-2}$. The lowest marketable yield was obtained at Vila Nova and Carlos Feitosa Urban Garden with 0,93 and 0,87 kg of FW $m^{-2}$ **(Figure 2-4)**. Regarding WUE, Soinho obtained the highest value (7,03 g FW $L^{-1}$ $H_2O$) and Carlos Feitosa, the lowest one with 1,99 g FW $L^{-1}$ $H_2O$ **(Figure 2-4)**.




**(a)**




**(b)**

**Figure 2-4.** Green Onion Marketable Yield (**a**) and Water Use Efficiency (WUE, **b**). Vertical bars represent standard errors. Different letters indicate significant differences with P≤0.05.

**Section 3**

The 90% of gardeners affirmed that they want to continue the activity in the next ten years for mainly three reasons:
- the garden is an opportunity to generate income and facilitate access to fresh food for the family;
- the garden allows gardeners to retire as rural farmers;
- the garden is a crucial socialization place for the gardeners and their family.

Sixty-one percent of interviewed are aware concerning the future water availability constrain, and water availability probably will decrease in the next ten years. The 92% of growers are conscious that their irrigation management must be improved mainly by reducing water wastefulness.
Forty-eight percentof gardeners pretend to change the cropping system from conventional or integrated cropping systems to organic systems. The market requirements and market price are the main reason why the farmer would be willing to change the cropping system. Only 13% of the interviewees cited motivation for climate change and natural resources (e.g. water resources).
Most of the gardeners (85%) consider soil and water analysis essential to improve the garden's management and make it more environmentally sustainable. Fifty-six percent out of 85% agree to carry out soil and water analysis only if performed and paid by public agencies such as SDR of Teresina City. The 29% of gardeners (mainly from Soinho, Tabuleta, and P. Ideal) are willing to pay for the analyses with their funds. The community gardens of Vilanova and Carlos Feitosa consider the analysis of irrigation water and soil not necessary since only 5% and 15% of the gardeners of their respective gardens gave a positive opinion **(Table 2-4)**.

**Table 2-4** Perception of beneficiaries regarding the management of the garden in the near future

| Description | Category | Answer (%) |
|---|---|---|
| **In the next ten years, do you intend to continue your activity in the community garden?** | Yes, I do | 90% |
| | No, I don't | 5% |
| | I don't know | 5% |
| **In the next ten years, in your opinion, what could be the scenario related to the availability of water for agriculture?** | Decrease availability | 61% |
| | It doesn't change | 14% |
| | Increase availability | 16% |
| | I don't know | 9% |
| | No, I don't | 33% |

| | | |
|---|---|---|
| **In the next ten years, do you intend to change the cultivation system?** | Yes, I do. According to market opportunity | 27% |
| | Yes, I do. According to the climate change situation and sustainable production. | 13% |
| | Yes, I do, to reduce the production cost. | 8% |
| | I do not Know | 19% |
| **Do you consider it important to perform periodic soil analysis to check the main soil fertility parameters?** | YES, I do. But only if performed and paid by public agencies | 56% |
| | Yes, I do. I would be willing to cover the costs of analysis | 29% |
| | No, it is not necessary | 11% |
| | I do not know | 4% |

### 2.4 Discussion

*Climate*

This survey's main outcome is that the community gardens involved in the study are managed with different cultivation systems and garden management methodology, leading to a significant difference in the productivity of the three main vegetable crops grown (Lettuce, Coriander, and Green onion). Wheeler et al. indicated 23 °C as the ideal daily temperature for growing lettuce, a condition that is far below the mean temperatures observed during the survey (Wheeler *et al*. 1993). The optimal growing temperature for coriander ranges 16-24° C (Silva *et al*., 2005), and for green onion20-25°C (Smith *et al*., 2011). Even though the average yearly temperature in Teresina is 28.9 °C and during the survey period the climatic conditions were absolutely not favourable for the cultivation of leafy vegetables, with average minimum temperatures of 21.8°C and maximum temperatures of 35.3°C, the yield was satisfactory. Outside this period, the air temperature rises considerably between September and November, with average minimum temperatures of 24.2 °C and maximum temperatures of 38.2 °C, and plant growth is limited. Between December and May, extreme rainy events occur, which lead to a reduction of up to 50% in production capacity compared to the period considered by the survey (beneficiaries' declaration). This is probably due to flooding and soil waterlogging that promote development of soil-borne diseases. Among them, the most significant are the pathogens that affect the root system, such as *Fusarium, Rhizoctonia* sp., and *Macrophomina phaseolina* (Martins, 2020). Boyer (1982) also observed that environmental stress is the leading cause of crop losses globally, decreasing average yields for most vegetables by more than 50% (Boyer 1982, Bray *et al*. 2000). La Pena *et al*. (2007), confirm that vegetable production in tropical areas is frequently limited during the rainy season due to excessive moisture caused by heavy rain. Most vegetables are highly sensitive to flooding, and genetic variation concerning this character is limited. Generally, damage to vegetables by flooding is due to reduced oxygen in the root zone, inhibiting aerobic processes (La Pena *et al*., 2007).

*Soil Characteristics and Management*

As reported by Pardossi *et al*. (2018), suitable pH for most vegetable crops ranges from 5.5 to 7. This pH range can assure the high bioavailability of most nutrients essential for vegetable growth and development (Ronen, 2016). The pH of the garden (average pH is 7.1) is much higher than that in the native area (4.5). The pH value obtained in the native place is similar to values observed by Silva Matias *et al*. (2009), in some areas of Piauì State. They found that native sites of the southeast region of Piauì State have an average pH of 4.8 (Silva Matias *et al*., 2009). Growers, based on technical recommendation, are adding limestone ($CaMg(CO_3)_2$) in the soil to adjust soil pH and, consequently, the % of soil base saturation (%BS). The pH values are neutral except for

Tabuleta UCG, which is weakly acidic, bringing a lower basic saturation. Except for Tabuleta UCG, pH values can be considered excessive due to excessive limestone and organic manure added into the soil to increase soil pH. All garden resulted in having high % values of BS (average 95.3%) except for the Tabuleta Garden that, according to the results, has a %BS of 73.3. Aquino *et al*. (2004) observed that the best value of base saturation should be 80% (Aquino *et al*., 2004). Decreasing pH provides greater nutrients availability. Studies have shown that increasing soil pH with liming results in a linear reduction of soil exchangeable $Al^{3+}$ contents (Araújo, 2009). Pavao *et al*. (2014) reported that calcium carbonates ($CaCO_3$) and magnesium carbonate ($MgCO_3$) react with soil hydrogen releasing water and carbon dioxide. The aluminium is insolubilized in the hydroxide form (Pavão *et al*., 2014). However, most of the gardens' pH can be considered high and not ideal for the targeted crops (Liu *et al*., 2012). When soil pH is adversely high, Fe, Mn, and Zn will become difficult for vegetable plants to be used. Thomson *et al*. (1993) reported in one study that bean (*Phaseolus vulgaris* L.) absorbed 93.3% more P, 53.8% more Fe, and 44.1% more Zn at pH 5.4 than at pH 7.3, respectively.

Moreover, high soil pH (greater than 7.2) causes ammonia volatilization from soils fertilized with ammoniacal-N sources, such as ammonium sulphate or ammonium-forming fertilizers (Enzo *et al*., 2001). At soil pH greater than 7.0, nitrate leaching increases proportionately as soil pH increases. Therefore, high soil pH exacerbates anionic nutrient leaching and reduces nutrient use efficiency (Costa and Seidel, 2010).

Electrical conductivity values are not limiting the production since the highest value does not reach 0.5 dS $m^{-1}$, and even sensitive crops should not have problems below 2 dS $m^{-1}$ (Jim J. Miller, 2006).

The organic matter in the soil can be considered adequate since values range between 2.5 and 3 % (Giandon, 2004; Carvalho Leite *et al*., 2014).

The measured cation exchange capacity can be considered average (>10 $cmol_c$/$dm^3$) for all the soil except for Tabuleta UCG that is 8.95 $cmol_c$/$dm^3$ (Giandon, 2004; Carvalho Leite *et al*., 2014). Probably this parameter is limited by the low clay content of the soils. Indeed, the only sample with loam texture (Carlos Feitosa) is the one with the highest cation exchange capacity (Carvalho Leite *et al*., 2014). However, the basic saturation is relatively high due to the pH values, allowing the buffer system to work correctly.

The concentration of adsorbed ions on the exchangers is entirely consistent with the pH values, and the percentages of cation exchange capacity do not deviate too much from the optimal ranges (Perelli, 2009).

The ESP (Exchangeable Sodium Percentage) was calculated, obtained the highest value in the Vila Nova soil sample (3.43%), but remains well below the limit value for sodic soil (15%) (Mohammad Zaman, 2018; Carvalho Leite *et al*., 2014). It is also considered the Mg/K ratio, which should be between 2 and 5. The values obtained are within the recommended range except for Parque Ideal, which obtained an Mg/K value of 6.22. Its value could negatively affect the potassium availability, and therefore, a higher supply of potassium should be added compared to magnesium supply (Perelli, 2009; Carvalho Leite *et al*., 2014).

Another aspect exalted by the soil analysis is related to the available phosphorus content in the gardens; mainly, the available phosphorus represents the critical fraction of the agronomic perspective. Native soil samples confirm the low range (3.9 mg/$dm^3$) of available phosphorus in tropical soils (Dabin, 1980). Despite it, the garden's soil samples' data showed very high available phosphorus (average content of 243 mg/$dm^3$). These results are consistent with the fertilization plan, consisting of continually adding high quantities of goat manure mixed with carnauba palm straw (used in carnauba wax extraction), rice husk throughout the year. The chemical composition of the organic mixture applied in the growers' cultivation plots, in general, does not differ from other compounds that usually present higher values for N, and apparently, P is not abundant. However, this material's C/N ratio is low, less than 10:1, thus favouring a high mineralization rate, which can be reflected in P's accumulation. Therefore, this last aspect associated with high amounts of phosphorus applied in the soil by gardeners leads to a high accumulation of phosphorus in the soil. Gardeners distribute high amount of the mentioned material, ranging from 6 to 8 kg per $m^{2,}$ and such quantity is added at the beginning of each crop cycle and, therefore, several times during the year. Some producers also use chicken manure to fertilize the beds before planting. These values are equivalent to 60 – 80 t $ha^{-1}$ of goat manure (corresponding to 1200 kg $ha^{-1}$ of $P_2O_5$ at each application), determining a continuous accumulation of phosphorus and potassium in the soil as shown by the soil analysis. Mantovani *et al*. (2014), in a study conducted in Mina Gerais – Brazil, stated that the amount of 800 kg $ha^{-1}$ of $P_2O_5$ is the most appropriate for the cultivation of lettuce. Nevertheless, the classic agronomic recommendations about the amount of phosphorus for vegetable production vary from 150 to 200 kg $ha^{-1}$ (Pardossi *et al*., 2018); therefore, even the 800 kg reported in the study mentioned above is to be considered excessive.

Moreover, the soil content of carbonates, which are almost absent contributes to further useless phosphorus availability. Indeed, when available phosphorus values are above 20 mg/$dm^3$ P fertilization is usually considered unnecessary, as crop response is virtually absent (Perelli, 2009; Carvalho Leite, *et al*., 2014). Therefore, phosphorus availability can be regarded as excessive in all the samples, making further fertilization not only superfluous but potentially dangerous (mainly during the rainy season) because the excess of phosphorus could be responsible for eutrophication phenomena (Klein *et al*., 2012).

Several works highlight the P enrichment of agricultural soils after years of P application above the harvested products' export capacity. In France, about 82% of soil total P is of anthropogenic origin (Ringeval *et al*., 2014). In Brazil, between 2008 and 2012, only 52% of the P applied as inorganic fertilizers were exported in harvested products (Roy *et al*., 2016). Withers *et al*. 2017 report that rural producers face a crisis in phosphorus availability and water pollution due to excessive use of this element. A crisis that will probably worsen in the next 50-100 years and lead to an increase in phosphorus and food prices. Therefore, there is an urgent need to reduce phosphorus supply in the soil (Withers *et al*., 2017).

It is clear that soil fertility management in Teresina's urban gardens is managed using a "rule of thumb" without considering the soil and crops' real needs. The results obtained from this survey indicate that additional phosphorus and potassium supply in the soil is unnecessary, and the priority is the identification of alternative sources of nitrogen to apply individually in the growing plots. The introduction of cover crops and green manure practice should be encouraged within urban gardens (Gaskell *et al*., 2007).

*Yield and WUE*

Concerning lettuce species, the highest yield and WUE values were associated with Parque Ideal UCG with 2.73 kg $m^{-2}$ and 8.51 g FW $L^{-1}$ $H_2O$, respectively. Significant differences were found between the marketable yield obtained in the Parque Ideal, Tabuleta and Carlos Feitosa UCGs. The average marketable yield obtained from the community gardens is 1,84 kg $m^{-2,}$ corresponding to 18,4 Mg $ha^{-1,}$ and that we can consider satisfactory and in agreement with productions obtained in similar contexts. An experiment carried out in Myanmar on lettuce, showed that average lettuce production cultivated on soil system in tropical areas range between 1.82 kg $m^{-2}$ and 2.4 kg $m^{-2}$ (Michelon *et al*, 2020a, b). Although yield is satisfactory, WUE in Teresina CUGs showed very low values (6,82 g FW $L^{-1}$ $H_2O$) as compared to WUE values obtained in Myanmar in similar soil and climate conditions where appropriate irrigation strategies were adopted. In Teresina UCGs the low WUE is attributable to high daily irrigation water provided by the beneficiaries in their gardens. Considering the months in which the study was conducted (August, September 2019), the average daily evapotranspiration was 5.2 mm. Considering the lettuce crop with the cycle divided into three phases and with Kc of 0.7, 1.0, and 0.95 (Michelon *et al*., 2020b), the monthly cumulative crop evapotranspiration ($Et_c$) of a lettuce cycle (with the length of 31 days after transplant) was 142 mm. Based on the beneficiaries' irrigation schedule usually adopted, they provided 223.2 mm, equivalent to 80 liter $m^{-2}$ or 57% more irrigation water than necessary considering to restore 100% of $ET_c$. As mentioned before, Michelon et al. (2020b) observed that it is possible to obtain a satisfactory lettuce yield, even providing only 50% of $ET_c$. Considering it, the amount of water that could be possible to save in a lettuce cycle in Teresina UCGs is equivalent to 152 mm of irrigation water corresponding to 68% of water actually applied. Since the large surface occupied by Teresina's urban garden (115 ha), the amount of irrigation water wasted just for one cycle of lettuce could be estimated in 93.127 $m^3$ and 174.800 $m^3$ as compared to the irrigation managed restoring 100% of $ET_c$ and 50% of $ET_c$, respectively. Michelon *et al*. (2020b) highlighted that adopting accurate irrigation management (accurate management of drip irrigation system and mulching practices) can significantly improve the water use efficiency in vegetable production (from 11 to 58 g FW $L^{-1}$ $H_2O$) (Michelon *et al*., 2020b). Maraseni *et al*. (2012) also detected the highest values of WUE (19 g FW $L^{-1}$ $H_2O$) in lettuce growth with a drip irrigation system in eastern Australia. Moreover, Fecondini *et al*. (2009b) observed that the introduction of simplified soilless system culture (SSC) in urban areas may also contribute to horticultural production and food security and maximize the WUE. Furthermore, Michelon *et al*. (2020a), in an experiment carried out in Teresina City, showed that the adoption of SSC considerable improved yield (35%) and WUE (7.7 times) as compared to traditional on-soil cultivation practiced by the growers of Teresina UCG.

Concerning coriander crop, the highest yield and WUE values were found in Soinho community garden with 2.35 kg $m^{-2}$ and 10.5 g FW $L^{-1}$ $H_2O$, respectively, and significant differences were found between the garden mentioned above and the others UCGs. The average marketable yield obtained from all the community gardens is 1,35 kg $m^{-2}$ of plant fresh weight, corresponding to 13,5 Mg $ha^{-1}$ that it is a reasonable production comparing to results obtained in others study on coriander. Angeli *et al*. (2012), in a study performed in Minas Gerais (Brasil) to evaluate the agriculture performance and the water use efficiency (WUE) in coriander subjected to different water depths and N doses, obtained a production of 2,9 kg FW $m^{-2}$.
Also in this case, the average WUE observed among gardens in this study is much lower as compared to values obtained in other researchs. Angeli *et al*., 2016, obtained values of WUE of 49.8 g FW $l^{-1}H_2O$. Again, also coriander WUE could be increased by growing it in the low cost-hydroponic system (SSC) as observed by Santos Júnior *et al*. (2015).
Concerning green onion species, the highest yield values were found in Parque Ideal, and Soinho Community gardens with 2.81 kg $m^{-2}$ (28,1 Mg $ha^{-1}$) and 2.58 kg $m^{-2}$ (25,8 Mg $ha^{-1}$), respectively, and significant differences were found comparing with the others community gardens. Simões *et al*. (2016) observed similar green onion marketable yield values in a study carried out in Acre State of Brazil aimed at evaluating the effect of the combination of plant density and harvest method on productivity and yield components of crop. They observed that the total and marketable productivity ranged between 2,98 and 3.53 kg $m^{-2}$, according to the plant spacing (21 and 22 cm, respectively) (Simões *et al*., 2016).
With regards to the WUE the highest values were obtained from the community garden of Soinho (7.03 g FW $L^{-1}$ $H_2O$), while the values obtained by Parque Ideal were lower (4.66 g FW $L^{-1}$ $H_2O$) and did not differ significantly from the other gardens. It indicates that the Parque Ideal UCG garden gardeners do not adequately manage the water resource providing much more water than plants need. The last sentence could also be confirmed, taking as reference another scientific article on the same topic. Silva *et al*. (2020), detected a WUE concerning Green onion production in the range of 5.2 g of dry mass per $L^{-1}$ $H_2O$, corresponding to 65 g FW $L^{-1}$ $H_2O$ (Leal *et al*., 2005).

These findings suggest that the gardeners of UCGs of Teresina city need more knowledge and tools to adapt and mitigate the adverse effects of local climate on vegetable productivity. Thus, simplified technologies, affordable, and accessible must be introduced to improve natural resources use efficiency by the beneficiaries. For instance, local growers could apply a shading net on the crop to reduce the sunlight intensity, and use soil mulching (utilizing, for example, locally available material as Carnauba leaves straw) during the hottest period of the year. Specific varieties selection and soil conservation practices to mitigate heavy rainfall and rainwater surface flow could be easily applied during the rainy season. Several studies report the benefits of the technology mentioned above. The utilization of 50% shading net on Rocket (*Eruca sativa* L.) production allowed to increase the production by 86.5% (Dalla Valle *et al*. 2016), while the use of straw mulching as a soil cover on lettuce grown in semiarid areas of Myanmar increased the fresh weight from 19% to 30% and WUE

from 21% to 22% as compared to lettuce cultivated on bare soil (Michelon *et al*., 2020b). In an experiment carried out in a semiarid area of the northeast of Brazil, soil mulching, using wood powder as a cover material, increased the dry weight of coriander by 18.2% (Neto *et al*., 2010). A similar trend was observed adopting as mulching material chopped "carnauba" straw (dos Santos *et al*., 2016).
In the community garden of Teresina, soil conservation practices (i.e. contour bunds) are also suggested to reduce run-off, soil erosion and waterlogging that lead to an inevitable reduction in production during the rainy season (Salviano *et al*., 1998; Hernandez, 2018).

It is evident how irrigation water management and awareness should be improved by the beneficiaries to enhance irrigation water use based on crop needs. It could be achieved by adopting soil moisture sensors. Michelon *et al*. (2020b), observed that it is possible to obtain a satisfactory yield of lettuce (1.8 kg $m^{-2}$) by restoring irrigation water based on the real soil moisture content, restoring water up to the field capacity whenever the soil moisture level fell below 50% of the available water (AW).

The constraints mentioned above, mainly related to high irrigation depths, low irrigation water efficiency, and impracticable soil during the rainy season, could also be overcome by adopting simplified soilless culture (SSC) systems. SSC showed high potentialities in terms of both yield and WUE compared with traditional on-soil cultivation technologies, which were evidenced by various experiments carried out in similar contexts (Gianquinto *et al*., 2006. Michelon *et al*., 2020a). The application in urban areas of such a system would have additional advantages: 1) production of leafy vegetables all year around; 2) independency from soil fertility and flooding occurrence **(figure 2-5)**; 3) use of recycling material (rice hull, gravel, coconut fiber) as substrates; 4) better plant nutrition; 5) reduced use of pesticides (absence of soil born diseases) and production of clean produce (absence of soil residuals) (Fecondini *et al*., 2009a; Fecondini *et al*., 2009b; Orsini *et al*., 2009; Gianquinto *et al*., 2006; Michelon *et al*., 2020a).

**Figure 2-5.** A simplified soilless system in Teresina - Brazil

**2.5 Conclusions**

Teresina's urban gardens can contribute to the integration into the region of many families, improving their livelihood, guaranteeing easier access to fresh food, and enhancing their food security and income through the sale of the production surplus. Indeed, despite an excellent yield capacity showed by the beneficiaries, the management of soil and water resources are relatively poor. It is clear that many of the beneficiaries still do not have enough knowledge and information about sustainable cultivation and good agriculture practices to guarantee better management of soil and water sources. Therefore, given the potential of urban gardens to produce a sufficient quantity of food, improved technical assistance, and an accurate irrigation management approach should be promoted within the gardens. An interdisciplinary approach and appropriate "dissemination & transference" will be essential to ensure that improved water management methodology will be implemented adequately by local institutions (PMT of Teresina) and beneficiaries.

## CHAPTER 3 – Use of different substrates and nutrient solution concentration for the production of Lettuce and Chinese cabbage seedlings in a semi-arid environment in central Myanmar

**Abstract.** The growing population of tropical countries has led to a new awareness of the importance of vegetables as a source of essential foods and nutrients. The success of vegetable cultivation depends to a large extent on high-quality seedlings. This work aimed at evaluating the effects of different substrates and different nutrient solution concentrations on the development of lettuce and Chinese cabbage seedlings in a semi-arid tropical area. Three independent experiments were conducted at the Soil and Water Research Station at Yezin Agriculture University, Myanmar (Myanmar, 19.83°N; 96.27°E). In all experiments a randomized block design was implemented with four treatments and three repetitions. In the first experiment the adaptability of lettuce seedling to two substrates (namely a Hulls Manure mix composed by 50% of mature cattle manure and 50% of carbonized rice husk and Soil Based Substrate constituted by 70% local soil, 20% burned rice husk, and 10% fresh cattle manure) and two nutrient solutions with different Electrical Conductivity (EC) ($W_{0.1}$, stored rainwater with EC=0.13 dS $m^{-1}$and $NS_{1.2}$, nutrient solution with EC=1.20 dS $m^{-1}$) were tested. In the second and third experiments, two species (lettuce and Chinese cabbage) were assessed for their response to nutrient solution concentrations. In both crops, 4 fertigation treatments ($W_{0.1}$; $NS_{0.6}$; $NS_{1.2}$; $NS_{1.8}$) were supplied, by modulating the concentration of a compound mineral fertilizer (15:15:15 ) in the following ranges: $W_{0.1}$: 0 g $L^{-1}$, Electrical Conductivity (EC) 0.13 dS $m^{-1}$, $NS_{0.6}$: 0.3 g $L^{-1}$, EC of 0.60 dS $m^{-1}$; $NS_{1.2}$: 0.6 g $L^{-1}$, 1.2 dS $m^{-1}$ EC, and $NS_{1.8}$: 0.9 g $L^{-1}$, 1.8 dS $m^{-1}$ EC. Adopting different substrates and applying different nutrient solutions significantly affected growth (fresh weight and leaf morphology) and some physiological parameters (stomatal conductance, leaf temperature, leaf chlorophyll content of lettuce and Chinese cabbage seedling. From the first experiment, the combination of Soil Based Substrate and $NS_{1.2}$ treatments allowed to improve seedlings' growth. In the second experiment, highest growth of lettuce and Chinese cabbage seedlings was associated with $NS_{1.2}$ and $NS_{1.8}$, respectively. The presented results allow for the optimization of both growing media and nutrient solution management when lettuce and Chinese cabbage seedling are produced in the Central Dry Zone of Myanmar.

**Keywords:** seedling quality, plant nursery; electrical conductivity, *Lactuca sativa* L., *Brassica juncea*.

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### 3.1 Introduction

Climate change and world population increase are leading to a new awareness on the importance of vegetable crops as a source of food. This is particularly relevant, since vegetables can supply essential nutrients (e.g., vitamins and minerals) that are otherwise not available from other foods (Bezerra *et al.*, 2003). Moreover, the current sanitary emergency due to the COVID19 pandemic will likely reinforce the importance of getting knowledge and awareness regarding the cultivation of own vegetables to increase family food security (Laborde *et al*., 2020; Vittuari *et al*., 2021). Small scale production of vegetables can improve food security and build greater resilience, mainly in vulnerable families (Burton *et al*., 2013). The Dry Zone of Myanmar lies in the central area of the country, crossed by the Ayeyarwady River, between latitudes 19° 20" to 22° 50" and longitudes 93° 40" to 96° 30." The area covers about 13 percent of the country's total area with a population of roughly 14.5 million, close to a third of the country's population. The Dry Zone population's livelihood is highly dependent on the south-west monsoon, which provides the region's annual share of rainfall. Precipitations are mostly confined to the period from June to mid-October (LIFT, 2020). The local horticulture production is basically limited to onion cultivated grown along the beds and banks of the surface streams. Other vegetables (tomato, Chinese cabbage, lettuce, chilli peppers, roselle and pumpkin) are cultivated for home consumption only and solely during the rainy season but actually, no particular care is paid to horticultural production (Gianquinto *et al*., 2007). People living in the Dry Zone of Myanmar generally face a food insecurity gap varying from 4 to 6 months each year and have to deal with irregular incomes due to limited job opportunities. As emerged by World Food Programme's survey 2013 (McCartney *et al*., 2013), food insecurity in the Dry Zone is mainly associated with poor access to food and markets. The limited alternative sources of income make the picture even more gloomy. Furthermore, in the Dry Zone no farmer can produce vegetables regularly due to a limited shortage of natural resources, limited budget and know-how, as well as the scarce access to innovative technologies for vegetable production. Accordingly, the local villagers' diet has been found unbalanced and extremely poor in vitamins and micronutrients, at least for half a year (LIFT, 2020). Fostering people to grow their own vegetables to reduce the food insecurity gap is therefore crucial. Nevertheless, the starting point to ensure final vegetable cultivation success depends mostly on high-quality seedlings (Bezerra *et al.*, 2003). Chinese cabbage *(Brassica juncea* L.*)* and lettuce (*Lactuca sativa* L.) are two leading fresh vegetables extensively grown in Myanmar. In the dry zone of Myanmar, the production of Chinese cabbage is high, reaching 763 MT year$^{-1}$ while lettuce production is still limited, achieving around 90 MT year$^{-1}$) (MoA, 2018). However, the increasing of leaf fresh vegetable production is one of the priorities identified by national and international agencies to stimulate the diversification of local vegetable production and improve the diet of people living in the dry zone of Myanmar by providing fresh vegetable (LIFT, 2009). From a nutritional perspective, both crops belong to the so-called green leafy vegetables, whose relevance in the diet is associated with their contributions in fibres, vitamins, and minerals (including calcium, iron, and phosphorous), carotenoids and other antioxidants (Prasad *et al*., 2008; Nicolle *et al*., 2004). People living in CDZ Myanmar consume minimal amounts of fresh vegetables while consuming mainly cooked vegetables. Chinese cabbage is consumed fried, resulting in some nutritional value loss because vitamins and antioxidants are lost through oxidation (Prasad *et al*., 2008; Nicolle *et al*., 2004; Humphries *et al*., 2002). Generally, lettuce and Chinese cabbage are transplanted, therefore appropriate seedling development is required. In countries with more developed economies (e.g. Europe or North America), seedlings are usually supplied by professional nurseries, who adopt commercial substrates in standard trays, which allow for saving both substrate and space while in South-East Asia vegetable seeds are usually broadcasted directly in the field, resulting in unequal distribution of seeds and subsequently uneven emergence and growth of seedlings (Ceglie, *et al*., 2010). Good quality seedlings guarantee a high rooting rate after transplanting, besides requiring less phytosanitary treatments (Oliveira *et al*., 1993). Furthermore, seedlings uniformity growing rate allows to save water, while also reducing damage to plants' roots at the time of transplanting (Cañizares *et al*., 2002). A main challenge for the vegetable production sector in the Central Dry Zone of Myanmar is represented by the scarce availability of good-quality seedlings (Trani *et al*., 2004). This study aims to assess the efficiency of simplified methodologies for the local production of lettuce and Chinese cabbage seedlings in CDZ-Myanmar by comparing two locally available substrates and different concentrations of a nutrient solution obtained by using a local compound fertilizer. The assumption is that the adoption of improved vegetable seedling production methodologies can ensure better quality seedling production compared to current traditional production. The study integrates figures from different crop features and management strategies to elaborate specific recommendations on the optimal management of seedling production.

## 3.2 Materials and Methods

### *3.2.1 Location*

Three experiments were conducted in open field conditions at Soil and Water Research Station of Yezin Agriculture University located in the University Campus, Central dry Zone of Myanmar, 16 km from the Capital Naypyidaw (19° 83' North and 96° 27' East, 122 m a.s.l.) **(figure 3-1a, b)**. According to Köppen's classification, the local climate is Aw type, which is tropical rainy with dry summer and rainy season concentrated between June and October.

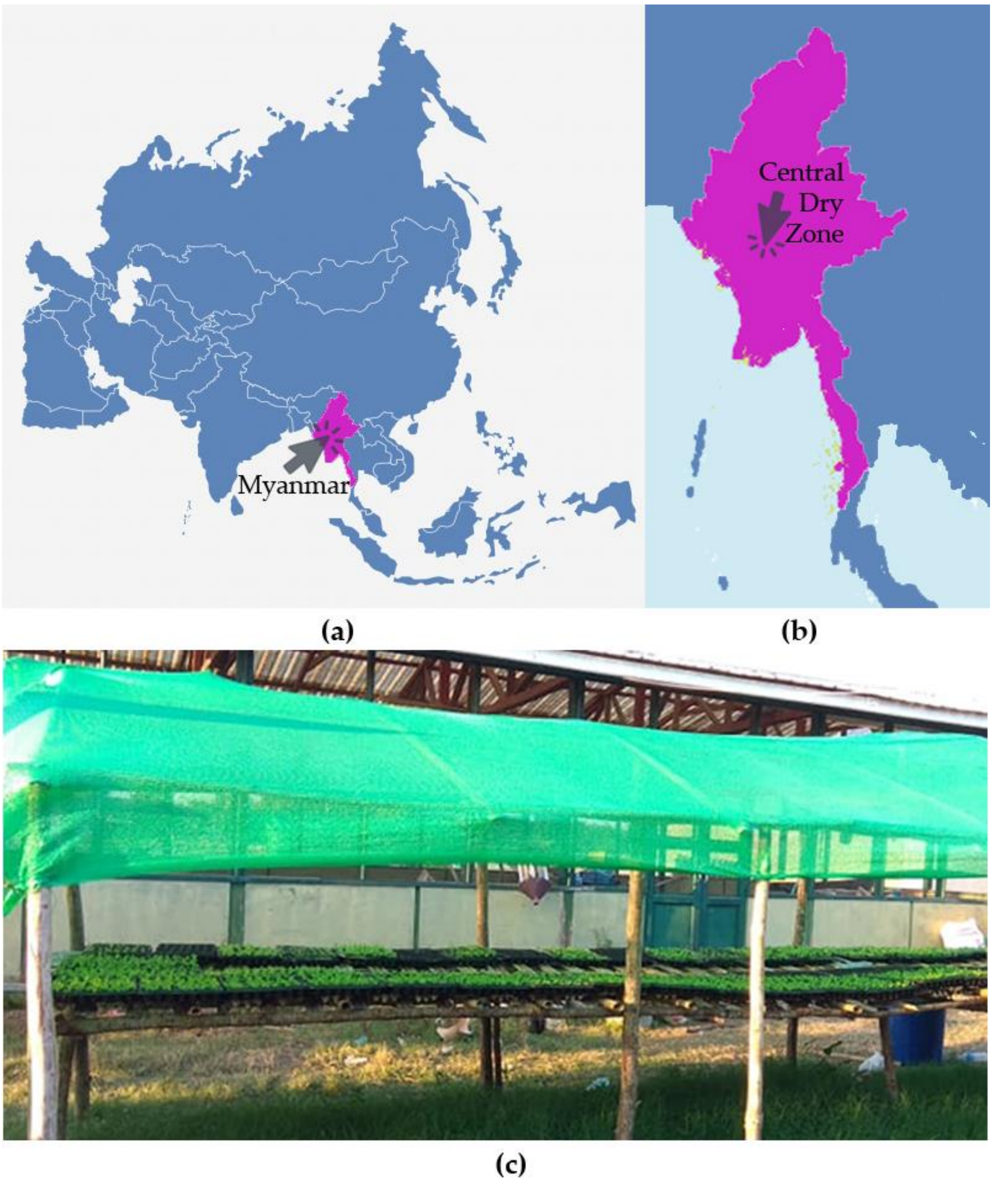



**Figure 3-1.** Location where the experiments took place in South-East Asia **(a)** and within the country **(a,b)**. Image of the low-tech experimental nursery used for the research **(c)**.

*3.2.2 Plant material and crop management*

The first two experiments were performed on lettuce (*Lactuca sativa* L.) cv. Green wave (Evergreen seeds, Sunnyvale, CA, USA), while the third one was carried out on Chinese cabbage (*Brassica juncea* L.*)* cv. Pavito (East West Seeds, Nanning, Guangxi, China). Both varieties are commonly sold in the local market of the main cities of dry zone such as Sagaing, Magway, and Mandalay. Sowing took place on January 9, 2020 (first experiment) and February 27, 2020 (second and third experiment). Crops were sown manually in 105 cells plastic seedling trays. The sizes of the seedling tray were the following: 45 cm length; 28 cm width and 5.5 cm dept. Plant density was 833 plants $m^{-2}$. Seedling trays were placed on a simple wooden/bamboo frame covered with a 70% shading net **(Figure 3-1c)** to reduce sunlight intensity while preserving air circulation from the open sides. For five days after sowing, irrigation was carried out only with clear water three times per day (at 7:00 a.m., 11:00 a.m., and 3:00 p.m.) to contribute also to washing the substrate, reducing its initial salinity identified in the laboratory. When 80% of seedlings presented fully expanded cotyledons, the germination process was considered completed, and treatments started. Plant fertilization was managed to supply 1 L per tray of nutrient solution twice a day (7:00 a.m. and 3:00 p.m.) while only water was supplied once a day at 11 a.m. using a 1-liter watering can.

*3.2.3 Treatments and experimental design*

*Experiment 1***:** A total of four treatments were considered, obtained by the factorial combination of two substrates (Soil Based Substrate, SBS, and Hulls Manure mix, HM-mix) and two nutrient solution concentrations (water, $W_{0.1}$, and water enriched with fertilizer, $NS_{1.2}$).

SBS (Soil Based Substrate) refers to the local common substrate generally used to grow vegetables seedlings, composed by 70% of local soil, 20% of burned rice husk, and 10% of fresh cattle manure. In this case, the rice husks are burned inside an iron tank up to turning husks into ashes. HM-mix (Hulls Manure mix) refers to a substrate formerly suggested for seedling production in the tropics (Fecondini *et al.*, 2008), composed by 50% of carbonized rice husk and 50% of well sifted mature cattle manure. Physical and chemical substrates characterization was performed at the laboratory of the Yezin Agriculture University of Naypyidaw (Myanmar). Electrical conductivity (EC) and pH were determined using the conductivity meter DS-51 and pH meter F-51 (HORIBA, Kyoto, Japan). Organic Matter (OM), Cation Exchange Capacity (CEC), and Water Holding Capacity (WHC) were determined using Tyurin's method, leaching method, and Keen-Razcowski measurement method, respectively (Seo *et al.*, 2004; Gillman *et al.*, 1983). Available N, P, and K were also analysed using the Alkaline permanganate method, Olsen's P-Malachite method, and Ammonium acetate extraction (Moe *et al.*, 2017; Beegle *et al.*, 1990).

During seedling preparation, local farmers commonly irrigate plants with harvested rainwater ($W_{0.1}$), featuring EC of 0.13 dS $m^{-1}$. Alternatively, a simplified nutrient solution ($NS_{1.2}$, featuring EC=1.2 dS $m^{-1}$) prepared using a compound fertilizer (N: 15%, P: 15%, K: 15%, S: 2%, CaO: 4.6%) at concentration of 0.8 g $L^{-1}$ was tested.

The experimental design was a completely randomized block design with four treatments and three replicates.

*Experiment 2 and 3***:** Four treatments were applied, obtained by using different mineral fertilizer concentrations, namely: $W_{0.1}$ (0 g $L^{-1}$ of fertilizer, EC=0.13 dS $m^{-1}$), $NS_{0.6}$ (0.4 g $L^{-1}$, EC=0.6 dS $m^{-1}$), $NS_{1.2}$ (0.8 g $L^{-1}$, EC=1.2 dS $m^{-1}$), and $NS_{1.8}$ (1.2 g $L^{-1}$, EC=1.8 dS $m^{-1}$). The cost for preparing 1000 litres of nutrient solution was of about 336 Kyats (0.25 USD) for $NS_{0.6}$; 672 Kyats (0.50 USD) for $NS_{1.2}$ and 1008 Kyats (0.75 USD) for $NS_{1.8}$. The same HM-mix adopted for experiment 1 (50% of rice husk and 50% of mature cattle manure) was used as growing media.

The experimental design was a completely randomized block design with four treatments and three replicates of each essay.

3.2.4 Rice husk carbonization process

The HM-mix is composed by cattle manure enriched with carbonized rice husk. The carbonization of the rice husk is performed by using a metal chimney (height of 1.5 m and diameter of 0.15 m, **Figure 3-2a)** that features a square perforated metal burner (28 cm height) at its base, where combustion takes place. The carbonization process starts with lighting a wood fire, which is quickly covered with the chimney. At this point, the rice husk is poured directly over the burner, creating a cone in contact with the chimney itself **(Figure 3-2b)** and undergoing a pyrolysis process. The carbonization process continues for around 3 hours, during which rice husk is turned several times to ensure homogeneous carbonization. When full carbonization is reached, the chimney is removed and water is poured over the carbonized rice husk to stop the combustion **(Figure 3-2c)**. The obtained carbonized rice husk (biochar) is then ready for use **(Figure 3-2d)**.


**Figure 3-2.** Phases of rice husk carbonization process: fire lighting and arrangement of the chimney (**a,b**) used for carbonization of rice husk (**b**). After cooling the rice husk with water (**c**), the carbonized rice husk (**d**) is ready for use. (Foto di Lorenzo Fellin)

*3.2.5 Measurements*

At 21 days after germination, morphological (experiment 1: leaf width and length; experiment 2 and 3: (seedling fresh weight, leaf number, leaf width and length) and physiological (experiment 1: leaf greenness and temperature; experiment 2 and 3: stomatal conductance, leaf greenness and leaf temperature) parameters were taken. Leaf temperature was assessed using an infrared thermometer model FLUKE 61 (Fluke Corporation, Everett, WA, USA). Stomatal conductance was measured using a handheld photosynthesis measurement system model CI-340 (Camas, WA, USA). Leaf greenness was estimated using SPAD 502 (Minolta, Osaka, Japan). Morphological measurements were obtained from 6 plants per treatment per each of the 3 replicates (n=18). Physiological measurements were made on the upper surface of the canopy on three leaves per each sampled plant, on 6 plants per treatment in each of the three replications (n=36).

*3.2.6 Statistical Analysis*

Data from experiment 1 were analysed using two-way ANOVA (substrate x nutrient solution), while data from experiment 2 and 3 were analysed using one-way ANOVA. Means were separated using the Tukey HSD test (Acutis *et al*., 2012) at $P \leq 0.05$. Before the analysis, all data were checked for normality and homogeneity of the variance. Averages and standard errors (SE) were calculated. Statistical analysis was carried out using R statistical software (version 3.3.2).

## 3.2 Results

*3.3.1 Climate during the experiments.*

The first experiment was carried out from January 9 to January 29, 2020. During cultivation, maximum air temperatures ranged between 28.5°C and 34.0°C, with an average of 32.3°C. Minimum temperatures ranged between 14.4 and 19.4 °C, with an average of 16.4°C. The average maximum relative humidity (RH) was73 %, and the minimum average RH was 50%. No rainfall occurred during the experiment.

The second and third experiments were carried out from February 27 to March 19, 2020. Maximum air temperatures ranged between 30.7°C and 38.6°C, with an average of 35.8°C. Minimum temperatures ranged between 16.0°C and 23.0°C, with an average of 21.0°C. The average maximum relative humidity (RH) was 59%, and the minimum average RH was 30%. No rainfall occurred during the experiment.

*3.3.2 Experiment 1-Lettuce*

Substrate

Results of physical and chemical substrates characterization are reported in **Table 3-1**.

**Table 3-1.** Physical and chemical substrates characterization

| Substrate | pH | EC[1] (dS $m^{-1}$) | Available N (mg $kg^{-1}$) | Available P (mg $kg^{-1}$) | Available K (mg $kg^{-1}$) | CEC[2] (meq 100 $gr^{-1}$) | OM[3] (%) | WHC[4] (mm $m^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| SBS | 6.3 | 4.0 | 99.5 | 311 | 800 | 5.6 | 0.14 | 41.7 |
| HM-mixed | 6.5 | 4.2 | 6.2 | 1433 | 6200 | 20.8 | 33.8 | 171 |

[1]EC= Electro Conductivity; [2]CEC= Cation Exchange Capacity; [3]OM= Organic Matter; [4]WHC= Water Holding Capacity

Both substrates have a sub-acid pH and a quite high EC, comparable to a moderately saline soil. Among the macronutrient analysed, the available nitrogen content was higher in SBS than in HM-mix. Contrarily, HM-mix had higher phosphorous and potassium, organic matter content and water holding capacity. The observed higher Cation Exchange Capacity (CEC) of HM-mixed substrate is also an indicator of a larger nutrient reserve available for the plant. Moreover, during irrigation/fertilization, water stagnation and runoff on the surface trays with the SBS substrate occurred, highlighting its low permeability, low infiltration capacity, and poor drainage compared to HM-mixed substrate.

Seedling Growth

For all parameters analysed no-significant interactions (p= 0.26 for leaf length; p= 0.20 for leaf width; p= 0.45 for leaf temperature and p= 0.77 for leaf chlorophyll content) between substrate and nutrient solution were observed, therefore the effect of the two factors is discussed separately. The adopted substrate only affected leaf length and width **(Table 3-2)**, whereas the nutrient solution affected all parameters analysed (**Table 3-2**). As compared with SBS, HM-mix use resulted in increased leaf length and width by 14% and 17%, respectively (**Table 3-2**). Leaf length and width as well as leaf greenness were the highest in seedlings grown with nutrient solution $NS_{1.2}$ (18.8 SPAD value), with 152%, 17% and 39% increase from seedling watered with clear water ($W_{0.1}$), respectively (**Table 3-3**). On the other hand, the highest leaf temperature was observed in seedling watered with $W_{0.1}$ (26.2°C). Seedling growth improvement is clearly visible from trays images (**Figure 3-3**).

**Table 3-2.** Experiment 1. Effect of substrate on lettuce seedlings leaf width and length. Data are means of the three replicates. SBS (Soil based substrate) = substrate composed of 70% soil, 20% burned rice husk, and 10% fresh cattle manure; HM-mix (Hulls Manure mix) =substrate composed of 50% mature cattle manure and 50% carbonized rice husk. Significance codes: **, significant differences at P≤0.01

| Treatment | Leaf length (cm) | Leaf width (cm) |
|---|---|---|
| SBS | 5.33 | 3.35 |
| HM-mix | 6.05 | 3.91 |
| | ** | ** |

**Table 3-3.** Experiment 1. Effect of nutrient solution ($W_{0.1}$: 0 g $L^{-1}$ of fertilizer, EC=0.13 dS $m^{-1}$; $NS_{1.2}$: 0.8 g $L^{-1}$ of fertilizer, EC=1.2 dS $m^{-1}$), on morphological and physiological parameters of lettuce seedlings. Significance codes: *, significant differences at P≤0.05; ***, significant differences at P≤0.001.

| Treatment | Leaf length (cm) | Leaf width (cm) | Leaf T (°C) | Leaf greenness (Spad value) |
|---|---|---|---|---|
| $W_{0.1}$ | 3.23 | 3.35 | 27.4 | 11.0 |
| $NS_{1.2}$ | 8.15 | 3.91 | 26.2 | 18.8 |
| | *** | *** | * | *** |

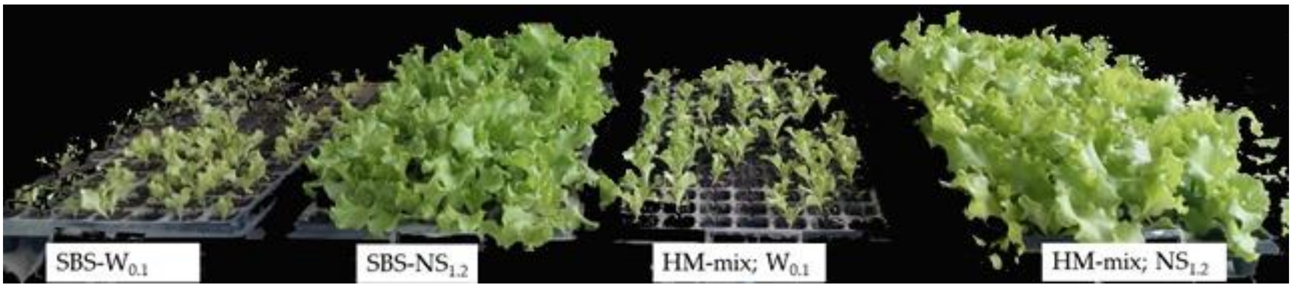



**Figure 3-3:** Experiment 1. Effect of nutrient solution and substrate on lettuce seedling growth. SBS (Soil based substrate) = substrate composed of 70% soil, 20% burned rice husk, and 10% fresh cattle manure; HM-mix (Hulls Manure mix) = substrate composed of 50% mature cattle manure and 50% carbonized rice husk. $W_{0.1}$=0 g $L^{-1}$ of fertilizer, EC=0.13 dS $m^{-1}$; $NS_{1.2}$= 0.8 g $L^{-1}$ of fertilizer, EC=1.2 dS $m^{-1}$.

*3.3.6 Experiment 2 -Lettuce*

Seedling Growth

*Productive and morphological parameters.* Seedling weight was affected by nutrient solution, reaching the highest value in seedlings grown in $NS_{1.2}$ (**Figure 3-4a**). The nutrient solution also influenced the number of leaves (**Table 3-4**), although significant differences were detected only between $W_{0.1}$ and the other nutrient solution treatments. Leaf length was the highest in $NS_{1.2}$ and $NS_{1.8}$ treatments and decreased with reducing the nutrient solution's mineral fertilizer concentration (**Table 3-4**). Finally, leaf width was not affected by nutrient solution treatments (**Table 3-4**).

*Physiological Parameter.* Leaf greenness was the highest in $NS_{1.8}$ and diminished with decreasing nutrient solution concentrations (**Figure 3-4b**). No significant difference was observed among $NS_{1.2}$ and $NS_{0.6}$, while the lowest value was obtained in $W_{0.1}$ treatment **(Figure 3-4b)**. Nutrient solution treatments affected stomatal conductance, which resulted to be the lowest in seedlings grown in $W_{0.1}$, while no significant differences were detected among the other nutrient solution treatments (average value of 315 mmol $m^{-2}$ $s^{-1}$) (**Figure 3-4c**). Leaf temperature was also affected by the nutrient solution concentration, with highest values in $W_{0.1}$ (33.4°C) and $NS_{0.6}$ (31.1°C), although, in this second case, without statistically significant differences as compared to $NS_{1.2}$ and $NS_{1.8}$ **(Figure 3-4d)**. Differences in plant growth are also visible in tray's images displayed in **Figure 3-5**.

**Figure 3-4.** Experiment 2. Effect of different nutrient solution concentration ($W_{0.1}$= 0 g $L^{-1}$ of fertilizer, EC=0.13 dS $m^{-1}$; $NS_{0.6}$= 0.4 g $L^{-1}$ of fertilizer, EC=0.60 dS $m^{-1}$; $NS_{1.2}$= 0.8 g $L^{-1}$ of fertilizer, EC=1.2 dS $m^{-1}$, and $NS_{1.8}$=1.2 g $L^{-1}$ of fertilizer, EC=1.8 dS $m^{-1}$) on morphological and physiological parameters of lettuce. **(a)** Seedling fresh weight (g $plant^{-1}$); **(b)** Leaf greenness; **(c)** Leaf stomatal conductance (gs, mmol $m^{-2}$ $s^{-1}$); (**d**) Leaf temperature (°C). NS=Nutrient Solution; Vertical bars indicate SE; different letters indicate significant differences with Tukey HSD test at P≤0.05.

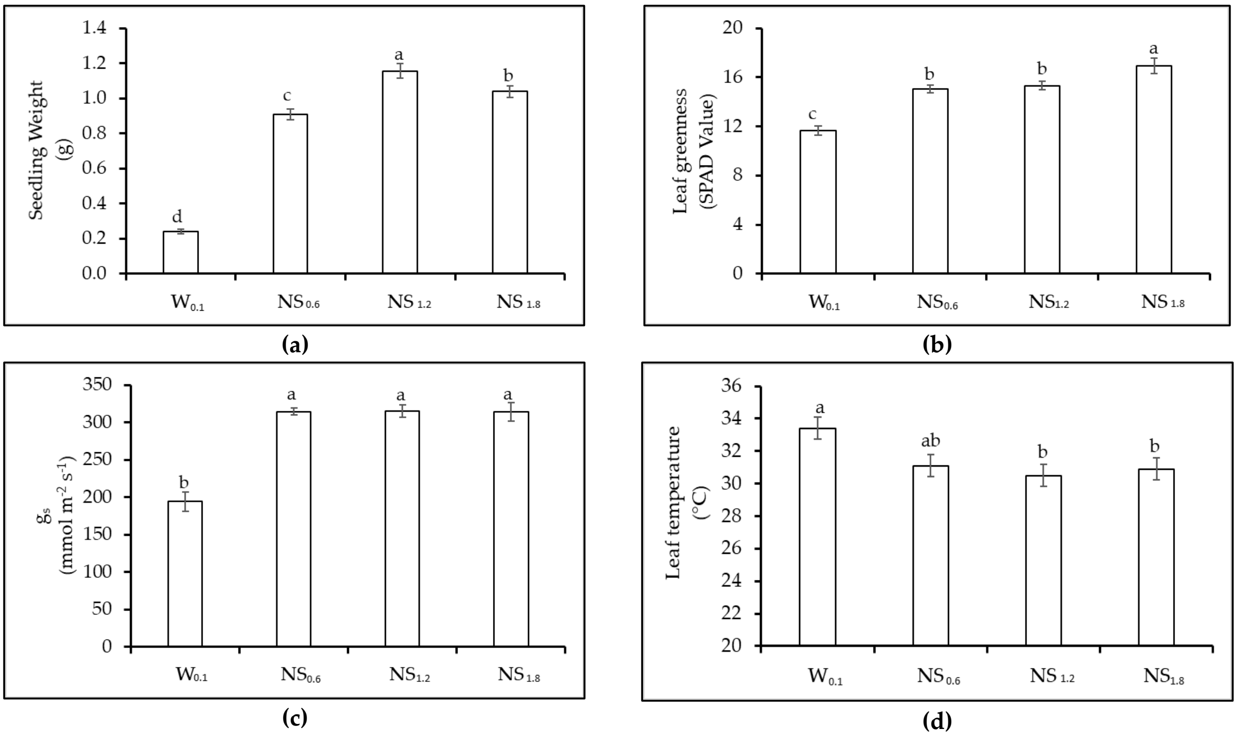
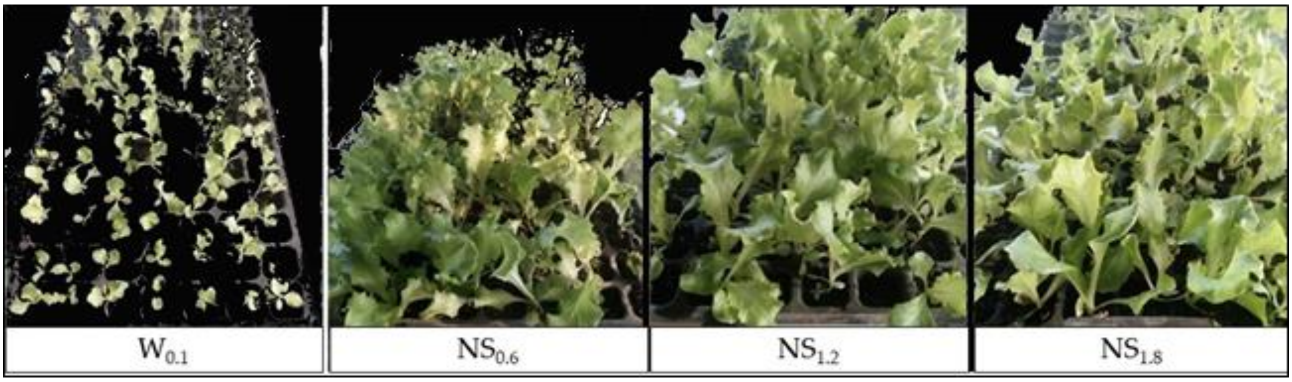


**Table 3-4.** Experiment 2. Effect of different nutrient solution concentration ($W_{0.1}$= 0 g $L^{-1}$ of fertilizer, EC=0.13 dS $m^{-1}$; $NS_{0.6}$= 0.4 g $L^{-1}$ of fertilizer, EC=0.60 dS $m^{-1}$; $NS_{1.2}$= 0.8 g $L^{-1}$ of fertilizer, EC=1.2 dS $m^{-1}$, and $NS_{1.8}$ =1.2 g $L^{-1}$ of fertilizer, EC=1.8 dS $m^{-1}$) on morphological parameters of lettuce. Significance codes: ***, significant differences at P≤0.001, "ns" = not significant. Different letters indicate significant differences with Tukey HSD test at P≤0.05.

| **Treatment** | **Leaf number (n plant$^{-1}$)** | **Leaf length (cm)** | **Leaf width (cm)** |
|---|---|---|---|
| $W_{0.1}$ | 2.33 (b) | 3.29 (c) | 2.67 |
| $NS_{0.6}$ | 3.33 (a) | 6.40 (b) | 3.16 |
| $NS_{1.2}$ | 3.78 (a) | 7.37 (a) | 3.39 |
| $NS_{1.8}$ | 3.89 (a) | 6.89 (ab) | 3.40 |
| | *** | *** | ns |




(**a**) (**b**) (**c**) (**d**)

**Figure 3-5.** Visual effect of different concentration of nutrient solution: $W_{0.1}$= 0 g $L^{-1}$ of fertilizer, EC=0.13 dS $m^{-1}$ (**a**); $NS_{0.6}$= 0.4 g $L^{-1}$ of fertilizer, EC=0.60 dS $m^{-1}$(**b**); $NS_{1.2}$= 0.8 g $L^{-1}$ of fertilizer, EC=1.2 dS $m^{-1}$ (**c**), and $NS_{1.8}$ =1.2 g $L^{-1}$ of fertilizer, EC=1.8 dS $m^{-1}$ (**d**) on lettuce seedling growth.

*3.3.4 Experiment 3 - Chinese Cabbage*

3.4.1 Seedling Growth

*Productive and morphological parameters.* When $NS_{1.8}$ was supplied, Chinese cabbage seedlings weight was the highest, and progressively decreased with the reduction of nutrient solution concentration (**Figure 6a)**. Also, leaf morphological parameters (leaf number, width and length) were affected by nutrient solution concentration, showing higher values in plants grown with $NS_{1.8}$ and $NS_{1.2}$ (**Table 3-5).**

*Physiological parameters.* Concerning leaf greenness, the highest values were found in $NS_{1.8}$, while the lowest values were observed in $W_{0.1}$ and $NS_{0.6}$ **(Figure 3-6b)**. The response in both stomatal conductance ($g_s$) and leaf temperature was consistent with lettuce's observations, with lowest $g_s$ values in seedlings grown in $W_{0.1}$ and no statistically significant differences among other nutrient solution treatments (average value of 481 mmol $m^{-2}$ $s^{-1}$) (**Figure 3-6c**). Leaf temperature was the greatest in $W_{0.1}$, while no statistically significant differences were detected among the other treatments **(Figure 3-6d)**. Visual images of the plants (**Figure 3-7**) confirms highest biomass associated with $NS_{1.8}$.

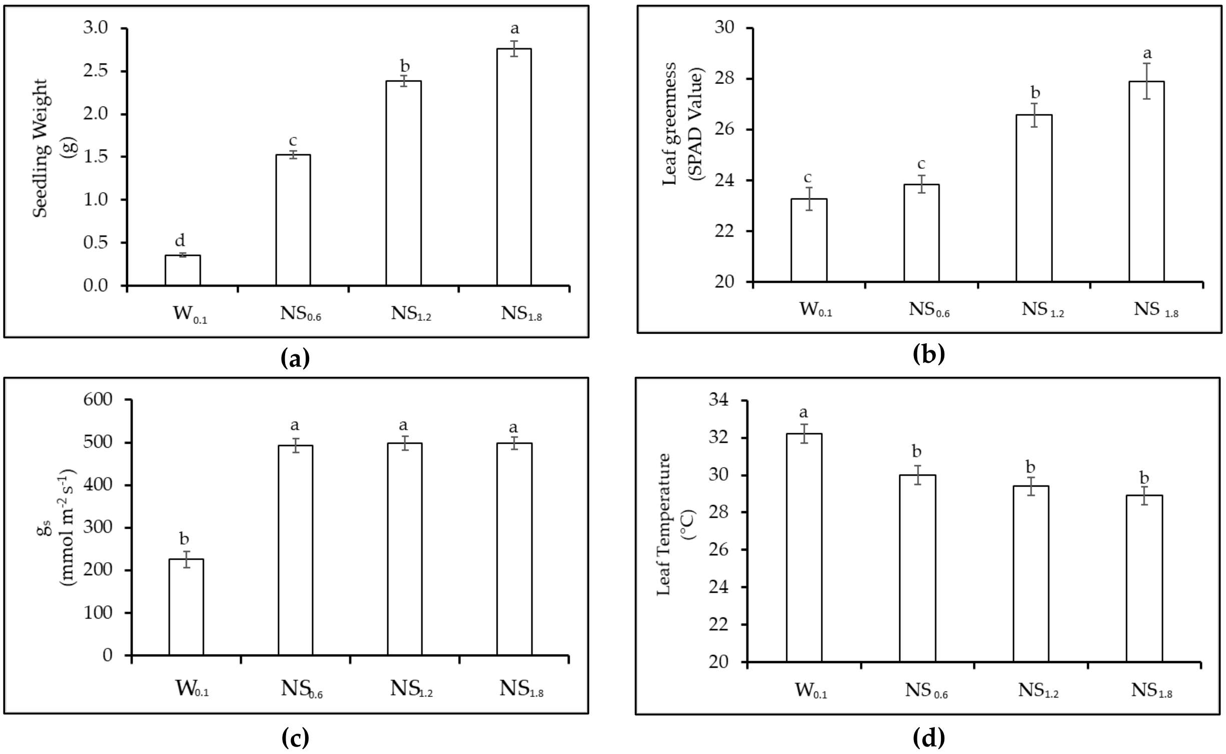



**Figure 3-6.** Experiment 3. Effect of different nutrient solution concentration ($W_{0.1}$= 0 g $L^{-1}$ of fertilizer, EC=0.13 dS $m^{-1}$; $NS_{0.6}$= 0.4 g $L^{-1}$ of fertilizer, EC=0.6 dS $m^{-1}$; $NS_{1.2}$= 0.8 g $L^{-1}$ of fertilizer, EC=1.2 dS $m^{-1}$, and $NS_{1.8}$ =1.2 g $L^{-1}$ of fertilizer, EC=1.8 dS $m^{-1}$) on Chinese cabbage seedling. (**a**) Seedling fresh weight (g $plant^{-1}$); (**b**) Leaf greenness; (**c**) Leaf stomatal conductance (gs, mmol $m^{-2}$ $s^{-1}$); (**d**) Leaf temperature (°C). NS=Nutrient solution; Vertical bars indicate SE; different letters indicate significant differences with Tukey HSD test at P≤0.05.

**Table 3-5.** Experiment 3. Effect of different concentration of mineral fertilizer ($W_{0.1}$= 0 g $L^{-1}$ of fertilizer, EC=0.13 dS $m^{-1}$; $NS_{0.6}$= 0.4 g $L^{-1}$ of fertilizer, EC=0.60 dS $m^{-1}$; $NS_{1.2}$= 0.8 g $L^{-1}$ of fertilizer, EC=1.2 dS $m^{-1}$, and $NS_{1.8}$ =1.2 g $L^{-1}$ of fertilizer, EC=1.8 dS $m^{-1}$) on morphological parameters of Chinese cabbage. NS=Nutrient Solution; Significance codes: ***, significant at P≤0.001. Different letters indicate significant differences with Tukey HSD test at P≤0.05.

| Treatment | Leaf number (n plant$^{-1}$) | Leaf length (cm) | Leaf width (cm) |
|---|---|---|---|
| $W_{0.1}$ | 3.00 (c) | 3.02 (c) | 1.51 (c) |
| $NS_{0.6}$ | 3.78 (b) | 6.31 (b) | 3.26 (b) |
| $NS_{1.2}$ | 4.33 (ab) | 8.50 (a) | 3.82 (a) |
| $NS_{1.8}$ | 4.56 (a) | 8.84 (a) | 4.05 (a) |
| | *** | *** | *** |


**Figure 3-7.** Visual effect of different concentration of Nutrient Solution ($W_{0.1}$= 0 g $L^{-1}$ of mineral fertilizer, EC=0.13 dS $m^{-1}$; $NS_{0.6}$= 0.4 g $L^{-1}$ of mineral fertilizer, EC=0.60 dS $m^{-1}$; $NS_{1.2}$= 0.8 g $L^{-1}$ of mineral fertilizer, 1.2 dS $m^{-1}$ EC, and $NS_{1.8}$ =1.2 g $L^{-1}$ of mineral fertilizer, 1.8 dS $m^{-1}$ EC) on Chinese cabbage seedling growth.

## 4. Discussion

Adopting different substrates and nutrient solutions significantly affected growth (fresh weight and leaf morphology) and physiological parameters (stomatal conductance, leaf temperature, SPAD units) of lettuce and Chinese cabbage seedlings grown in Central Dry Zone, Myanmar. The quality of seedlings affects their growth and yield after transplanting, given that good-quality seedlings exhibit morphological characteristics such as thick stems, thick leaves, dark green leaves, and large white roots (Oda *et al.*, 2007). In the first experiment, lettuce seedlings with the longest leaf length and width were associated with HM-mix substrate and $NS_{1.2}$ nutrient solution treatment. Physiological parameters (leaf temperature and SPAD values) were affected only by nutrient solution (**Table 3-3**). The combination of HM-mix and $NS_{1.2}$ allowed obtaining most appropriate seedlings for transplanting. Although both substrates have similar EC and pH, the former quite high while the latter adequate for lettuce growth, the obtained results differ probably due to other HM-mix substrate's intrinsic physical and chemical features. According to substrate analysis, SBS substrate showed a larger nitrogen content as compared to HM-mix substrate, probably resulted by the inclusion of fresh cattle manure (Muhereza *et al.*, 2020) that negatively affected seedling growth. In a previous study by Sapkota *et al.* (Sapkota *et al.*, 2019) elevate nitrogen concentration in substrate depressed root metabolism leading to shorter roots.

The high content of carbonized rice husks (biochar) in the HM-mixed substrate may be responsible of its good agronomic performances, given that rice husk features elevate content of silicon and potassium (Varela *et al.*, 2013). The carbonization process is needed to avoid that rice husk turn to ash, keeping the original shape and ensuring several benefits associated with its capacity for decreasing bulk density, enhancing water holding capacity, adding organic carbon, increasing available nutrients, and ultimately increasing crop yields (Williams *et al.*, 1972; Yamato *et al.*, 2006). Accordingly, carbonized rice husk use as growing substrate should be promoted among farmers, especially in those areas where it is readily available as in Asian countries, where rice residues are estimated at 560 million tons for rice straw and 112 million tons for rice husks (Varela *et al.*, 2013). Therefore, the promotion of this biochar production should also be stimulated to increase vegetable local quality seedling production.

The low permeability and poor drainage showed by SBS substrate during the irrigation/fertilization time, probably determines continuous waterlogged conditions reducing oxygen in the substrate and negatively affects seedling growth (Parent *et al*., 2008; Patel *et al*., 2014). Main constraints generated by water stagnation in agriculture include detrimental effects on both soil/substrate chemical and physical properties when anaerobic conditions persist repetitively (Patel *et al*., 2014). Furthermore, the application of adequate nutrient solution assures higher and prompt nutrient availability to the seedlings, and the root growing media may affect plants' response to salinity (Andriolo *et al*., 2005; Samarakoon *et al*., 2006). According to the results obtained in the first experiment, the combination of HM-mixed substrate and $NS_{1.2}$ nutrient solution proved to be a valid option to produce quality lettuce seedling in Myanmar's central dry zone.

Within the second experiment, the definition of the optimal nutrient solution concentration was targeted. Albeit limited literature has addressed to date the definition of optimal nutrient solution strength on lettuce and Chinese cabbage nursery production in tropical areas, comparison can be made against existing literature on commercial hydroponic production. Accordingly, it was observed that whenever nutrient solution salinity levels are elevate (above 2.0 dS $m^{-1}$) lettuce fresh yield and plant growth may be reduced (Andriolo *et al*., 2005). Although the high electrical conductivity (EC) showed by the substrate adopted (**Table 3-1**), the present study points out that the optimal nutrient solution EC for lettuce seedlings production was 1.2 dS $m^{-1}$ ($NS_{1.2}$), while for the cultivation of Chinese cabbage seedlings ranged between 1.2 and 1.8 dS $m^{-1}$ ($NS_{1.2}$; $NS_{1.8}$) (**Tables 3-4** and **3-5**). The effect of the initial high EC of the substrate on production was probably reduced by salinity reduction of the substrate due to the washing practice performed in the first five days after sowing applying only clear water with EC of 0.13 dS $m^{-1}$ on seedling trays. According to Bustamante *et al*. (Bustamante *et al*., 2021) in an experiment on the effect of washing treatments on different composts used as nursery growing media for seedling pepper production showed that the electrical conductivity (EC) clearly decreased in all the composts subjected to washing treatments, with percentages of diminution up to 40.7 %. From an economic point of view, maximum recommendable fertilizer addition would be in the range of 0.8 g of fertilizer $L^{-1}$. Considering the cost for 1000 L nutrient solution preparation, it is possible to estimate in 33% the economic savings that the farmer could obtain in preparing $NS_{1.2}$ as compared to $NS_{1.8}$ without compromising crop growth e.g., in lettuce. It is also clear that the use of only water or nutrient solutions with low electrical conductivity for seedling production, such as in the case of $W_{0.1}$ and $NS_{0.6}$ treatments, does not guarantee the achievement of satisfactory seedlings size, resulting in lower leaf dimensions probably due to the scarce nutrients availability (**Tables 4** and **5**). For instance, in lettuce plants, plants leaf size was formerly affected by nutrient solution composition and water availability (Sapkota *et al*., 2019; Fraile-Robayo *et al*., 2017; Michelon *et al*., 2020). Moreover, seedlings grown under $W_{0.1}$ and $NS_{0.6}$ showed lower values of leaf greenness as compared to $NS_{1.2}$ and $NS_{1.8}$. According to Trani *et al*. (Trani *et al*., 2004), lettuce seedlings, at the time of transplanting, which should occur between 20-25 days after sowing, should have intense green leaves of approximately 5 cm in length, a condition that was not met e.g., in $W_{0.1}$. It emerges how obtaining lettuce seedlings of elevate quality is highly dependent on whether their nutritional requirements are met (Soundy *et al*., 2005). Besides, $W_{0.1}$ treatment, both in lettuce and Chinese cabbage, showed the lowest values for stomatal conductance ($g_s$), the highest foliar temperature, and lowest SPAD values compared to the other treatments (**Figure 3-6**). It is evident that seedlings under $W_{0.1}$ treatment had to deal with abiotic stressors, most probably nutritional deficits. Plants' stomatal conductance is closely related to plants' nutritional status, with a confirmed linear relationship with leaf nitrogen concentration for broad categories of vegetables (Schulze *et al*., 1994). The application of clear water ($W_{0.1}$) clearly did not meet the nutritional requirements of the seedlings, and fertigation yet at nursery stage would be recommended to obtain seedlings suitable for transplant and marketing. On the other hand, it resulted also important not to provide too elevate fertilizer concentration, which would ultimately result in limited improvements of plant growth. Indeed, significant decreases in total, marketable yields and leaf transpiration in different lettuce cultivars were observed by

Orsini *et al.*, when salinity stress associated with excessive minerals was experienced (Orsini *et al.*, 2018). Accordingly, lettuce has been considered a moderately salt-sensitive crop with a threshold electrical conductivity (EC) of 1.3 dS $m^{-1}$ and a negative slope of 13.0 for each unit added salinity above this threshold value (Kim *et al.*, 2008; Munns, 2008). Finally, the three experiments highlighted the importance of using the natural resource available accurately, considering the impact of some technical choices also on climate change. The HM-mix substrate used in the three experiments has proven to be a suitable local substrate for seedling production. Considering the growth potential of the horticultural sector in Myanmar to contribute to food security (LIFT, 2020), the adoption of such a substrate will have a lower impact on climate change by limiting the use of substrates commonly used for seedling production as peat. Peat comes from peatland ecosystems, which are very important for carbon sequestration. Hence, when peat is used as a substrate, the stored carbon is released, negatively affecting the environment and $CO_2$ balance (Gruda *et al.*, 2019). The same is also true for the use of mineral fertilizer. The second and third experiments showed that the proper use of fertilizer guarantees the production of good quality seedlings without exceeding the use of mineral fertilizer, which, besides determining an economic loss for the growers, negatively impacts the environment. Indeed, $N_2O$ is considered to be highly damaging to the ozone layer. About 80% of anthropogenic $N_2O$ emissions are attributed to agriculture (Antón *et al.*, 2012; Rashti *et al.*, 2015; Hénault *et al.*, 2012; Liu *et al.*, 2017).

## 5. Conclusions

The three experiments highlight the importance of adopting accurate substrates and nutrient solution concentration to improve vegetable seedlings production in semi-arid areas such as the Central Dry Zone of Myanmar. It is possible to affirm that proper substrate selection associated with a proper nutrient solution management increase seedling quality and improves physiological parameters of lettuce and Chinese cabbage seedling production. Under limited resources, the substrate adoption named HM-mixed and nutrient solution $NS_{1.2}$ allowed for obtaining high quality seedlings. An interdisciplinary approach and appropriate dissemination and knowledge transfer will be essential to guarantee that the seedling management methodology and technology for nursery purposes will be put in place adequately by local institutions and farmers.

## Chapter 4 - Strategies for improved Water Use Efficiency (WUE) of field grown lettuce (*Lactuca sativa* L.) under semi-arid climate

This chapter is based on the journal paper:

*Michelon, N., Pennisi, G., Myint, N. O., Orsini, F., & Gianquinto, G. Strategies for Improved Water Use Efficiency (WUE) of Field-Grown Lettuce (Lactuca sativa L.) under a Semi-Arid Climate. Agronomy 2020, 10(5), 668; https://doi.org/10.3390/agronomy10050668*

**Abstract:** water use efficiency is a main research target in agriculture, which consumes 70% of global freshwater. This study aims at identifying sustainable water management strategies for the lettuce crop in a semi-arid climate. Three independent experiments were carried out on a commercial variety of lettuce (*Lactuca sativa* L.) applying different irrigation levels based on crop evapotranspiration ($ET_c$), estimated through both Hargreaves-Samani and Penman-Monteith equations. In the first experiment, one treatment was also guided by soil moisture sensors. In the second and third experiments, a factorial combination was used, combining the different irrigation levels with two soil mulching treatments, namely soil without mulch, and soil mulched with dried rice straw residues. The application of different irrigation levels significantly affected plant growth, yield, and physiology. Both, the adoption of sensors for guiding irrigation and the application of mulching with straw promoted higher yield. As the irrigation water level was reduced, the WUE increased. WUE was also increased by covering the soil with mulch. The experiments point out that accurate management of irrigation water using drip irrigation system associated with soil mulching increase yield and improve WUE of lettuce crop in Central Dry Zone, Myanmar.

**Keywords:** Yield; stomatal conductance; leaf temperature; soil mulching; irrigation management; deficit irrigation; evapotranspiration; Hargraves-Samani equation; Penman-Monteith equation; soil moisture sensors

### 4.1 Introduction

Water is essential for agricultural production and food security of the world population. In the coming decades, a growing number of regions will face increasing water scarcity (Fereres Castiel *et al*., 2011) while, due to the global population expected to reach more than 9 billion people by 2050, demand for food is expected to surge by more than 50% (Godfray *et al*., 2010). Considering that about 70% of global freshwater withdrawals are directly used in agriculture (Kummu *et al*., 2012), accurate management of agricultural water resources to increase crop water use efficiency (WUE) is one of the main targets in research on plant-soil-water relations. Different strategies are available to predict soil water availability for plants and maximize crop WUE, including wireless soil moisture sensors (Dursun *et al*., 2011). However, novel irrigation technologies need to be adapted to local environmental conditions and available technical solutions, particularly in simplified growing systems that are generally found in developing countries (Berihun *et al*., 2011). Proper management of irrigation water can be beneficial for the farmers since it enables to both improve and stabilize yield in areas of water shortages (Dağdelen *et al*., 2009). Furthermore, it can lower the competition for water use among domestic, industrial, and agricultural sectors (Godfray *et al*., 2010). In this context, reference evapotranspiration ($ET_0$) allows to effectively define precise water requirements for crops and irrigation scheduling (Kumar *et al*., 2012). Various models/approaches are available for estimating $ET_0$, including Class A Pan, FAO Penman-Monteith (PM), and Hargreaves Samani (HS) equations (Kumar *et al*., 2012). Different studies have been focused on the definition of appropriate water management through the estimation of evapotranspiration (Valipour *et al*., 2012; Valipour *et al*., 2014; Valipour *et al*., 2015; Rezaei *et al*., 2016) suggesting the superiority of the HS as compared with the PM, by analysing data over a study period of 9–years (Valipour *et al*., 2017). Trajkovic observed $ET_0$ estimates by HS to be in close agreement with FAO PM forecasts in different experimental locations, with average overestimation limited to about 1%. Traikovic's study strongly supports the use of the HS when only temperature data are available (Traikovic, 2007).

In the Central Dry Zone (CDZ) of Myanmar, water is scarce, vegetation cover is thin, and soils are mostly luvisol, sandy, degraded, and infertile (Gianquinto *et al*., 2007) with low water holding capacity (Herridge *et al*., 2019). Annual rainfall ranges 300 to 800 mm per year, and is characterised by uneven distribution and high variability across years. Moreover, rain events are recently showing a shorter duration and increased intensity (Herridge *et al*., 2019). In the coming decades, current trends of drought and water scarcity in the CDZ are expected to intensify in response to climate change (FAO, 2014). The combination of relatively low and erratic rainfall with land features that include sloped fields with mainly infertile sandy and sandy loam soils have led to low agricultural productivity in the region (LIFT, 2015). Furthermore, the limited water resources are also poorly managed, especially regarding irrigated agriculture, despite the reported potential for creating small, medium, and large-scale irrigation systems (LIFT, 2015). For these reasons, both irrigated and dryland cropping areas in the region will have to be developed or improved in the future. In such conditions, raising awareness on efficient agricultural water use and the development of small-scale irrigation schemes at family level is therefore crucial. Hence, given the limited water availability, the application of water-saving methods to improve WUE is urgent.

Lettuce (*Lactuca sativa* L.) is a major fresh vegetable extensively grown all over the world, particularly in temperate regions (Araújo *et al*., 2010; Kang *et al*., 2001). Despite lettuce is a C3 plant that requires adequate irrigation management to ensure satisfactory production, it is also widely cultivated in tropical areas due to its capacity to ensure adequate production and reasonable water use efficiency (Gomes *et al*., 2014).

World lettuce production was extended over 1 million ha and estimated to reach approximately 24 million metric tons in 2009 (Domingues *et al*., 2012), with about two-thirds of the total area devoted to lettuce production found in Asia (Beiquan *et al*., 2008). From a nutritional perspective, lettuce belongs to the so-called green leafy vegetables, whose relevance in the diet is associated with their contributions in terms of fibers, vitamins, and minerals (including calcium, iron, and phosphorous) (Prasad *et al*., 2008). Under field conditions, Araújo *et al*. assessed the effect of different water levels on the productive behaviour of lettuce. The highest WUE values (12 g $L^{-1}$) were obtained when 40% of $ET_0$ were restored, as compared with other treatments respectively restoring 60, 80, 100 and 120 % of $ET_0$. The experiment showed that WUE decreased linearly with the increase in the water level applied (Araújo *et al*., 2010). This may be achieved by minimizing leaf water loss while preserving crop productivity (Kang *et al*., 2001). In the CDZ, the combination of drip irrigation techniques altogether with sustainable cropping practices is expected to increase in the near future in order to guarantee sustainable vegetable production and food security (Gianquinto *et al*., 2007). Among cropping practices, soil coverage (e.g., with plastic mulching) showed to preserve soil moisture content by reducing both water evaporation and drainage, avoid soil crusting (Dursun *et al*., 2011), prevent soil erosion, and increase crop productivity (Prosdocimi *et al*., 2016). Moreover, organic mulching contributes to soil organic matter content improving nitrogen balance and soil biological activity (Hooks *et al*., 2003). Results obtained in Bangladesh by Asaduzzaman *et al*.2010, indicate that soil organic mulching increases lettuce yield as compared with no-mulched lettuce (Asaduzzaman *et al*., 2010). In a difficult context, such as CDZ of Myanmar, an adequate irrigation management must be matched with all crop practices able to enhance water use efficiency and allow high yield. Therefore, the present study was aimed at investigating the effect of different irrigation strategies and the use soil organic mulching on the water use efficiency and yield of lettuce grown in the semi-arid areas of CDZ, Myanmar.

## 4.2. Materials and Methods

### *4.2.1. Location*

The experiments were conducted in open field conditions at Soil and Water Research Station of Yezin Agriculture University located in the University Campus, Central dry Zone of Myanmar, 16 km far the Capital NayPyiTaw. The geographic coordinates are 19° 83' North and 96° 27' East, with an altitude of 122 m a.s.l. The local climate, according to Köppen's classification, is Aw type, which is tropical rainy with dry summer and rainy season concentrated between June and October.

The soil presented loamy sand texture with 82% of sand, 9.3% of silt, and 8.7% of clay, a wilting point of 6.1% v:v, and field capacity of 13.0% v:v. The soil chemical characteristics in the 0-0.20 m layer were as following: pH ($H_2O$) 6.2; EC 0.13 dS $m^{-1}$; 0.38% organic matter; 54 mg $kg^{-1}$ of total N; 10.9 mg $kg^{-1}$ of available P; 25 mg $kg^{-1}$ of exchangeable K.

*4.2.2. Treatments and experimental design*

Three independent experiments were carried out on a commercial variety of lettuce (*Lactuca sativa* cv. Green wave, Evergreen seeds, Sunnyvale, CA, USA) commonly sold in the local market.

**Experiment 1:** Four irrigation strategies were applied, three based on crop evapotranspiration ($ET_c$), respectively restoring 25, 50 and 100% of crop $ET_c$ (details on $ET_c$ calculation are included in the following sections) measured by using Hargreaves-Samani equation (HS), and one guided by soil moisture sensors. In the sensors-guided treatment, the irrigation schedule was based on real soil moisture content, restoring water up to field capacity whenever soil moisture level fell below 50% of available water (AW). The experimental design was a completely randomized block design with 4 treatments and three replicates.

**Experiment 2:** A factorial combination was carried out, combining four irrigation strategies, based on crop evapotranspiration ($ET_c$) combined with two soil mulching (M) treatments namely soil without mulch (bare soil, BS), and soil mulched with dried rice straw residues (straw mulching, SM). The irrigation strategies provided restoring 75, 100 and 125% of ETc estimated by using HS equation and 100% of crop ETc estimated by using Penman-Monteith (PM) equation. In this experiment, for the calculation of ETo, the Penman Monteith method has been included with the main purpose of validating the more straightforward method, such as Hargreaves Samani formula.

**Experiment 3:** Six strategies of irrigation (based on crop evapotranspiration, $ET_c$), respectively restoring 25%, 50% and 100% of crop $ET_c$ measured by using either HS or PM equations, were factorially combined with two soil mulching (M) treatments namely soil without mulch (bare soil, BS), and soil mulched with dried rice straw residues (straw mulching, SM). Again, PM was included to check HS. However, as crops respond to the water supply and not to the method to estimate ET0, the HS and PM methods were not considered as different factors, but as different levels of the same factor (irrigation strategy). The restitution of different percentage of ET0, estimated either with HS or PM, represents different irrigation depth. The experimental design was a completely randomized block with twelve treatments and three replicates.

For the three experiments, the experimental unit consisted of a 5.4 $m^2$ plot, including 72 plants.

*4.2.3. Plant material and crop management*

In all experiments, lettuce was sown manually in 105 cells plastic seedling trays, and the seedlings were transplanted 21 days after sowing (DAS), on December 28th, 2018 for the first experiment, on January 7th, 2019 for the second experiment and on February 14th, 2019 for the third experiment. Plants spacing was 0.25 m between rows and 0.3 m within rows, resulting in a plant density of 13.3 plant $m^{-2}$, according to the habits of the local farmers. Harvest was carried out 31 days after transplanting (DAT) in all experiments.

Before the first experiment the soil was amended with 1.5 kg $m^{-2}$ of mature cattle manure, mainly to improve soil structure and water holding capacity. Soil fertilization was managed as normal for the area, supplying 0.025 kg $m^{-2}$ of NPK fertilizer 15-15-15 (corresponding to 37.5 kg $ha^{-1}$ of N, $P_2O_5$ and $K_2O$), which was applied in each experiment 3 days before transplanting. Both organic and mineral fertilizers were broadcasted manually. No additional fertilizer was applied across the growing season. During the experiments, no diseases or pests were detected; therefore, no pest control products were applied.

In experiments 2 and 3, soil mulching treatments consisted in the application of around 0.75 kg $m^{-2}$ of dry rice straw, assuring a mulching height of about 0.15 m.

*4.2.4. Irrigation management*

The irrigation management, except for the sensor-guided treatment, was based on crop evapotranspiration ($ET_c$), calculated by using the following equation (**Equation 4-1**)

$$ET_c = ET_0 * K_c \qquad \textbf{(Equation 4-1)}$$

where $ET_c$ (mm $day^{-1}$) is the calculated crop evapotranspiration, $ET_0$ (mm $day^{-1}$) is the reference evapotranspiration, and $K_c$ is the FAO crop coefficient for lettuce (Traikovic, 2007).

For the estimation of the reference evapotranspiration ($ET_0$), two different methods were used. The first one utilized the Hargreaves - Samani (HS) equation (**Equation 4-2**)

$$ET_0 = 0.0023\ (T_{mean} + 17.8)\ (T_{max} - T_{min})^{0.5}\ R_a \qquad \textbf{(Equation 4-2)}$$

where $ET_0$ (mm day$^{-1}$) is the reference evapotranspiration rate, $R_a$ (W m$^{-2}$ day$^{-1}$) is the extraterrestrial solar radiation, $T_{mean}$, $T_{max}$ and $T_{min}$ the mean, maximum and minimum temperature (°C) of the day, respectively (Domingues *et al.*, 2012).

The second method applied the Penman-Monteith (PM) equation (**Equation 4-3**) (Capra *et al.*, 2016)

$$ET_0 = \frac{0.408\Delta\ (R_n - G) + \gamma \frac{900}{T + 273}\ u_2\ (e_s - e_a)}{\Delta + \gamma\ (1 + 0.34u_2)} \qquad \textbf{(Equation 4-3)}$$

where $ET_0$ (mm day$^{-1}$) is the reference evapotranspiration, $R_n$ (MJ m$^{-2}$ day$^{-1}$) is the net radiation at the crop surface, G (MJ m$^{-2}$ day$^{-1}$) is the soil heat flux density, T (°C) is the mean daily air temperature at 2 m height, $u_2$ (m s$^{-1}$) is the wind speed at 2 m height, $e_s$ (kPa) is the saturation vapor pressure, $e_a$ (kPa) is the actual vapor pressure, $e_s - e_a$ (kPa) is the saturation vapor pressure deficit, $\Delta$ (kPa °C$^{-1}$) is the slope vapor pressure curve, $\gamma$ (kPa °C$^{-1}$) is the psychrometric constant.

The meteorological data for the determination of the reference evapotranspiration were daily downloaded from the website of the Agro-Meteorological Department of Yezin Agriculture University (http://www.yau.edu.mm/), located inside the University Campus, excluding extraterrestrial radiation $R_a$ for HS equation that was calculated according with Duffie and Beckman (Duffie *et al.*, 2020). The $ET_0$ estimated by PM equation was obtained using the FAO CropWat 8.0 software.

The amount of water to be used for each irrigation was calculated based on plant water balance in consonance with soil property, root depth, and climate data also considering occurred rainfall, if any. Daily ETc was estimated considering FAO crop coefficient for lettuce crop growth stages. In all experiments, lettuce cycles have been divided into three growth stages, and the Kc used was 0.7, 1.0, and 0.95, respectively. The time of irrigation was determined when readily available soil water (50% available soil water) was depleted.

In the sensor-guided treatment of the Experiment 1, CropX sensors (CropX, Tel Aviv, Israel) were used. These sensors measure the soil water content at 20 cm and 46 cm depth by estimating the soil bulk permittivity (or dielectric constant), which determines the velocity of an electromagnetic wave or pulse through the soil. The sensors have a wireless connection to a system that collects and analyses data. The insights produced by the system share information (through a smartphone application) on when and how much irrigation are actually needed. In this treatment, the irrigation schedule was based on real soil moisture content, restoring water to field capacity whenever soil moisture level reached 50% of water actually available.

In all experiments, 16 mm diameter drip pipes were used. Drippers had a flow rate of approximately 1.3 L h$^{-1}$, and each plant was supplied with a single dripper. A flow rate test and calculation of distribution uniformity (DU) were carried out before transplanting. The DU was calculated following the indications from Baum *et al*. (2005).

The irrigation management (time and rate) was performed manually, through individual records for each treatment.

*4.2.5. Measurements*

At harvest (31 DAT), plants were cut at the base of the head, which was weighed to determine the fresh weight (g plant$^{-1}$). Marketable yield (kg m$^{-2}$) was assessed, excluding the external leaves, which appeared damaged or wilted. Plants dry weight was quantified after drying the samples at 70°C per 72 hours. Dry matter was calculated as the ratio between leaf dry weight and leaf fresh weight and expressed as a percent value. Leaf number and leaf size (length and width) were also recorded. Water Use Efficiency (WUE) was determined as the ratio between the fresh weight and the volume of water used and expressed as g FW L-1 H2O, as generally done for lettuce crop (Bozkurt *et al.*, 2011).

Stomatal conductance was measured using a handheld photosynthesis measurement system model CI-340 (Camas, WA, USA), equipped with 6.25 $cm^2$ cuvette. Infrared thermometer model FLUKE 61 (Fluke Corporation, Everett, WA, USA) was used to measure leaf temperature and leaf greenness was estimated by using SPAD 502 (Minolta, Osaka, Japan). Measurements were made at 27 DAT on the upper surface of the canopy on 3 leaves per each plant from 10:00 to 14:00h taking approximately one hour to complete each replication. All plants were measured on a single day. The cuvette conditions were as follows: PAR, 1258± 130, 1460± 150, 1533± 101 $\mu m\ m^{-2}\ s^{-1}$; air temperature 39.8± 0.46, 41.8 ± 0.47, 39.4± 1.39° C; relative humidity 27.4 ± 0.51, 28.4± 0.97, 26.4±2.66 % RH; CO2 concentration 337± 6.2, 332 ± 10.1, 271.8 ± 5.8 ppm (experiment 1, 2 and 3, respectively).

*4.2.6. Statistical Analysis*

The physiological measurements were taken on three plants per plot, while harvest considered 12 plants collected from the central part of each plot. Data from experiment 1 were analyzed by using one-way ANOVA, while data from experiments 2 and 3 were analyzed by using two-way ANOVA (irrigation strategies x mulching). Means were separated using Tukey HSD test (Acutis *et al*., 2012) at $P \leq 0.05$. Before the analysis, all data were checked for normality and homogeneity of the variance. Averages and standard errors (SE) were calculated. Statistical analysis was carried out using R statistical software (version 3.3.2, package "emmeans" and "car").

### 4.3 Results

*4.3.1. Climate and irrigation management during the experiments.*

During the first experiment, maximum air temperatures ranged between 25.0°C and 34.0°C, with an average of 31.5°C. Minimum temperatures ranged between 14.4 and 20.4°C, with an average of 16.7°C. The daily relative humidity (RH) range between a minimum of 48% and a maximum of 73%. No rainfall occurred during the first experiment (**Table 4-1**). During the second experiment, maximum air temperatures ranged between 20.4°C and 36.5°C, with an average of 32.3°C. Minimum air temperatures ranged between 14.4 and 25.0°C, with an average of 17.0°C. The maximum relative humidity (RH) was 73%, and the minimum RH was 50%. The accumulated precipitation during the second experiment was 2 mm, quantity irrelevant for the irrigation management (**Table 4-1**). During the third experiment, maximum air temperatures ranged between 30.7°C and 38.6°C, with an average maximum temperature of 35.6 °C. Minimum temperatures ranged between 16.0 and 23.0°C, with an average minimum temperature of 19.5°C. The maximum relative humidity (RH) was 59%, and the minimum RH was 30%. No rainfall occurred during the third experiment (**Table 1**). The growing degree days (GDD) from transplanting to harvest ranged from 662°C (experiment 1) to 731°C (experiment 3).

**Table 4-1.** Main climatic features during the experiments.

| Exp. | Average air temperature(°C) | | RH (%) | | DLI[1] (mol $m^{-2}$ $d^{-1}$) | Wind Speed (m $s^{-1}$) | $ET_0$ (mm) | | GDD[4] (°C) |
|---|---|---|---|---|---|---|---|---|---|
| | min | max | max | min | | | HS[2] | PM[3] | |
| Exp. 1 | 16.7 | 31.5 | 73 | 48 | 17.0 | 1.0 | 4.1 | - | 662 |
| Exp. 2 | 17.0 | 32.3 | 73 | 50 | 16.7 | 1.4 | 4.0 | 3.8 | 730 |
| Exp. 3 | 19.5 | 35.6 | 59 | 30 | 20.9 | 1.9 | 5.6 | 4.8 | 731 |

[1] DLI = average daily light integrals;

[2] HS = $ET_0$ estimate by using Hargraves-Samani equation;

[3] PM = $ET_0$ estimate by using Penman-Monteith equation;

[4] GDD = growing degree days, calculated based on a crop base temperature of 4°C.

*4.3.2. Experiment 1.*

**Physiological Parameter**

Water treatments affected stomatal conductance, which resulted the lowest in the plants grown in $HS_{25}$, while no significant differences were detected among the other irrigation treatments (average value of 232 mmol $m^{-2}$ $s^{-1}$) (**Table 4-2**). The highest leaf temperature was observed in plants grown under the lowest amount of irrigation ($HS_{25}$), with comparable values also obtained in plants irrigated by using moisture sensors (**Table 4-2**). Concerning SPAD values, the only difference was detected between plants grown under sensors based irrigation (22.3 SPAD value) and plants grown in $HS_{50}$ (16.7 SPAD value) (**Table 4-2**).

**Table 4-2**. Experiment 1. Effect of irrigation strategy on the physiological parameters of lettuce. Different letters indicate significant differences at Tukey HSD test (P≤0.05). Data are means of the three replicates. Significance codes: *, significant at P≤0.05; **, significant at P≤0.01; ***, significant at P≤0.001, "Ns" = not significant. $HS_{25}$ = recovery of 25% ETc calculated by Hargraves-Samani equation; $HS_{50}$ = recovery of 50% ETc calculated by Hargraves-Samani equation; $HS_{100}$ = recovery of 100% ETc calculated by Hargraves-Samani equation.

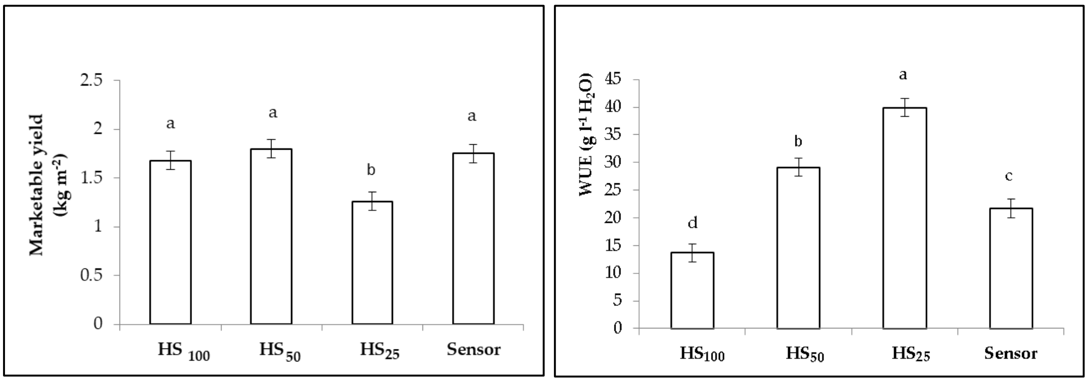
| Water level | Irrigation (mm) | Stomatal conductance (mmol $m^{-2}$ $s^{-1}$) | Leaf temperature (°C) | SPAD value |
|---|---|---|---|---|
| **$HS_{100}$** | 130.4 | 234 a | 22.7 b | 17.7 ab |
| **$HS_{50}$** | 65.2 | 229 a | 23.0 b | 16.7 b |
| **$HS_{25}$** | 32.6 | 115 b | 24.7 a | 21.6 ab |
| **Sensors** | 84.4 | 233 a | 24.2 ab | 22.3 a |
| **mean** | - | *** | ** | * |

## Morphological and productive parameters

Irrigation affected plant fresh weight (FW) and marketable yield, but significant differences were detected only between $HS_{25}$ and the other irrigation treatments. In $HS_{25}$ treatment, plant FW and marketable yield were the lowest with reduction of 29% and 27%, respectively, as compared to the means among the other water strategies (141 g plant$^{-1}$ and 1.74 kg m$^{-2}$, respectively) (**Table 4-3 and Figure 1a**). The same trend was also observed for the dry weight (**Table 4-3**). Dry matter percentage was the highest in plants receiving the lowest amount of water ($HS_{25}$), with comparable values also obtained in plants grown by using sensors-based irrigation management (**Table 4-3**). Finally, water use efficiency (WUE) was the highest in $HS_{25}$ treatment and progressively decreased with the increase of the amount of irrigation distributed to the plants (**Figure 4-1b**). Leaf number and leaf dimension were not affected by irrigation strategy (data not shown).

**Table 4-3.** Experiment 1. Fresh and dry matter yield and dry matter percentage as affected by irrigation strategy in lettuce. Different letters indicate significant differences at Tukey HSD test ($P \leq 0.05$). Data are means of the three replicates. Significance codes: *, significant at $P \leq 0.05$; **, significant at $P \leq 0.01$; ***, significant at $P \leq 0.001$, "Ns" = not significant. $HS_{25}$ = recovery of 25% ETc calculated by Hargraves-Samani equation; $HS_{50}$ = recovery of 50% ETc calculated by Hargraves-Samani equation; $HS_{100}$ = recovery of 100% ETc calculated by Hargraves-Samani equation.

| Water level | Irrigation (mm) | Plant FW (g plant$^{-1}$) | Plant DW (g plant$^{-1}$) | Dry Matter (%) |
|---|---|---|---|---|
| **$HS_{100}$** | 130.4 | 137 a | 13.4 a | 7.19 b |
| **$HS_{50}$** | 65.2 | 146 a | 14.0 a | 7.63 b |
| **$HS_{25}$** | 32.6 | 100 b | 5.90 b | 9.15 a |
| **Sensors** | 84.4 | 141 a | 12.3 a | 8.55 ab |
| **mean** | - | *** | *** | ** |




**(a)** **(b)**

**Figure 4-1**. Effect of irrigation strategy ($HS_{100}$ = recovery of 100% $ET_c$ calculated by Hargraves-Samani Equation; $HS_{50}$ = recovery of 50% $ET_c$ calculated by Hargraves-Samani Equation; $HS_{25}$ = recovery of 25% $ET_c$ calculated by Hargraves-Samani Equation; Sensors = recovery of irrigation through soil moisture sensors) on lettuce (**a**) Marketable yield, (kg FW m$^{-2}$) and (**b**) Water use efficiency, (WUE, g FW L$^{-1}$ $H_2O$). Vertical bars indicate SE, different letters indicate significant differences with $P \leq 0.05$

4.3.3. Experiment 2

**Physiological parameter**

Stomatal conductance was affected by the interaction between mulching and irrigation strategy (**Table 4-4**). Indeed, the use of straw mulching resulted in higher stomatal conductance as compared to plants cultivated on bare soil, but the interaction showed that the effect was significant only at $HS_{75}$ irrigation strategy **(Table 4-5)**. The main factors (irrigation strategy and soil mulching) did not influence plants leaf temperature, but interaction was significant at $P \leq 0.001$ **(Table 4-4)**. Accordingly, while no effect of soil mulching was detected at $HS_{100}$ and $PM_{100}$, at $HS_{75}$ and at $HS_{125}$ plants grown on bare soil had lower and higher leaf temperature as compared to plants grown using mulching, respectively (**Table 4-5**).

SPAD value were not affected by irrigation strategy and soil mulching treatments (**Table 4-4**), resulting in a SPAD index of 16.6 as mean value (data not shown).

**Table 4-4.** Experiment 2. Effect of irrigation strategy and soil mulching on physiological parameters of lettuce. Significance codes: *, significant at $P \leq 0.05$; **, significant at $P \leq 0.01$; ***, significant at $P \leq 0.001$, "Ns" = not significant

| | **Stomatal Conductance (mmol $m^{-2}$ $s^{-1}$)** | **Leaf Temperature (°C)** | **SPAD** |
|---|---|---|---|
| Irrigation strategy (IS) | Ns | Ns | Ns |
| Soil mulching (M) | *** | Ns | Ns |
| WL x M | ** | *** | Ns |

**Table 4-5**. Experiment 2. Effect of interaction between irrigation strategy and soil mulching on physiological parameters of lettuce. Different letters indicate significant differences at Tukey HSD test ($P \leq 0.05$). Lower case letters indicate differences between treatments; capital letters indicate differences between means of soil mulching factor. Data are means of the three replicates. $HS_{75}$ = recovery of 75% $ET_c$ calculated by Hargraves-Samani equation; $HS_{100}$ = recovery of 100% $ET_c$ calculated by Hargraves-Samani equation; $HS_{125}$ = recovery of 125% $ET_c$ calculated by Hargraves-Samani equation; $PM_{100}$ = recovery 100% of $ET_c$ calculated by Penman-Monteith equation. SM=Straw Mulching; BS= Bare Soil.

| **Irrigation strategy** | **Irrigation (mm)** | **Stomatal Conductance (mmol $m^{-2}$ $s^{-1}$)** | | **Leaf Temperature (°C)** | |
|---|---|---|---|---|---|
| | | SM | BS | SM | BS |
| $HS_{100}$ | 154 | 312 ab | 207 bc | 29.4 abc | 30.5 a |
| $HS_{75}$ | 116 | 351 a | 201 c | 30.4 ab | 28.5 c |
| $HS_{125}$ | 193 | 253 abc | 264 abc | 28.6 bc | 30.5 a |
| $PM_{100}$ | 133 | 280 abc | 235 bc | 29.8 abc | 30.6 a |
| mean | - | 299 A | 227 B | - | - |

**Morphological and productive parameters**

Significant interaction effects were noticed for plant fresh weight, dry matter, marketable yield and WUE (**Table 4-6**).

Plants grown using mulching treatment showed higher plant FW as compared with plants grown on bare soil when $HS_{100}$ and $HS_{75}$ irrigation strategies were adopted, while no differences were observed when straw mulching was used in the other water treatments. The highest plant FW was obtained in mulched plants under $HS_{100}$, $HS_{75}$, and $HS_{125}$ (**Table 4-7**). Similar trend was observed for marketable yield where difference between mulched and no mulched plants was noticed only in $HS_{100}$ and $HS_{75}$ treatments (**Figure 4-2a**).

Plants dry weight was affected only by mulching (**Table 4-6**). Accordingly, plants mulched with rice straw had a greater dry yield as compared to plants grown on bare soil (12.3 and 9.6 g plant$^{-1}$, respectively). The interaction effect between soil mulching and irrigation strategy on dry matter was evident only at $HS_{125}$, where a significant increase of dry matter was observed in plants grown in mulched soil as compared to bare soil (**Table 4-7**).

Plants grown on mulched soil showed higher WUE as compared with plants grown on bare soil when $HS_{100}$ and $HS_{75}$ irrigation strategies were applied, while no differences were observed when straw mulching was provided in the other water treatments. The highest plant WUE was attained in mulched plants undergone $HS_{75}$ and $HS_{100}$ irrigation strategies **(Figure 4-2b)**.

Irrigation strategy and soil mulching did not affect the number of leaves per plants, while both leaf length and width were influenced by soil mulching and a significant interaction (between irrigation strategy and soil mulching) was detected (data not shown). Leaf length and width resulted the highest in plants grown in mulched soil at $HS_{100}$ (17.1 cm length, and 17.3 cm width), and the lowest in both $HS_{100}$ and $PM_{100}$ in plants grown on bare soil (13.7 cm and 14.1 cm length, and 14.2 and 14.2 cm width, respectively).

**Table 4-6**. Experiment 2. Effect of irrigation strategy and soil mulching on productive parameters of lettuce. Significance codes: *, significant at P≤0.05; **, significant at P≤0.01; ***, significant at P≤0.001, "Ns" = not significant. FW = fresh weight; DW = dry weight; WUE = Water use efficiency.

| | **Plant FW (g plant$^{-1}$)** | **Plant DW (g plant$^{-1}$)** | **Dry Matter (%)** | **Marketable yield (kg m$^{-2}$)** | **WUE (g FW L$^{-1}$ $H_2O$)** |
|---|---|---|---|---|---|
| Irrigation strategy (IS) | Ns | Ns | * | Ns | *** |
| Mulch (M) | *** | ** | Ns | *** | *** |
| WL x M | ** | Ns | * | *** | *** |

**Table 4-7.** Experiment 2. Effect of interaction between irrigation strategy and soil mulching on productive parameters of lettuce. Different letters indicate significant differences at Tukey HSD test (P≤0.05). Lower case letters indicate differences between treatments; capital letters indicate differences between means of (1) soil mulching or (2) irrigation strategy factor. Data are means of the three replicates. $HS_{75}$ = recovery of 75% $ET_c$ calculated by Hargraves-Samani equation; $HS_{100}$ = recovery of 100% $ET_c$ calculated by Hargraves-Samani equation; $HS_{125}$ = recovery of 125% $ET_c$ calculated by Hargraves-Samani equation; $PM_{100}$ = recovery 100% of $ET_c$ calculated by Penman-Monteith equation. SM=Straw Mulching; BS= Bare Soil.

| Irrigation strategy | Irrigation (mm) | Plant FW (g plant$^{-1}$) | | Dry Matter (%) | | |
|---|---|---|---|---|---|---|
| | | SM | BS | SM | BS | mean[2] |
| $HS_{100}$ | 154 | 211 a | 134 c | 7.10 a | 6.56 ab | 6.84 AB |
| $HS_{75}$ | 116 | 191 ab | 138 c | 6.80 ab | 6.58 ab | 6.70 AB |
| $HS_{125}$ | 193 | 186 ab | 161 bc | 6.91 a | 5.30 b | 6.11 B |
| $PM_{100}$ | 133 | 156 bc | 140 c | 7.29 a | 7.07 a | 7.19 A |
| mean[1] | - | 186 A | 143 B | - | - | - |

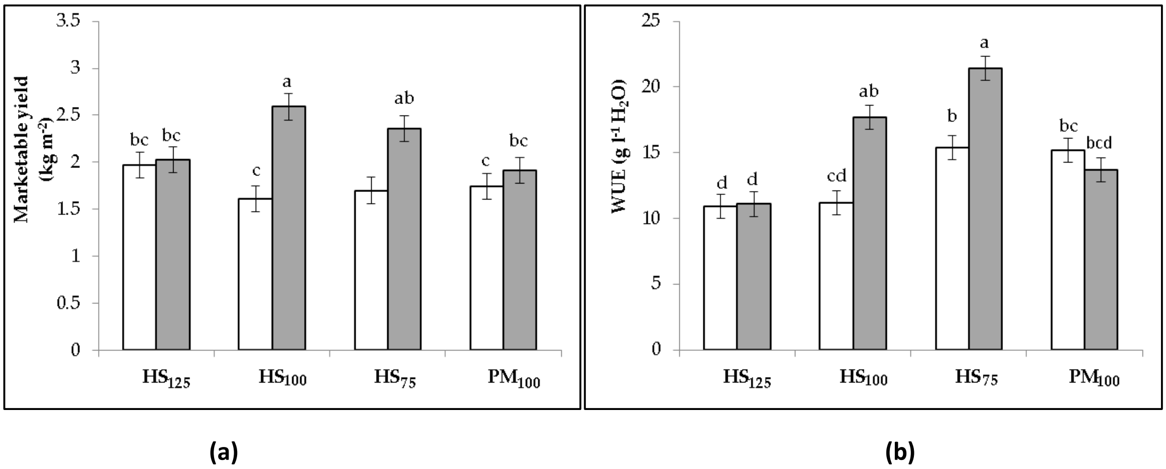



**Figure 4-2**. Experiment 2. Effect of irrigation strategy ($HS_{175}$ = recovery of 125% $ET_c$ calculated by Hargraves-Samani Equation; $HS_{100}$ = recovery of 100% $ET_c$ calculated by Hargraves-Samani Equation; $HS_{75}$ = recovery of 75% $ET_c$ calculated by Hargraves-Samani Equation; $PM_{100}$ = recovery of $ET_c$ calculated by Penman Monteith Equation) and mulching (white bars, no mulched, black bars, mulched) on soil-grown lettuce (**a**) marketable yield (kg FW m$^{-2}$) and water use efficiency (WUE, g FW L$^{-1}$ $H_2O$). Vertical bars indicate SE; different letters indicate significant differences with P≤0.05.

*4.3.4 Experiment 3.*

**Physiological parameter**

Stomatal conductance, leaf temperature and SPAD readings were affected by the irrigation strategy, while soil mulching influenced only the SPAD unit and interaction effects were never noticed (**Table 4-8)**. Stomatal conductance was higher in $PM_{100}$, $HS_{100}$, and $PM_{50}$ (**Table 4-9**). As far as leaf temperature is concerned, the highest values were shown in plants receiving the lower amount of water, $HS_{25}$ and $PM_{25}$, and the lowest in plants grown under $HS_{100}$ irrigation strategy (**Table 4-9**). Greater SPAD values were detected in plants grown at $HS_{50}$ and $HS_{25}$ treatment as compared to plants grown at $PM_{100}$ (**Table 4-9**). Moreover, higher SPAD values was observed when soil mulching was applied (20.6 SPAD value as compared to 18.4 SPAD value measured in plants grown on bare soil).

**Table 4-8.** Experiment 3. Effect of irrigation strategy and soil mulching on physiological parameters of lettuce. Significance codes: *, significant at P≤0.05; **, significant at P≤0.01; ***, significant at P≤0.001, "Ns" = not significant

| | Stomatal conductance (mmol $m^{-2}$ $s^{-1}$) | Leaf Temperature (°C) | SPAD Value |
|---|---|---|---|
| Irrigation strategy (IS) | *** | *** | ** |
| Soil mulching (M) | Ns | Ns | *** |
| WL x M | Ns | Ns | Ns |

**Table 4-9**. Experiment 3. Effect of irrigation strategy on physiological parameters of lettuce. Different letters indicate significant differences at Tukey HSD test (P≤0.05). Data are means of the four replicates. $HS_{75}$ = recovery of 75% $ET_c$ calculated by Hargraves-Samani equation; $HS_{100}$ = recovery of 100% $ET_c$ calculated by Hargraves-Samani equation; $HS_{125}$ = recovery of 125% $ET_c$ calculated by Hargraves-Samani equation; $PM_{25}$ = recovery 25% of $ET_c$ calculated by Penman-Monteith equation; $PM_{50}$ = recovery 50% of $ET_c$ calculated by Penman-Monteith equation; $PM_{100}$ = recovery 100% of $ET_c$ calculated by Penman-Monteith equation.

| Water Level | Irrigation (mm) | Stomatal Conductance (mmol $m^{-2}$ $s^{-1}$) | Leaf temperature (°C) | SPAD Value |
|---|---|---|---|---|
| $HS_{100}$ | 153 | 359 abc | 28.5 c | 19.3 ab |
| $HS_{50}$ | 77 | 322 bc | 30.4 b | 20.6 a |
| $HS_{25}$ | 38 | 272 c | 33.1 a | 20.7 a |
| $PM_{100}$ | 141 | 416 a | 30.8 b | 18.0 b |
| $PM_{50}$ | 70 | 365 ab | 30.8 b | 18.9 ab |
| $PM_{25}$ | 35 | 283 bc | 33.3 a | 19.5 ab |

**Morphological and productive parameters**

Irrigation strategy significantly affected plant FW, marketable yield and WUE, whilst soil mulching had a significant effect on all the parameters considered, and an interaction effect between water level and mulching was observed for all these parameters excluding dry matter (**Table 4-10**).

When PM equation was adopted no significant differences occurred between mulched and bare soil grown plants for FW and DW (**Table 4-11**). Alternatively, when the irrigation was managed through HS equation, in soil-mulched grown plants, FW was not affected by water level and was greater as compared to those grown on bare soil (**Table 4-11**). Contrarily, the lowest FW was achieved in plants grown on bare soil at $HS_{25}$, with comparable values obtained also in BS plants at $HS_{100}$ and $PM_{25}$ (**Table 4-11**).

Plants grown on mulched soil showed greater dry weight as compare to bare soil grown plants. Significant different was noted only between the irrigation treatment $HS_{25}$ (**Table 4-11**).

While irrigation strategy did not affect the marketable yield of plants grown on mulched soil. Significant different was showed only between treatment $HS_{50}$ and $PM_{25}$ which had a lower marketable yield among mulched treatments. Lowest marketable yield values were found among plants grown on bare soil and associated with $HS_{25}$) (**Figure 4-3a**).

As the irrigation volume was decreased, higher WUE values were observed (**Figure 4-3b**). Straw mulching had a positive effect in enhancing the WUE but only in $HS_{25}$ irrigation strategy (**Figure 4-3b)**).

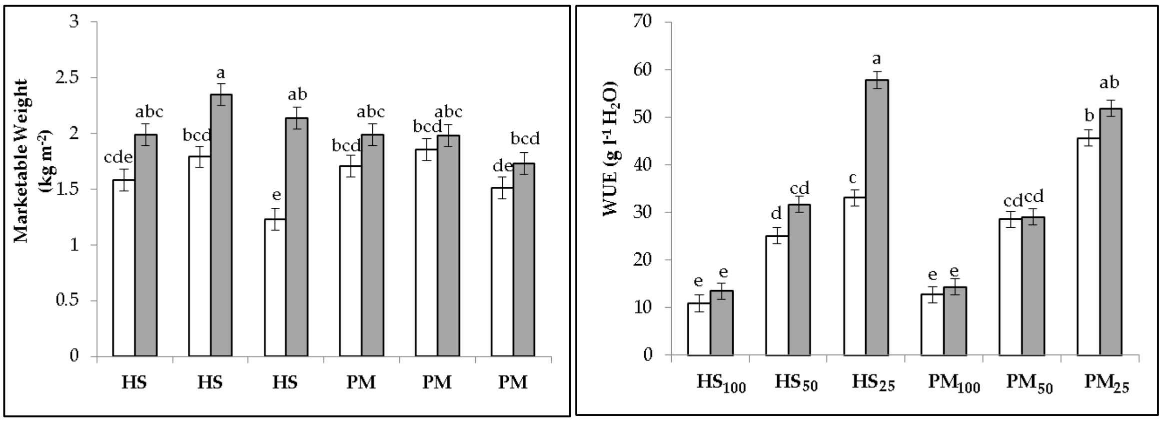
Dry matter was only influenced by the soil management and plants grown on bare soil showed higher values as compared with plants grown on straw mulching (6.8 and 5.9 g $plant^{-1}$, respectively, data not shown). No significant differences were observed regarding number of leaves per plant and leaf morphology (data not shown).

**Table 4-10**. Experiment 3. Effect of irrigation strategy and soil mulching on productive parameters of lettuce. Significance codes: *, significant at P≤0.05; **, significant at P≤0.01; ***, significant at P≤0.001, "Ns" = not significant. FW = fresh weight; DW = dry weight; WUE = Water use efficiency.

| | Plant FW ($g\ plant^{-1}$) | Plant DW ($g\ plant^{-1}$) | Dry Matter (%) | Marketable yield ($kg\ m^{-2}$) | WUE ($g\ FW\ L^{-1}\ H_2O$) |
|---|---|---|---|---|---|
| Irrigation strategy (IS) | *** | Ns | Ns | *** | *** |
| Mulch (M) | *** | *** | *** | *** | *** |
| WL x M | *** | * | Ns | *** | *** |

**Table 4-11.** Experiment 3. Effect of interaction between irrigation strategy and soil mulching on productive parameters of lettuce. Different letters indicate significant differences at Tukey HSD test (P≤0.05). Lower case letters indicate differences between treatments; capital letters indicate differences between means of [(1)] soil mulching or [(2)] irrigation strategy factor. Data are means of the three replicates. $HS_{100}$ = recovery of 100% $ET_c$ calculated by Hargraves-Samani equation; $HS_{50}$ = recovery of 50% $ET_c$ calculated by Hargraves-Samani equation; $HS_{25}$ = recovery of 25% $ET_c$ calculated by Hargraves-Samani equation; $PM_{100}$ = recovery of 100% $ET_c$ calculated by Penman-Monteith equation; $HS_{50}$ = recovery of 50% $ET_c$ calculated by Penman-Monteith equation; $HS_{25}$ = recovery of 25% $ET_c$ calculated by Penman-Monteith equation. SM=Straw Mulching; BS= Bare Soil; WUE = Water use efficiency.

| Irrigation strategy | Irrigation (mm) | Plant FW ($g\ plant^{-1}$) | | | Plant DW ($g\ plant^{-1}$) | | |
|---|---|---|---|---|---|---|---|
| | | SM | BS | mean[2] | SM | BS | mean[2] |
| $HS_{100}$ | 153 | 160 (abc) | 128 (cd) | 144 B | 10.7 (abc) | 8.46 (abc) | - |
| $HS_{50}$ | 77 | 187 (a) | 147 (bc) | 167 A | 11.5 (ab) | 8.72 (abc) | - |
| $HS_{25}$ | 38 | 179 (ab) | 97.6 (d) | 134 B | 12.6 (a) | 6.88 (c) | - |
| $PM_{100}$ | 141 | 155 (abc) | 137 (bc) | 147 AB | 9.73 (abc) | 9.57 (abc) | - |
| $PM_{50}$ | 70 | 156 (abc) | 154 (abc) | 153 AB | 9.12 (abc) | 9.60 (abc) | - |
| $PM_{25}$ | 35 | 140 (bc) | 124 (cd) | 132 B | 9.70 (abc) | 8.29 (bc) | - |
| mean[1] | - | 162 A | 131 B | - | 10.5 A | 8.61 B | - |




**(a)** **(b)**

**Figure 4-3**. Experiment 3. Effect of irrigation strategy ($HS_{100}$= recovery of 100% $ET_c$ calculated by Hargraves-Samani Equation; $HS_{50}$=recovery of 50% $ET_c$ calculated by Hargraves-Samani Equation; $HS_{25}$ = recovery of 25% $ET_c$ calculated by Hargraves-Samani Equation; $PM_{100}$ =recovery of 100% $ET_c$ calculated by Penman Monteith Equation; $PM_{50}$ =recovery of 50% $ET_c$ calculated by Penman Monteith Equation; $PM_{25}$ =recovery of 25% $ET_c$ calculated by Penman Monteith Equation) and mulching (white bars, no mulched, black bars, mulched) on soil-grown lettuce (**a**) marketable yield and (**b**)water use efficiency (WUE, g FW $L^{-1}$ $H_2O$). Vertical bars indicate SE, different letters indicate significant differences with P≤0.05.

### 4.4. Discussion

The application of different irrigation strategies significantly affected growth (including fresh and dry weight, leaf morphology), yield (marketable yield) and some physiological parameters (stomatal conductance, leaf temperature, SPAD units) of lettuce grown in Central Dry Zone, Myanmar.

The main outcome of these three experiments is that it is possible to obtain high yield of lettuce by restoring with irrigation only a fraction of estimated crop evapotranspiration. Accordingly, the reduction of irrigation water allowed to obtain either the highest yield or yield comparable to the restitution of 100% $ET_c$ in all the experiments.

In the first experiment, the highest yield was associated with $HS_{50}$ treatment (146 g plant$^{-1}$, corresponding to 1.90 kg m$^{-2}$ marketable yield) (**Table 4-3 and Figure 4-1a**). No significant differences were observed by comparing it with $HS_{100}$ and Sensor treatments, which produced 137 and 141 g plant$^{-1}$, respectively (1.68 and 1.83 kg m$^{-2}$ marketable yield) (**Table 4-3 and Figure 4-1**). The use of the wireless sensors, although easy to use and showing some advantages such as diminishing excessive water usage as compared to $HS_{100}$, appears still not affordable by farmers of Central Dry Zone of Myanmar due to their cost. In the second experiment, when soil was covered with straw mulching, both $HS_{100}$ and $HS_{75}$ treatment gave the best results producing 2.59 and 2.36 kg m$^{-2}$, respectively (**Table 4-7**). Even in the third experiment, the highest production was observed in mulched soil in all water treatments excluding $PM_{25}$ (with mean marketable yield of 2.09 kg m$^{-2}$) (**Table 4-11**).

The second experiment also pointed out that over-irrigation is not recommended since lettuce production did not benefit from $HS_{125}$ treatment (**Table 4-7**). Nevertheless, when soil was mulched with rice straw the excess humidity caused a 22% reduction in yield as compared to $HS_{100}$ treatment (**Figure 4-2a**). This is a relevant aspect to consider when training growers on the benefits of a rational use of irrigation water and to minimize the negative impact of water overuse in agriculture.

An important aspect that the second and the third experiments have underlined is that there is an effect on lettuce behavior, although not always significant, which is related to the method used for estimation of ETc and, consequently, with time and amount of water restored by irrigation. Generally, the Hargraves-Samani method (HS) overestimated $ET_0$, as compared with Penman Monteith (PM), being 14% and 8% higher in the second and third experiment, respectively (**Table 4-5** and **Table 4-7**). In addition to a 10-15% higher irrigation volume, this overestimation entailed more frequent water supplies during the crop cycle (18 waterings every 1.6 days in HS treatments, and 15 waterings every 2 days in PM treatments). This probably led to a more uniform hydration of root zone, which combined with the mulching of the soil allowed adequate control of the soil temperature, better use of nutrients and negligible infestation of weeds and finally a higher yield. Therefore, the Hargraves-Samani formula can be suggested as a method for estimating $ET_0$, particularly where the availability and access of climate data are limited, such as the Central Dry Zone of Myanmar. Under such circumstances, the HS equation actually based on the maximum and minimum air temperature could easily be used to estimate $ET_0$, contrarily to the Penman-Monteith equation which, although being the recommended system as a standard for calculating the reference evapotranspiration, requires a large number of parameters not always easily available locally.

In all experiments, the lower the irrigation water level the higher the water use efficiency (WUE) (**Figure 4-1b, 4-2b and 4-3b**). In the first experiment, WUE was around 40 g L$^{-1}$ $H_2O$ in the treatment $HS_{25}$ followed by $HS_{50}$, Sensor and $HS_{100}$ treatments where values around 30, 22 and 14 g L$^{-1}$ $H_2O$ were observed, respectively (**Figure 4-1b**). The same trend was observed in the second and third experiments where the use of rice straw as soil mulching allowed a further increase of WUE, as shown by the higher values compared with the treatments without mulching (**Figure 4-2b** and **Figure 4-3b**). As commonly experienced, the greater WUE was associated with the lowest irrigation treatments, but despite the limited water availability, the lettuce plants were able to extract the soil solution and to guarantee a satisfactory production as well. Similar WUE trend was observed by Dağdelen *et al*. (2009) in cotton crops grown with drip irrigation system. An increase in WUE was observed when 25% of ETc was applied, reaching 1.46 g L$^{-1}$, while in irrigation with 100% ETc, the WUE was 0.81 g L$^{-1}$. Furthermore, Singh *et al.* (2010), experiencing water deficit on cotton in a semi-arid region, finding a significant relationship between WUE and the different irrigation depths studied. The treatment wherein the irrigation was returning 100% of the ETc obtained a value of 0.54 g L$^{-1}$, while the 50% ETc obtained a value of 0.64 g L$^{-1}$ Related to lettuce production, Barbosa *et al*. (2015) comparing lettuce growth with drip irrigation system in the conventional field and hydroponic system found a value of WUE of 4 and 50 g l$^{-1}$

respectively. Moreover, Maraseni *et al*. (2012) detected a WUE of 19 g $l^{-1}$ in lettuce growth with drip irrigation system in eastern Australia.

Irrigation strategy significantly affected also stomatal conductance and leaf temperature (**Table 4-2**, **Table 4-5** and **Table 4-9**). Plants undergoing water stress (due to either reduced water supply or absence of straw mulching) have shown decreased stomatal conductance and higher leaf temperature. According to Turner (Turner *et al*., 1974), stress conditions can influence the stomatal action as well as the pressure deficit of water vapor. Under the hereby described experimental conditions, stomatal conductance and leaf temperature status were shown to efficiently allow for detection of water deficiency.

In both experiments where the soil mulching was tested, it significantly affected lettuce behavior, influencing plant fresh and dry weight, marketable yield and water use efficiency, Furthermore, it also affected stomatal conductance in experiment 2 and both dry matter percentage and SPAD units in experiment 3. On average, the use of straw mulching on lettuce crop increased the fresh weight from 19% (3$^{rd}$ experiment) to 30% (2$^{nd}$ experiment) and the WUE from 21% (2$^{nd}$ experiment) to 22% (3$^{rd}$ experiment) as compared to lettuce cultivated on bare soil. It is therefore possible to state that the use of mulching for lettuce vegetable production in semi-arid environmental conditions is crucial in order to improve the soil micro-environment around the root zone and to promote the conservation of soil moisture which can contribute to increasing both the quantitative and qualitative parameters of production.

### 4.5. Conclusions

The three experiments highlight the importance of the adoption of accurate irrigation management associated with innovation in diagnostic tools and sensors as a strategy to improve water use efficiency for vegetable production in semi-arid areas such as Central Dry Zone of Myanmar. It is possible to affirm that accurate irrigation management associated with drip irrigation systems and mulching technology increase yield and improve WUE of lettuce production in the Central Dry Zone of Myanmar. Under-water limiting conditions, irrigation management returning 50% of ETc, resulted in efficient water use and higher yields. An interdisciplinary approach and appropriate dissemination activities will be essential to guarantee that improved water management methodology and technology for agriculture will be put in place adequately by local institutions and farmers.

## Chapter 5 - Strategies for improved yield and Water Use Efficiency of lettuce (*Lactuca sativa* L.) through simplified soilless cultivation under semi-arid climate

This chapter is based on the journal paper:

*Michelon, N., Pennisi, G., Myint, N. O., Dall'Olio, G., Batista, L. P., Salviano, A. A. C., ... & Gianquinto, G. (2020). Strategies for Improved Yield and Water Use Efficiency of Lettuce (Lactuca sativa L.) through Simplified Soilless Cultivation under Semi-Arid Climate. Agronomy, 2020, 10(9), 1379; https://doi.org/10.3390/agronomy10091379*

**Abstract:** Simplified soilless cultivation (SSC) systems have globally spread as growing solutions for low fertility soil regions, low availability of water irrigation, small areas, and polluted environments. In the present study, four independent experiments were conducted for assessing the applicability of SSC in Northeast of Brazil (NE-Brazil) and Central Dry Zone of Myanmar (CDZ-Myanmar). In the first two experiments, the potentiality for lettuce crop production and water use efficiency (WUE) in a SSC system against traditional on-soil cultivation was addressed. Then, the definition of how main crop features (cultivar, nutrient solution concentration, system orientation and crop position) within the SSC system affect productivity was evidenced. The adoption of SSC improved yield (+35% and +72%, in NE-Brazil and CDZ-Myanmar) and WUE (7.7 and 2.7 times higher, in NE-Brazil and CDZ-Myanmar) as compared to traditional on-soil cultivation. In NE-Brazil, an eastern orientation of the system enabled to achieve higher yield for some selected lettuce cultivars. Furthermore, in both the considered contexts, a lower concentration of the nutrient solution (1.2 vs. 1.8 dS m-1) and an upper plant position within the SSC system enabled to achieve higher yield and WUE. The experiments validate the applicability of SSC technologies for lettuce cultivation in tropical areas.

**Keywords:** urban agriculture; simplified soilless culture; hydroponics; conventional agriculture

### 5.1. Introduction

In the last years, the detrimental effects of climate change are resulting in dramatic environmental, economic, and social consequences across the world (Eileen, 2009). Current projections show an overall increase in temperatures, with rainfall being irregularly distributed and characterized by heavy downpours (Bisbis *et al*., 2018; Gruda *et al*., 2019b). Erratic climate can negatively affect natural resources availability (e.g., water and agricultural land), as well as posing severe risks on both ecosystems and human health (Bisbis *et al*., 2018; IPCC, 2007). Many developing countries, also located in tropical areas, are vulnerable to climate change due to their dependence on rain-fed agriculture, widespread poverty, limited access to innovative technologies and improved agricultural practices (Dowuona Nii Nortey and Kwaghe, 2014). An evident interdependence between climate change, economic vulnerability, and migrations exists (Barbieri *et al*., 2010). Accordingly, climate change is also resulting in a growing rate of migration toward urban and peri-urban areas of large cities. However, adaptation mechanisms are not yet in place or are not strong enough to mitigate the economic vulnerability of the most impoverished strata of the population (Barbieri *et al*., 2010). Particularly in the tropical areas of Latin America and South-East Asia, health concerns are related to different forms of malnutrition frequently associated with a lack of micronutrients and vitamins in the population diet and low dietary diversification (Orsini *et al*., 2013).

In Latin America, the Piaui State, located in the North-East area of Brazil (NE-Brazil), is one of the areas most affected by climate change due to its natural resources scarcity and extreme climatic conditions (i.e., semi-dry zone with a rainy season from December to May) (Barbieri *et al*., 2010). Furthermore, after years of deforestation for agricultural purposes, soil presents a low amount of organic matter which negatively affects agricultural production (Souza *et al*., 2006). Similarly, to Piaui State, also the Central Dry Zone in Myanmar (CDZ-Myanmar) is considered as one of the most food-insecure regions of South-East Asia (Cho *et al*., 2016). Climate of CDZ-Myanmar is characterized by a dry season without precipitation from November to March which compromises and minimizes the agricultural choices of the farmers. Accordingly, climate and water scarcity are considered among the most significant problems of this area (Pavelic *et al*.,2015) and are expected to worsen in the future due to climate change (Aoki *et al*., 2009).

In both NE-Brazil and CDZ-Myanmar, the introduction of innovative agricultural technologies which allow vegetables production even in urban and peri-urban areas, while fostering water-saving techniques to improve crop water use efficiency (WUE), is a crucial priority. According to Gianquinto *et al*. (2007), it may be advisable to adopt simplified soilless cultivation (SSC) systems, which are independent of soil fertility and soil-borne diseases, do not require large spaces and intensive work labor and are characterized by high water and nutrient use efficiency thanks to the use of recirculating systems for the nutrient solution (Gianquinto *et al*., 2007; Savvas and Gruda, 2018). Specially, SSC systems are adapted from the concept of commercial hydroponics by integrating the advantages of easy construction and maintenance, while also reducing the initial economic investment or input requirements (Orsini *et al*., 2010). Different system designs exist for SSC, which mainly differ in the construction material, substrate used for plant growth, and management of the nutrient solution (Izquierdo, 2007).

The aim of this study is to assess the viability of a SSC system for the production of lettuce against traditional on-soil cultivation techniques in both NE-Brazil and CDZ-Myanmar, considering yield, water use efficiency and the overall physiological plant response. The assumption is that the adoption of SSC can increase yield and reduce water consumption of lettuce as compared to traditional on-soil grown crop also in very highly challenging contexts where soil quality is poor, climate is unfavorable and access to land by many people living in urban and peri-urban areas of large cities is limited. Moreover, the study integrates figures from different crop features and management strategies, such as crop positioning and garden orientation, and cultivar traits to elaborate specific recommendations on the optimal management of the SSC systems proposed.

## 5.2. Materials and Methods

### *5.2.1 Location*

**North-East of Brazil (NE-Brazil):** The experiments were carried out at the Horticulture Demonstration and Research Centre located at Fazenda Nova Esperança (5°01' S and 42°46' W, 87 m a.s.l.), owned by the Foundation Pe. Antonio Dante Civiero, placed on the outskirts of the city of Teresina, capital of Piaui. According to Köppen's classification, the local climate is Aw type, with dry summer and a rainy season between January and May.

**Central Dry Zone of Myanmar (CDZ-Myanmar):** The experiments were conducted at Soil and Water Research Station of Yezin Agriculture University (19°83' N and 96°27' E, 122 m a.s.l.), located at University Campus, in the peri-urban fringes of the Capital NayPyiTaw. According to Köppen's classification, the local climate is Aw type, with dry summer and a rainy season between June and October.

All experiments have been carried out in open field during the dry season, although the simplified soilless systems were equipped with a shading net (see description in section 2.3).

### 5.2.2. Experimental design

Four independent experiments were performed with commercial varieties of lettuce. In all experiments, lettuce (*Lactuca sativa* L.) was sown manually in 105 cells plastic seedling trays, and seedlings were transplanted 21 days after sowing (DAS).

***Experiment 1 (NE-Brazil):*** The trial considered a curly green lettuce (cv 'Isabela'). Conventional on-soil cultivation and SSC system were compared. Plants were transplanted on June 24th, 2009 and were harvested when reaching full maturity, which occurred at 40 days after transplanting (DAT) and at 31 DAT for traditional on-soil and in the SSC system, respectively. The experimental design was a strip block design with two treatments and three replicates.

***Experiment 2 (CDZ-Myanmar):*** The experiment was carried out with a curly green lettuce (cv 'Green wave'). Conventional on-soil cultivation and SSC systems were compared. Plants were transplanted on December 28th, 2018. Harvest occurred at 31 DAT in both systems. The experimental design was a completely randomized block design with two treatments and three replicates.

***Experiment 3 (NE-Brazil):*** Three green curly lettuce cultivars, namely cv 'Isabela', 'Veronica', and 'Mimosa verde', and one red curly cultivar, namely cv 'Banchu Red Fire', were tested on their adaptability on SSC system. The four cultivars were factorially combined with two different garden/plant rows orientation (East and West exposure). Plants were transplanted on July 18th, 2009. Harvest occurred at 31 DAT. The experimental design was a completely randomized block design with eight treatments and three replicates.
***Experiment 4 (CDZ-Myanmar)**:* Experiment was carried out on two curly green lettuce, namely cv 'Green wave' and 'Rapido 344'. Plants were tested for their adaptability on SSC, and two different concentrations of nutrient solutions' salinity, characterized by an electrical conductivity (EC) of 1.2 dS $m^{-1}$ ($NS_{1.2}$) and E.C. 1.8 dS $m^{-1}$ ($NS_{1.8}$), were used. Moreover, the effect of plant growing position (upper position, UP vs lower position, LP) within the garden was evaluated. UP refers to the plant growing in the upper part of the SSC that receives the nutrient solution directly from the nutrient solution tank. LP refers to the plants growing in the lower part of the system, which get the nutrient solution drained from the upper part of the SSC system (Figure 1). Plants were transplanted on February 19$^{th}$, 2019 and were harvest at 31 DAT. The experimental design was a randomized block design with eight treatments and three replications.

*5.2.3. Simplified soilless cultivation system*

The SSC system used was the so-called *Bottles* system (**Figure 5-1**), developed and tested in the northeast of Brazil since 2005 (Gianquinto *et al*., 2006). It is composed of a wooden/ bamboo frame and a gravity-flow system, where nutrient solution drains from a tank of 310 L volume, placed above the system at 2 m height. Hydraulic pipes with an emitter flow rate of 2 L $h^{-1}$ direct the flux into the declined garden with a slope of 24%, which is composed by connecting plastic drinking bottles that host both substrate (rice husk in all experiments) and plants. The excess nutrient solution is then directed through a drainage pipe system to another tank placed below. A 50% shading net was placed above the system, to reduce light intensity. In NE-Brazil, the system used for the experiments was 6 m long and 3 m wide (18 $m^2$) and accounted for 20 lines of 2 L plastic bottles (8 bottles $line^{-1}$). Each bottle presented two holes for hosting plants; therefore, at full regime, the system could accommodate 320 plants. In CDZ-Myanmar, the system was tailored to the local context to meet the vegetables production needs of individual households. Accordingly, the system size was reduced (5 m long and 2 m wide, resulting in a garden surface of 10 $m^2$), and a smaller tank for the nutrient solution (100 L) was adopted. Each module hosted 240 plants. When also considering the surrounding paths allowing for garden access (about half a meter on each side and in internal paths), the net planting density was of 26 plants $m^{-2}$ in both NE-Brazil and CDZ-Myanmar.

In NE-Brazil, a nutrient solution ($NS_{1.6}$) previously adopted for local SSC cultivation was used (18,19). The $NS_{1.6}$ was prepared with locally available simple mineral salts and soluble fertilizers and was characterized by electrical conductivity (EC) of 1.6 dS $m^{-1}$ and pH of 6.5. In CDZ-Myanmar, for both experiments, the NS was prepared by using locally available NPK fertilizer (15-15-15). During the experiment 2, the nutrient solution presented EC of 1.2 dS $m^{-1}$ and pH 7.7, while in experiment 4 the nutrient solution was prepared at two concentrations, respectively 0.6 g $L^{-1}$ in $NS_{1.2}$ (EC=1.2 dS $m^{-1}$, pH=7.3) and 0.8 g $L^{-1}$ in $NS_{1.8}$ (EC=1.8 dS $m^{-1}$, pH=7.5).

Details on macronutrient and micronutrient concentrations of nutrient solutions are reported in **Table 5-1** and **Table 5-2**.

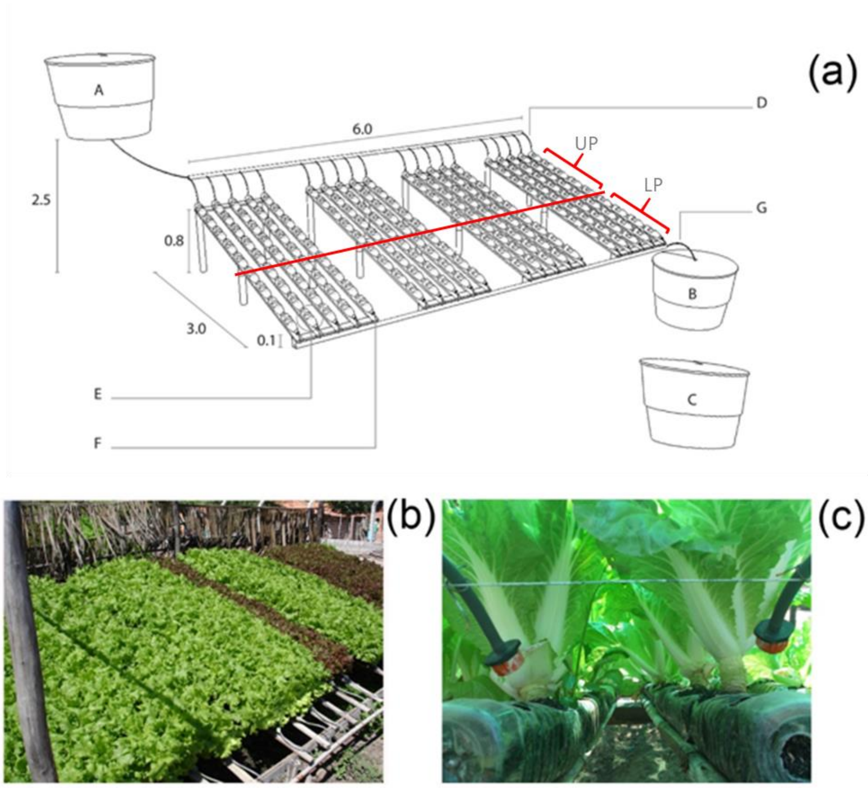



**Figure 5-1.** (a) Schematic drawing of the growing system used, with measures (in meters) adopted. The system includes a top (A) and a drainage (B) tank, as well as a fresh nutrient solution reservoir (C). The system is fitted with a gravity flow drip-irrigation system (D) that deliver the nutrient solution to 20 lines of recycled plastic bottles (E). Excess nutrient solution is then drained to a recollection pipe (F) which is connected (G) to the drainage tank (B). UP= Upper position; LP=Lower position. Images of the systems in the cities of (b) Teresina (Piaui, Brazil) and (c) NayPyiTaw (Myanmar).

**Table 5-1**. Macronutrient concentrations in water and nutrient solutions (NS) adopted in the experiments in NE-Brazil and in CDZ-Myanmar.

| | Exp. | N (mmol $L^{-1}$) | P (mmol $L^{-1}$) | K (mmol $L^{-1}$) | S (mmol $L^{1}$) | Ca (mmol $L^{-1}$) | Mg (mmol $L^{-1}$) |
|---|---|---|---|---|---|---|---|
| | | | | **NE-Brazil** | | | |
| **Water** | 1, 3 | 1.2 | nd | 0.6 | Nd | 0.4 | 0.2 |
| **$NS_{1.6}$** | 1, 3 | 11.7 | 0.7 | 3.4 | 2.6 | 3.1 | 1.7 |
| | | | | **CDZ-Myanmar** | | | |
| **Water** | 2, 4 | Nd | nd | 0.05 | Nd | 0.2 | 0.06 |
| **$NS_{1.2}$** | 2, 4 | 6.4 | 2.9 | 2.3 | 3.7 | 1.0 | 0.05 |
| **$NS_{1.8}$** | 4 | 8.6 | 3.4 | 3.1 | 3.1 | 1.3 | 0.07 |

nd = not determined

**Table 5-2.** Micronutrient concentrations in water and nutrient solutions (NS) adopted in the experiments in NE-Brazil and in CDZ-Myanmar.

| | Exp. | Fe ($\mu$mol $L^{-1}$) | Mn ($\mu$mol $L^{-1}$) | Cu ($\mu$mol $L^{-1}$) | Zn ($\mu$mol $L^{-1}$) | B ($\mu$mol $L^{-1}$) | Mo ($\mu$mol $L^{-1}$) |
|---|---|---|---|---|---|---|---|
| | | | | NE-Brazil | | | |
| **Water** | 1, 3 | Nd | 0. 5 | nd | 0.4 | 2.0 | nd |
| **$NS_{1.6}$** | 1, 3 | 26.9 | 12.4 | 1.6 | 4.6 | 21.5 | 0.5 |
| | | | | CDZ-Myanmar | | | |
| **Water** | 2, 4 | 0.005 | 0.005 | nd | Nd | nd | nd |
| **$NS_{1.2}$** | 2, 4 | 10.7 | 0.5 | 0.3 | 0.1 | nd | 0.01 |
| **$NS_{1.8}$** | 4 | 14.3 | 0.7 | 0.4 | 0.13 | nd | 0.02 |

nd = not determined

### *5.2.4. Traditional on-soil cultivation*

The soil of the two regions presented loamy sand texture with similar hydrological soil parameters (wilting point and field capacity at 6% v:v and 13% v:v, respectively). The physical and chemical characteristics of the soil in the two locations are described in **Table 5-3**. In both NE-Brazil and CDZ-Myanmar, soil has been overturned and dug with a hoe prior cultivation. Soil fertilization provided a supply of 1.5 kg $m^{-2}$ of cattle manure and 3.75 g $m^{-2}$ of N, P, and K (mineral fertilizer 10-10-10 and Nitrophoska 15-15-15 in NE-Brazil and CDZ-Myanmar, respectively). Fertilizer was manually applied three days before transplanting. No additional fertilizer was applied during the crop cycles. Due to low soil pH, in NE-Brazil, 0.15 kg $m^{-2}$ of dolomitic limestone was added into the soil. The plots were raised by 20 cm, and a trapezoid shape was developed, ensuring a base 1.2 m wide and a top 1.0 m wide. Finally, each plot was adjusted with a rake. Between the experimental plots, a space of approximately 0.7 m has been left to facilitate maintenance, data collection, and harvesting process. In both countries, plant spacing was 0.25 m between rows and 0.3 m within rows, resulting in a planting density of 13.3 plant $m^{-2}$, according to the habits of the local farmers. The elemental unit consisted of a plot of 10 $m^2$ (133 plants) or 5.4 $m^2$ (72 plants) in NE-Brazil and CDZ-Myanmar, respectively.

**Table 5-3.** Chemical characterization of the soils in the two locations

| OM[1] (%) | pH | EC (dS $m^{-1}$) | Available | | | Exchangeable | | | CEC[2] (cmol (+) $kg^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| | | | N | P | K | Ca | Mg | Na | |
| | | | | NE-Brazil (Exp. 1) | | | | | |
| 1.01 | 5.1 | nd | Nd | 9.0 | 35.2 | 1.4 | 0.1 | 9.2 | 4.51 |
| | | | | CDZ-Myanmar (Exp. 2) | | | | | |
| 0.38 | 6.2 | 0.11 | 54 | 10.9 | 25 | 3.04 | 0.2 | 34.8 | Nd |

[1] OM= Organic Matter; [2] CEC= Cation Exchange Capacity, nd = not determined

*5.2.5 Irrigation management*

In SSC system, nutrient solution flux started early in the morning (at 7:00 am), and continued until dusk (6:00 pm). Three-times per day (at 7:00 am, 11:00 am, and 3:00 pm), the drained nutrient solution was moved back to the upper tank. The daily nutrient solution consumption was calculated by the difference between the nutrient solution volume between the upper tank (at the beginning of the day) and the bottom tank (at the end of the day). The nutrient solution in the system was refreshed every day by adding new nutrient solution to a set level

When plants were grown on the soil-based system, the irrigation management was different in NE-Brazil and CDZ-Myanmar experiments. In NE-Brazil, irrigation management was carried out based on a traditional local habit of the farmers by using manual irrigation. Water was distributed across experimental plots through manual labor, and a 12 L watering bucket was used. The amount of water distributed in a plot was based on farmers' experience. In CDZ-Myanmar, the irrigation management of soil-based treatments was based on crop evapotranspiration (ETc), restoring 100% of crop ETc by means of a drip irrigation system

ETc was calculated by using the following equation (**Equation 5-1**)

$$ET_c = ET_0 * K_c \qquad \textbf{(Equation 5-1)}$$

Where $ET_c$ (mm day$^{-1}$) is the calculated crop evapotranspiration, $ET_0$ (mm day$^{-1}$) is the reference evapotranspiration, and $K_c$ is the FAO crop coefficient for lettuce (Trajkovic, 2007).

For the estimation of the reference evapotranspiration ($ET_0$), the Hargreaves - Samani (HS) equation (**Equation 5-2**) was used,

$$ET_0 = 0.0023\,(T_{mean} + 17.8)\,(T_{max} - T_{min})^{0.5}\,R_a \qquad \textbf{(Equation 5-2)}$$

Where $ET_0$ (mm day$^{-1}$) is the reference evapotranspiration rate, $T_{mean}$, $T_{max}$ and $T_{min}$ are the mean, maximum and minimum temperature (°C) of the day, respectively, and $R_a$ (W m$^{-2}$ day$^{-1}$) is the extraterrestrial solar radiation (Trajkovic, 2007).

The meteorological data for the determination of the reference evapotranspiration were daily downloaded from the website of the Agro-Meteorological Department of Yezin Agriculture University (http://www.yau.edu.mm/), located inside the University Campus, excluding extraterrestrial radiation Ra for HS equation that was calculated according to Duffie and Beckman (Duffie *et al*., 2020).

The amount of water used for each irrigation was calculated based on plant water balance considering soil properties, root depth, and climate data (including rainfall, if any). Daily ETc was estimated considering FAO crop coefficient for lettuce crop growth stages. Lettuce cycles were divided into three growth stages, and the Kc used was 0.7, 1.0, and 0.95, respectively. The time of irrigation was determined when readily available soil water (50% available soil water) was depleted.

Sixteen mm diameter drip pipes were used. Drippers had a flow rate of approximately 1.3 L h$^{-1}$, and each plant was supplied with a single dripper. A flow rate test and calculation of distribution uniformity (DU) were carried out before transplanting. The DU was calculated following the indications from Baum *et al*. (Baum *et al*., 2005). The irrigation management (time and rate) was manually performed.

*5.2.6 Plant Measurements*

At harvest, plants were weighed to determine the fresh weight (g plant$^{-1}$). Yield (kg m$^{-2}$) was assessed by excluding the external leaves which appeared damaged or wilted. Leaf number was also counted. Water Use Efficiency (WUE) was determined as the ratio between fresh weight and the volume of water used and expressed as g FW L$^{-1}$ $H_2O$. In experiment 4, leaf stomatal conductance was also measured using a handheld photosynthesis measurement system model CI-340 (Camas, WA, USA), equipped with 6.25 cm$^2$ cuvette. Measurements were made at 27 DAT on the upper surface of the canopy on 3 leaves per each plant from 10:00 to 14:00 taking approximately one hour to complete each replication. All plants were measured on a single day. In the system, EC and pH were constantly monitored using a Combo pH/EC/TDS/Temp tester Model

HI98130 (HANNA®, Brazil). In the experiments, 2 and 4, the nutrient solution temperature was also monitored twice a week.

*5.2.7 Statistical Analysis*

Data were collected on 12 plants from the central part of each plot. Data from experiments 1, and 2 were analyzed using one-way ANOVA. Data from experiments 3, and 4 were analyzed by using two- and three-way ANOVA, respectively. Means were separated using Tukey HSD test at $P \leq 0.05$. Before the analysis, all data were checked for normality and homogeneity of the variance. Averages and standard errors (SE) were calculated. Statistical analysis was carried out using R statistical software (version 3.3.2, package "emmeans" and "car").

## 5.3. Results

*5.3.1. Climate during the experiments.*

**NE-Brazil**

During experiment 1, maximum air temperatures ranged between 31.4 and 34.7 °C, with an average of 33.0 °C. Minimum temperatures ranged between 17.8 and 22.4 °C, with an average of 19.8°C. The daily relative humidity (RH) ranged between a minimum of 57% and a maximum of 97% (**Table 5-4**). Furthermore, 20.3 mm of effective rainfall occurred. During experiment 3, maximum air temperatures ranged between 31.7 and 35.4 °C, with an average maximum temperature of 34.0 °C. Minimum temperatures ranged between 17.8 and 22.4 °C, with an average minimum temperature of 19.8 °C. The maximum relative humidity (RH) was 97%, and the minimum RH was 55% (**Table 5-4**). The growing degree days (GDD) from transplanting to harvest ranged from 710 °C (experiment 3) to 920 °C (experiment 1).

**CDZ-Myanmar**

During the experiment 2, maximum air temperatures ranged between 25.0 and 34.0 °C, with an average of 31.5°C. Minimum temperatures ranged between 14.4 and 20.4 °C, with an average of 16.7 °C. The daily relative humidity (RH) range between a minimum of 48%and a maximum of 73% **(Table 5-4)**. During the experiment 4, maximum air temperatures ranged between 30.7 and 38.6°C, with an average maximum temperature of 35.6 °C. Minimum temperatures ranged between 16.0 and 23.0°C, with an average minimum temperature of 19.5 °C. The maximum relative humidity (RH) was 59%, and the minimum RH was 30%. No rainfall occurred during the experiments. The growing degree days (GDD) from transplanting to harvest ranged from 662 °C (experiment 2) to 731 °C (experiment 4) (**Table 5-4**).

**Table 5-4.** Main climatic features during the experiments.

| Average air temperature (°C) | | RH[1] (%) | | DLI[2] ($mol\ m^{-2}\ d^{-1}$) | Wind Speed ($m\ s^{-1}$) | GDD[3] (°C) |
|---|---|---|---|---|---|---|
| Max | min | Max | min | | | |
| | | | NE-Brazil (Exp. 1) | | | |
| 33.0 | 19.8 | 97 | 57 | 24.3 | 0.9 | 920*/698** |
| | | | CDZ-Myanmar (Exp. 2) | | | |
| 31.5 | 16.7 | 73 | 48 | 17.0 | 1.0 | 662 |
| | | | NE-Brazil (Exp. 3) | | | |
| 34.0 | 19.8 | 97 | 55 | 24.7 | 1.0 | 710 |
| | | | CDZ-Myanmar (Exp. 4) | | | |
| 35.6 | 19.5 | 59 | 30 | 20.9 | 1.9 | 731 |

[1]RH= Relative Humidity; [2]DLI = average daily light integrals; [3]GDD = growing degree days, calculated based on a crop base temperature of 4°C (23); *on soil-based system (40 days cropping cycle); ** on simplified soilless system (31 days crop cycle);

*5.3.2. Experiment 1 – NE-Brazil*

Lettuce yield resulted higher (+35%) in the SSC system, with a mean value of 2.3 kg $m^{-2}$, as compared to 1.7 kg $m^{-2}$ achieved on soil (**Figure 2a**). This was mainly due to a larger size of the leaves (data not shown), while leaf number was higher in plants grown on soil (**Figure 2b**). The increased yield was obtained with a daily water use (L $m^{-2}$ $d^{-1}$) approximately four times lower in SSC system, as compared to conventional on-soil cultivation (1.8 vs 7.5 L $m^{-2}$ $d^{-1}$) (data not shown). As a consequence, WUE in SSC system was 7.7 times higher, as compared to the conventional on-soil system, with mean values of 43.7 and 5.6 g $L^{-1}$ $H_2O$, respectively (**Figure 2c**).

*5.3.3. Experiment 2 – CDZ-Myanmar*

During experiment 2 the average minimum temperature of the nutrient solution was 19.6±1.64°C while the average maximum temperature was 29.2 ±1.69°C. The average pH was 7.7, ranging 7.4 to 8.1. The average EC was 1.28, ranging 1.12 to 1.46 dS $m^{-1}$ (data not shown).

Yield (kg $m^{-2}$) was increased by 72% (3.1 vs 1.8 kg $m^{-2}$) in SSC in comparison to soil treatment (**Figure 2d**) and also in this case the leaf number resulted significantly higher in soil-grown lettuce as compared to soilless-grown plants (**Figure 2e**). Daily water use (L $m^{-2}$ $d^{-1}$) was approximately two-times lower in SSC system (2.66 l $m^{-2}$ $d^{-1}$) as compared to conventional on soil production (4.07 l $m^{-2}$ $d^{-1}$). WUE in SSC system was found to be 2.7 times higher than that obtained on conventional cultivation, with average values of 37.1 and 13.7 g L-1 H2O, respectively (**Figure 2 f**).

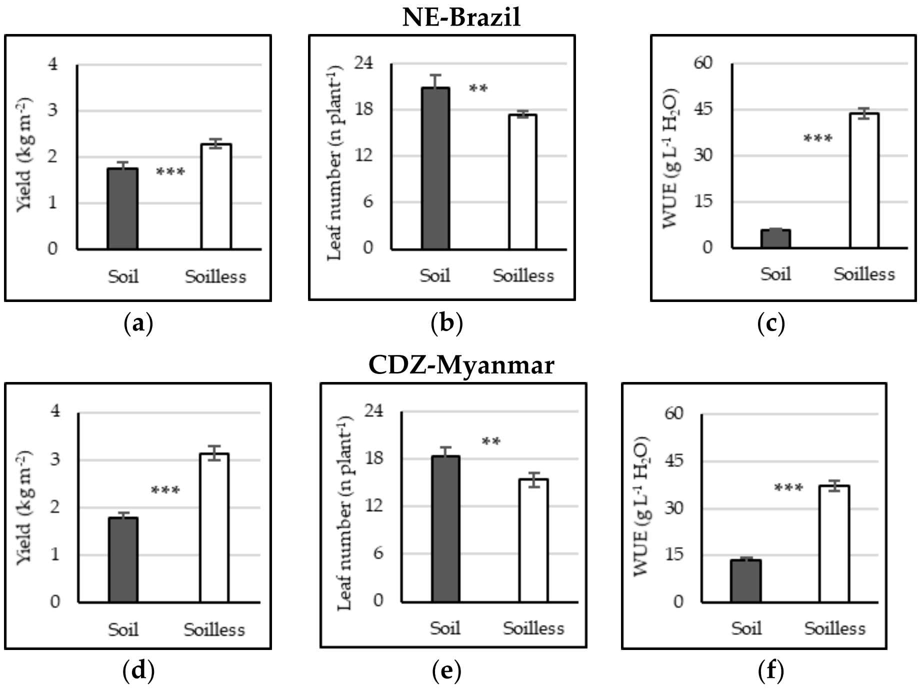



**Figure 5-2.** Results from experiments 1 (Brazil, top row) and 2 (Myanmar, bottom row). Lettuce yields (**a, d**), leaf number (**b, e**), and Water Use Efficiency (WUE, **c, f**). Vertical bars represent standard errors. Significant differences at P≤0.05 (*), P≤0.01 (**), P≤0.001 (***).

*5.3.4 Experiment 3 – NE-Brazil*

Considering the system orientation, significant differences for yield were found only in Veronica and Banchu cultivars, for which the west oriented system showed a reduction in yield of 10 and 44%, respectively as compared to the east oriented one. Contrarily, yield of cv Isabela and cv Mimosa was not affected by the SSC system orientation (**Figure 5-3**). Daily water use was about 1.8 L $m^{-2}$ $d^{-1}$, as for exp. 1.

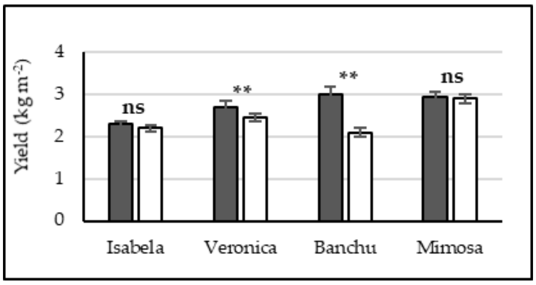



**Figure 5-3.** Results from experiments 3 (NE-Brazil). Yield response to the simplified soilless system orientation (East, grey columns, West, white columns) in four lettuce cultivars (Isabela, Veronica, Banchu, and Mimosa). Vertical bars represent standard errors. Significant differences at P≤0.01 (**), ns=not significant differences.

*5.3.5 Experiment 4 – CDZ-Myanmar*

The average minimum temperature of the nutrient solution was 20.7±1.1°C while the average maximum temperature was 39.5±0.87 °C. Daily water use was 2.50 L $m^{-2}$ $d^{-1}$ for $NS_{1.2}$ and 2.23 L $m^{-2}$ $d^{-1}$ for $NS_{1.8}$. The average pH was 7.3 and 7.5 for $NS_{1.2}$ and $NS_{1.8}$, respectively. It ranged 6.4–8.7 for the former, and 6.6– 8.9 for the latter. Average EC was 1.25 and 1.83 dS $m^{-1}$ for $NS_{1.2}$ and $NS_{1.8}$, respectively, ranging 1.14–1.48 dS $m^{-1}$ for solution $NS_{1.2}$ and 1.59–2.06 dS $m^{-1}$ for solution $NS_{1.8}$ (data not shown). Results of analysis of variance in **Table 5-5** show that EC of nutrient solution (EC), lettuce cultivar (Cv), and plants position (P) significantly affected plant morphological and productive parameters, as well as WUE and the crop physiological response.

Yield, stomatal conductance and WUE were affected by EC, Cv, and P - wherein a significant interaction between the three factors was noted – while leaf number was only affected by EC and Cv, with a significant interaction between the two factors **(Table 5-5)**. Yield of plants placed in the lower position (LP) was not affected by Cv and EC, while for both cultivars the plants in the upper position (UP) yielded more when $NS_{1.2}$ was used **(Table 5-6)**. The yield of plants belonging to cv Thai and grown by using $NS_{1.2}$ was 4-times higher, as compared to yield of Thai lettuce supplied with $NS_{1.8}$ and placed in the same position within the system **(Table 5-6)**. The increased yield was mainly due to leaf number, as Thai plant grown adopting $NS_{1.2}$ showed the highest number of leaves (12.9 leaves $plant^{-1}$) while no differences were observed between the other treatments (data not shown). Stomatal conductance resulted the highest (212 mmol $m^{-2}$ $s^{-1}$) in Thai lettuce grown on the upper part of the system by using $NS_{1.2}$ **(Table 5-6)**. For plants grown in the lower part of the system (LP), stomatal conductance was only affected by CV, resulting higher in cv Thai for both considered EC (**Table 5-6**). Leaf temperature was only affected by the position (P) in the system (data not shown), resulting the lowest in plants grown on the top of the system (28.8°C compared to 29.8°C measured in plants grown at the bottom of the system). In cv Thai, WUE resulted the highest in plants fed with $NS_{1.2}$ and grown in the upper position (UP) of the system, while for cultivar Rapido 344 the only statistically significant difference was evidenced between plants grown on the upper position and fed with $NS_{1.2}$ and plants grown in the lower position of the system and fed with $NS_{1.8}$ **(Table 5-6)**.

**Table 5-5**. Results from the ANOVA on experiment 4 (CDZ-Myanmar). Effect of EC of the nutrient solution (EC), Cultivar (Cv), and position within the garden (P) on lettuce yield, leaf number, and water use efficiency (WUE). Significant differences at P≤0.05 (*), P≤0.01 (**) and P≤0.001 (***), ns=not significant differences.

| | **Yield (kg m$^{-2}$)** | **Leaf number (n plant$^{-1}$)** | **$g_s$ (mmol m$^{-2}$ s$^{-1}$)** | **WUE (g L$^{-1}$)** |
|---|---|---|---|---|
| EC of nutrient solution (EC) | *** | *** | *** | *** |
| Cultivar (Cv) | ** | *** | *** | * |
| Position (P) | *** | ns | *** | *** |
| EC x Cv | * | ** | ** | * |
| EC x P | *** | * | ** | *** |
| Cv x P | Ns | ns | ns | ns |
| EC x Cv x P | ** | ns | * | ** |

**Table 5-6**. Results from experiment 4 (CDZ-Myanmar). Effects of factorial combination of EC of the nutrient solution (EC, 1.2 vs 1.8 dS m$^{-1}$), Cultivar (Cv, Thai vs EW) and position (P, upper position, UP vs lower position, LP) within the garden on lettuce yield, stomatal conductance ($g_s$)and water use efficiency (WUE). Different letters indicate significant differences at P≤0.05

| **EC (dS m$^{-1}$)** | **Cultivar** | **Yield (kg m$^{-2}$)** | | **$g_s$ (mmol m$^{-2}$ s$^{-1}$)** | | **WUE (g L$^{-1}$ $H_2O$)** | |
|---|---|---|---|---|---|---|---|
| | | **UP** | **LP** | **UP** | **LP** | **UP** | **LP** |
| 1.2 | Thai | 2.88 (a) | 1.18 (bc) | 212 (a) | 118 (b) | 38.4 (a) | 15.7 (bc) |
| 1.2 | Rapido 344 | 1.79 (b) | 1.14 (c) | 100 (b) | 44 (de) | 24.0 (b) | 15.2 (bc) |
| 1.8 | Thai | 0.71(c) | 0.65 (c) | 121 (b) | 91 (bc) | 10.57 (c) | 9.71 (c) |
| 1.8 | Rapido 344 | 0.82 (c) | 0.57 (c) | 78 (c) | 35 (e) | 12.3 (c) | 8.54 (c) |

### 5.4 Discussion

The application of different cropping systems significantly affected yield, physiological response and water use efficiency of lettuce grown in both NE-Brazil and CDZ-Myanmar.

Water availability is one of the majors constrains for agriculture development and food production. The first and second experiments aimed to determinate whether SSC lettuce production is a suitable and sustainable alternative to conventional on-soil production in both locations. Barbosa *et al*. (2015), when comparing commercial (high-tech) hydroponic greenhouses against on-soil lettuce production, found that hydroponics could increase yield by 11-fold, thanks to improved nutrition and environmental control. According to our results obtained in both experiments, the use of simplified (low tech) soilless system allowed to increase the yield of lettuce but in a lesser extended (+35% in NE-Brazil and +72% in CDZ-Myanmar, Figure 2a and 2d). Yield increase can be the result of higher planting density (26 vs. 13 plants m-2, on SSC and on-soil cultivation respectively), fast plant growth and precocity of production (31 vs 40 DAT of the soil growing cycle according to experiment 1) and the improved environmental conditions maintained within the SSC system, including plant nutrition, uniform and constant irrigation as well as the shading cover integrated in the SSC system. According to Zhao *et al*., the adoption of a shading net as a cover for lettuce production in the summer season in Kansas led to slightly lower daily maximum air temperature relative to the open field, with an average reduction of ≈0.4 °C (Zhao and Carey, 2009).

Moreover, Zhao *et al*. (2019) reported also that the shading net has a significant impact on soil temperature and leaf temperature. Indeed, in comparison with the open field, when the shading net is adopted, a considerable reduction of the leaf surface temperature, by 1.5 to 2.5 °C, was observed (Zhao and Carey, 2009), thus affecting the plant's capacity to absorb water and nutrients (Falah *et al*., 2010). In the SSC system, the higher frequency of fertigation has probably affected production capacity. Silber *et al*., experimented on the effect of fertigation frequency on yield, water, and nutrient uptake of lettuce. The main finding of the investigation was that high fertigation frequency (from 2 to 10 events a day) induced a significant increase of 13-15% in the lettuce fresh weight (FW) (Silber *et al*., 2003).

Furthermore, SSC systems are also considered water-saving technologies, thanks to the capability to deliver water directly to the plant root (Sanchez, 2020; Gruda, 2019). Despite the limited soil exploration by the shallow rooting system of lettuce, in NE-Brazil, when conventional growing system was adopted, irrigation water was applied by means of a bucket or can on the entire soil surface and consequently a relevant amount of water is lost through evaporation and percolation into the sandy soil. Increase in the use of low-flow and more targeted irrigation techniques such as the adoption of drip irrigation system could lower the overall water use of conventional farming (Barbosa, 2015). As a matter of fact, drip irrigation was the system used as control in CDZ-Myanmar experiments. In the hereby presented research, the adoption of SSC system enabled a reduction of water use by 76% and 59% in NE-Brazil and in CDZ-Myanmar, respectively, as compared to on-soil production. The observed water savings are also consistent with previous literature, e.g. when a SSC system was adopted in Colombia and water use was reduced by 90% as compared to the traditional on-soil cropping system (Bradley and Marulanda, 2000).

A consequence of higher yield and lower water use was an increased WUE in the SSC systems. In NE-Brazil and CDZ-Myanmar WUE was, respectively, 7.7 and 2.7 fold higher, as compared to conventional on-soil production (**Figure 5-2c** and **5-2f**). Similarly, WUE for lettuce in hydroponics was previously found in the range of 2.9 g of dry mass per $L^{-1}$ $H_2O$ (Wheeler *et al*., 1997), or 41 g of fresh mass per $L^{-1}$ $H_2O$ (Michelon *et al*., 2020a). Lettuce grown in high-tech hydroponic conditions showed a reduction in water use by 13-fold, as compared with traditional on-soil cultivation (Barbosa *et al*., 2015). Under the expected climate change scenarios and water limitation for agriculture, SSC systems could be a valuable strategy to sustain highly productive agriculture in contexts where the adoption of high-technology systems is not affordable (Gruda, 2019; Martínez-Alvarez *et al*., 2018; Gruda *et al*., 2019a; Gruda *et al*., 2019b).

In the third experiment, the adaptability of four lettuce cultivars to two different garden orientations was addressed to have a deeper understanding of the SSC system management. It emerged that the response of plants growth to the garden orientation was cultivar dependent **(Figure 5-3)**. Accordingly, Veronica and Banchu achieved a higher yield with the eastern garden exposure **(Figure 5-3)**, which received lower solar radiation in the afternoon mitigating the high air temperatures. Wheeler *et al*. (1993) indicated 23 °C as the optimal daily temperature for growing lettuce, a condition that is far below mean temperatures observed in NE-Brazil during the experiment. The heat stress could also result in a greater osmotic stress caused by nutrient solution, resulting in lower water uptake and reduced plant growth (Sanchez, 2020). Moreover, due to elevated temperatures in the root zone environment, hypoxia may emerge, inhibiting root respiration, mineral uptake, and water movement into the roots (Ehret *et al*., 2010). In the fourth experiment, the growth response of plants grown in different positions within the system was addressed as a function of both plant cultivar and the concentration of the nutrient solution (**Table 5-5**). Accordingly, the highest yield was associated with Thai cultivar supplied with $NS_{1.2}$ (**Table 5-6**). Possibly, under the local climate, plants preferred a nutrient solution with lower EC, and the Thai cultivar better responded to reduced osmotic stress. Furthermore, the yield was the highest when Thai cultivar was grown in the upper part of the system. (**Table 5-6**). As reported by Gianquinto *et al*. (2007), this aspect could be due to increased temperature reached by the nutrient solution during the flow between the top and the bottom tank. It would suggest that by the time the nutrient solution reached the lower section of SSC, it was significantly warmed up by irradiance in the plastic bottles, although this statement should further be confirmed by punctual determination of nutrient solution and substrate temperatures in the different positions. Thompson *et al*. (1998) showed that 24 °C root temperature in hydroponic systems is the ideal temperature whereby lettuce growth can be maximized even with elevated air temperature. Different studies also reported that high nutrient solution temperature depresses water and nutrient uptake through reduced oxygen availability, also affecting physiological processes such as the root browning and the active transport in membranes (Trejo-Téllez and Gómez-Merino, 2012). Moreover, it was also observed that high solution temperature might decrease nutrient concentration (particularly of N, K and Ca) in the root, which may ultimately decrease crop growth (Falah *et al*., 2010). It should be further studied, however, whether this may be associated with increases of nutrient solution temperature as the water flow through the system or by selective absorption of specific nutrients from those plants that receive the nutrient solution first. In this regard, it could also be considered to add additional hydraulic pipes with emitters in the middle of the system.

### 5.5 Conclusions

The study addressed the application of SSC technologies for lettuce production in a tropical wet and dry climate. Elevate potentialities in terms of both yield increase and improved water use efficiency in comparison with traditional on-soil cultivation technologies were evidenced in both locations. Furthermore, the study explores alternative crop management strategies evidencing differences in cultivar adaptability and potential productivity. For instance, garden orientation was also shown to affect crop productivity on a cultivar dependent basis. Finally, under the elevate temperatures that are locally experienced, it is advisable to reduce the concentration of the nutrient solution (with EC of 1.2 dS $m^{-1}$ providing better results than EC of 1.8 dS $m^{-1}$). Interestingly, the yield was also improved when the plants were hosted in the upper positions of the garden. Government and local support services could influence the future of soilless farming, as subsidies could be used to offset the relatively high initial cost of SSC infrastructure. We conclude that simplified soilless system could become one of the efficient strategies for contributing to sustainably feeding the world's growing population especially in challenging area, such us North East of Brazil and the Central Dry Zone of Myanmar.

## CHAPTER 6 - Drought stress affects yield and water use efficiency in hybrid and open-pollinated lines of tomato (*Solanum lycopersicum* L.)

**Abstract.** Water availability is considered one of the most determinant cultivation factors and seriously affects plant growth in several world agricultural regions. Identifying water-efficient crop species and cultivars is currently one of the leading research objectives in plant sciences. Tomato (*Solanum lycopersicum* L.) is one of the most grown horticultural crops in the Mediterranean basin and world around. In the past decades, commercial plant breeding has mainly addressed yield or quality traits, with little effort to improve drought tolerance. The identification of drought-tolerant lines was mainly addressed by breeding water-efficient rootstocks, which often are selected among wild tomato relatives. This study aims at elucidating drought-tolerant traits in open-pollinated tomato cultivars as compared to the commercial hybrid.

**Keywords:** *Solanum lycopersicum* L., genotypes, irrigation management, yield, water use efficiency, stomatal conductance, leaf temperature

## 6.1 Introduction

The Earth is covered by 1,390 million $km^3$ of water. About 97.5% is salty water and is represented by the seas and oceans. The remaining 2.5% is freshwater, 99% of wich is in ice in Antarctica and Greenland or lies underground, too deep to be accessible; only 1% is freshwater available to be taken and used (Franco *et al.*, 2014). Excepting for Europe and North America, agriculture is the leading water consumption sector, accounting for about 70% of all withdrawals globally.

In comparison, civil/domestic use accounts for about 8% and industrial use for about 22% (Velasco-Muñoz, 2018). A significant percentage of water is also used in Italy for agriculture purposes. It holds the record at the European level with 78% (E.U. average consumption of 30%) with its 4.5 million hectares of irrigated land (Bartolini, 2007). A considerable and variable amount of water is used in agriculture and livestock. For instance, 15,500 liters of water are needed for the production of 1 kg of meat while, vegetable origin products have a much lower water demand, (e.g. 200 liters of water are required to produce 1kg of tomatoes) (Pimentel, 2004). Such intensive water use for agricultural purposes can inevitably deplete resources. Twenty countries worldwide are in critical condition, as more than 40% of their renewable water resources are only used for agriculture (Bruinsma, 2003).

On one side, there is reduced water availability for agriculture and other uses, accompanied by reduced arable land and increased demand for food due to increased population (Nath, 2015). On the other side, climate change is negatively affecting the situation. The Intergovernmental Committee on Climate Change reports that the planet's average temperature has increased by about 0.6°C since 1861. Besides, based on current trends in greenhouse gas emissions, a further increase in the Earth's temperature is estimated between 1.4 and 5.8°C over the period 1990-2100 (Change, 2013). Improved water management in agriculture, more rational and efficient use of water supported by modern technologies, and recovery and enhancement of heirloom plant species and varieties will play a vital role in fighting the future water crisis (Dağdelen, 2009).

Tomato is one of the most popular and widely grown vegetables globally, ranking second in importance to potato (Kumar, 2007). Currently, tomatoes are cultivated on 4 million hectares, with a total production of 160 million tonnes and an average harvest of 34 tonnes per hectare (FAOSTAT, 2019). China, India, U.S.A., Turkey, Egypt, Iran, and Italy are the major tomato producing countries. Italy is Europe's largest producer, ahead of Spain, Greece, Portugal, and France, with 5.8 million tons and 103,000 ha cultivated, of which 77,000 ha from industry tomatoes and 26,000 ha from table' tomatoes, for a gross saleable production of € 800 million (FAOSTAT, 2019). Due to the tomato fruits' remarkable consumption, its importance is appreciated for its organoleptic characteristics, such as fresh products and different processing industry (Kumar, 2007). With its derived products, tomatoes are one of the primary food sources of carotenoids, providing an estimated 80% daily intake of lycopene, folate, ascorbic acid, and flavonoids a-tocopherol, and potassium in the western diet (Erba, 2013). The varietal selection, combined with proper use of the water for agriculture, plays a fundamental role in ensuring the sustainability of tomato production, especially in those areas where water resources are scarce (Grassbaugh, 2002). In the past decades, commercial plant breeding has mainly addressed yield or quality traits, with little effort was made to improve drought tolerance. With the recent introduction of grafting tecniques in some vegetable crops, such as tomato, watermelon and others, the identification of drought-tolerant lines was mainly addressed by breeding water-efficient rootstocks, which often are selected among wild tomato relatives (Bolger *et al.*, 2014). Several studies have focused on the comparison between open-pollinated plants and hybrid tomato and others showed that tomatoes grown in Mediterranean areas under controlled and moderately water stress situations could improve water-use efficiency without a negative impact on yield (Games *et al.*, 2011; Keterji *et al.*, 2013; Patanè *et al.*, 2011).

Baye Berihun observed that the adoption of a drip irrigation system combined with different irrigation volume and mulching practices in tomatoes production positively affected the number of fruits per plant, average weight of marketable fruits, and total fruit yield (Berihun, 2011).

Moreover, Singh *et al*. (2009) observed also that the adoption of a drip irrigation system supplying 80% of the evapotranspiration (E.T.) crop based on pan evaporation gave significantly higher fruit yield (45.57 Mg $ha^{-1}$) as compared to the surface irrigation (29.43 Mg $ha^{-1}$) (Singh, 2009). This study aims at elucidating drought-tolerant productivity performance in four open-pollinated (OP) tomato cultivars as compared to four commercial hybrids, undergoing non limiting and limited water restoring. The work's central hypothesis is to obtain good tomato production despite water-stressed treatments that do not meet 100% of the water plants' needs.

## 6.2 Materials and Methods

### *6.2.1 Location*

The experiments were conducted during the spring-summer seasons of years 2017 and 2018 in open field conditions at Cadriano Farm of Agriculture Science and Technology Department (DISTAL) of Bologna University located at Cadriano, (44° 54' North and 11° 41' East, 32 m a.s.l.). According to Köppen's classification, the local climate is the Cfa type, Humid Subtropical Climate with relatively high temperatures and evenly distributed precipitation throughout the year.

The soil presented a loamy texture with 25% of sand, 47% of silt, and 18% of clay, a wilting point of 11.7% v:v, and field capacity of 26.6% v:v. The soil chemical characteristics in the 0-0.30 m layer were the following: pH ($H_2O$) 6.9; 1.45% organic matter; C.S.C 25.9 meq 100 $g^{-1}$; 0.09 % of Total N; 54.4 mg $kg^{-1}$ of available P; 143 mg $kg^{-1}$ of exchangeable K.

### *6.2.2 Treatments and experimental design*

Two independent experiments were carried out on eight genotypes of tomato (*Solanum lycopersicum* L.).

In both experiments, three irrigation levels were applied, based on crop evapotranspiration ($ET_c$), respectively restoring 25 ($HS_{25}$), 50 ($HS_{50}$), and 100% ($HS_{100}$) of crop $ET_c$ (details on $ET_c$ calculation are included in the following sections) measured by using Hargreaves-Samani equation (HS). The experimental design was a strip-split-plot, with irrigation treatments on the main strips and genotypes distributed in plots inside the strip, with three replications per treatment and six plants per replicate.

### *6.2.3 Plant material and plant management*

Eight genotypes of tomatoes (*Solanum lycopersicum* L.) for fresh market were used for the experiments **(Figure 6-1)**. The eight genotypes used in this experiment were accurately selected among 16 genotypes (8 Hybrid and 8 OP) and were the ones that obtained promising productivity performance in previous experiments carried out by the staff of DISTAL-UNIBO (Sanoubar, 2014).

The 8 genotypes were namely:

- 4 Open Pollinated (Demeter seeds, Darmstadt, DE): Black cherry (OP1), Mexican Honey (OP4), Dattelweine (OP8), Yellow pear (OP11)
- 4 Hybrids (Esasem, Verona, Italy): Kirill F1 (H1), Strillo F1 (H5), Lobello F1 (H6), Paki F1 (H7)

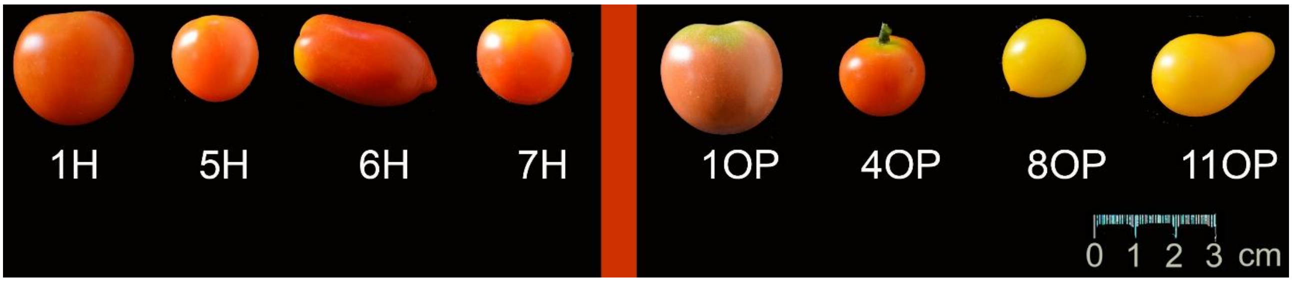



**Figure 6-1**: The eight varieties used in the experiments: 1H=Kirill; 5H=Strillo; 6H=Lobello; 7H=Paki; 1OP= Black Cherry; 11OP= Yellow Pear Shaped; 8OP= Dattelwein; 4OP=Mexikanische Honigtomate

**Kirill:** undetermined growth plant with high vigor. Fruits, roundish in shape, with inflorescence that have a maximum of 14-16 fruits. The berries are bright red with a uniform size of 35mm and a weight of about 25g. It is resistant to *Verticillium Dahliae* (Vd), *Fusarium oxysporum* (Fol 1,2); *Tomato mosaic virus* (ToMV), *Fulvia fulva* ex *Cladosporium fulvum* (Ff A-E). It has undetermined resistance to nematodes and Tomato Yello Leaf Curl Virus (TYLCV).

**Strillo:** undeterminate growth variety, producing small red Cherry. Within the production cycle, an average of 9/10 inflorescences is produced close together, giving rise to cluster of 16 fruits of small size, with an average weight of around 15g. The variety is resistant to *Fusarium oxysporum* (Fol 0-1), *Verticillium albo-atrum* (Va), *Verticillium dahliae* (Vd), *Tomato mosaic virus* (ToMV).

**Lobello**: It is a variety producing "datterino" fruit. with indeterminate growth. Berry with deep red color and 18-22 g weight; the length is 40-45 mm with a 25 mm diameter, the clusters carry from 12 to 14 fruits. It has a high resistance to cracking, in addition to *Fusarium oxysporum* (Fol 0-1), *Verticillium albo-atrum* (Va), *Verticillium dahliae* (Vd), *Tomato mosaic virus* (ToMV 0-2), and tolerance to Meloidogyne sandstone nematodes (Ma), Meloidogyne incognita (Mi), Meloidogyne javanica (Mj).

**Paki:** It is a cherry tomato characterized by indeterminate growth and medium vigor. It produces very uniform fruit weighing about 25g, characterized by bright red color, with resistance to cracking, *Fusarium oxysporum* (Fol 0-1), *Verticillium albo-atrum* (Va), and *Verticillium dahliae* (Vd). The potential production in greenhouses is around 9-10 kg $m^{-2}$.

**Black Cherry**: It is a OP cherry tomato. The plant is characterized by indeterminate growth. Intense red color distinguishes the fruits with a uniform shape and with an average weight of 30-40 g. The plant reaches heights of 180-240 cm and produces about 2-5 kg of fruit, in greenhouses can reach 4-8 kg.

**Mexikanische Honigtomate:** It is named "Cocktail" OP tomato. The plant has an indeterminate growth with around 120-150 cm height. The weight of the fruit is about 25-30g, with a bright red color.

**Dattelwein:** The variety is characterized by medium vigor, and it is an OP variety. The fruit is a "datterino" with yellow color and small size (12-14 g weight each berry), and 2-2,5 cm length. It is considered a variety with tolerance to Fusariosis, Verticillium, and Tomato Mosaic Virus.

**Yellow Pear Shaped**: It is an OP variety with pear-shaped "datterino" with yellow color. The plant presents an indeterminate growth, of a size of 15-20g. It is a variety susceptible to cracks in water shortages.

For both experiments, sowing occurred within the first week of April. Crops were sown manually in 105 cells, plastic seedling trays filled with peat. The seedling trays were placed in a controlled environment with air temperature of 24-25 °C and relative humidity 90%. After about two weeks, the trays were moved to a plastic greenhouse. Seedlings irrigation was managed by suppling 1 liter a day of water per each seedling tray while fertilization provided 1-liter a week of nutrient solution per each seedling trays.

Undamaged, reasonably uniform, and healthy seedlings were selected and transplanted 30 days after sowing within the last week of May 2017 for the first experiment and second week of May 2018 for the second experiment. Plants spacing was 1.2 m between rows and 0.6 m within rows, resulting in a plant density of 1.4 plant $m^{-2}$.

For the first experiment, harvest started on July 24, 2017, and ended on September 15, 2017, 115 days after transplanting (DAT). For the second experiment, harvest started on July 18, 2018, and ended on September 14, 2018, 121 DAT.

Two weeks after transplanting, 50 mg of N-P-K + MgO granular fertilizer 16.9.18 (MgO) for each plant was provided for both experiments. No additional fertilizer was applied across the growing season. The standard agronomic management was used in the field.

*6.2.4. Irrigation management*

The irrigation management was based on crop evapotranspiration ($ET_c$), calculated by using the following equation (**Equation 6-1**)

$$ET_c = ET_0 * K_c \qquad \textbf{(Equation 6-1)}$$

where $ET_c$ (mm $day^{-1}$) is the calculated crop evapotranspiration; $ET_0$ (mm $day^{-1}$) is the reference evapotranspiration; and $K_c$ is the F.A.O. crop coefficient for tomato (Trajkovic, S., 2007).

For the estimation of the reference evapotranspiration ($ET_0$), the Hargreaves - Samani (H.S.) equation (**Equation 6-2**) was used.

$$ET_0 = 0.0023\,(T_{mean} + 17.8)\,(T_{max} - T_{min})^{0.5}\,R_a \qquad \textbf{(Equation 6-2)}$$

where $ET_0$ (mm $day^{-1}$) is the reference evapotranspiration rate, $R_a$ (W $m^{-2}$ $day^{-1}$) is the extraterrestrial solar radiation, $T_{mean}$, $T_{max}$ and $T_{min}$ the mean, maximum and minimum temperature (°C) of the day, respectively (Capra 2016).

The meteorological data for the determination of the reference evapotranspiration were daily downloaded from the website (http://www.dipsa.digiteco.it/) of the Agro-Meteorological station of Agriculture Science and Technology Department (DISTAL), located in an area adjacent to the experimental field, excluding extraterrestrial radiation Ra that was calculated according to Duffie and Beckman (Duffie *et al.*, 2020).

The amount of water used for each irrigation was determined based on plant water balance in consonance with soil property, root depth, and climate data, also considering rainfall. Daily ETc was estimated using the FAO crop coefficient for tomato crop growth stages. Tomato cycle has been divided into three growth stages, and the Kc used were 0.60, 1.15, and 0.80, respectively. The irrigation time was established when readily available soil water (50% available soil water) was depleted.

Sixteen mm diameter drip pipes were adopted. Drippers had a flow rate of approximately 1.2 L $h^{-1}$. A flow rate test and calculation of distribution uniformity (D.U.) were carried out before transplanting. The D.U. was calculated following Baum *et al*. (2005).

*6.2.5 Measurements*

On two plants each plot, physiological plant measurements (stomatal conductance, leaf temperature and greenness) were carried out during the second week of August. Measurements were taken on the canopy's upper layer on three leaves per each plant at time from 10 am to 2 pm, taking approximately one and a half hours to complete each replication. All plants were measured on a single day. Stomatal conductance was measured using a handheld porometer measurement system model AP4 Leaf Porometer. The infrared thermometer model FLUKE 61 (Fluke Corporation, Everett, WA, USA) was used to measure leaf temperature, and leaf greenness was assessed using SPAD 502 (Minolta, Osaka, Japan).

At harvest, the fruits were collected from 6 plants each plot, counted and weighed to determine the yield expressed as fresh weight per plant (g plant$^{-1}$) and the average fruit weight (g). Water Use Efficiency (WUE) was established as the ratio between yield and the water volume used and expressed as g FW L$^{-1}$ $H_2O$.

*6.2.6. Statistical Analysis*

Data obtained were analyzed using two-way ANOVA (irrigation volume x variety). Means were separated using the Tukey HSD test (Acutis *et al*., 2012) at P≤0.05. Before the analysis, all data were checked for normality and homogeneity of the variance. Averages and standard errors were calculated. Statistical analysis was carried out using R statistical software (version 3.3.2, package "emmeans" and "car").

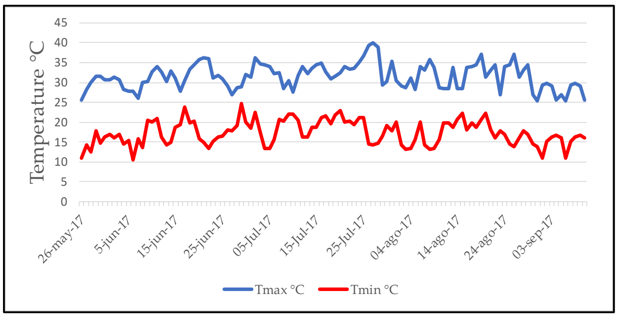
## 6.3 Results

*6.3.1 Air temperature, evapotraspiration and irrigation volume during the experiments.*

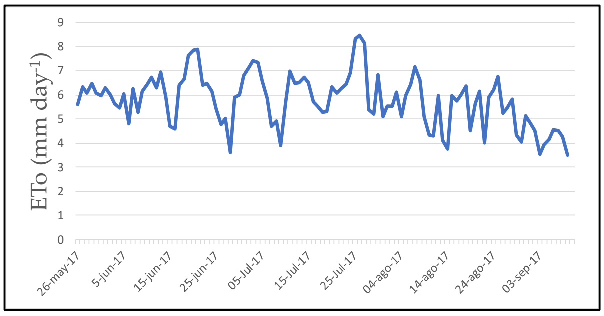
**Experiment 1:**

During the crop cycle, maximum temperatures ranged between 25,5 and 40,0°C, with an average maximum temperature of 31,7°C **(Fig. 6-2a)**. Minimum temperatures ranged between 10,5 and 24.7°C, with an average minimum temperature of 17,5°C. Air temperature were used to estimate the $ET_o$ using the HS equation. The trend of $ET_o$ across the growing season is shown in figure 2b **(Fig. 6-2b)**.

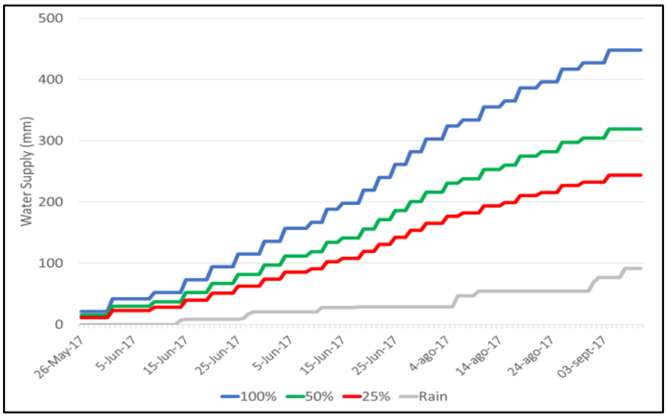
Plants under control treatment (100%) received a total (useful rain + irrigation) 539 mm of water ($HS_{100}$), plants under 50% irrigation treatment received a total of 315 mm of water ($HS_{50}$), and plants under 25% irrigation treatment received a whole 230 mm ($HS_{25}$) **(Fig. 6-2c)**.




**(a)**




**(b)**

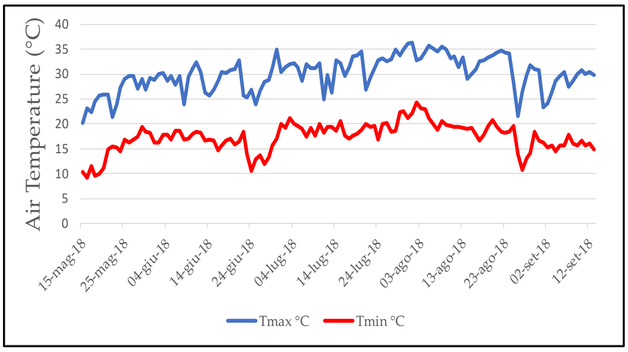



**(c)**

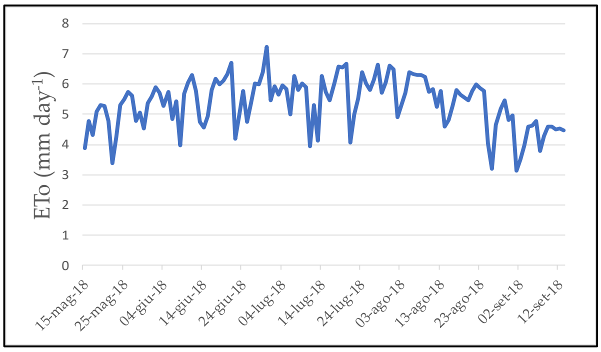
**Figure 6-2.** (2a) Maximum (red line) and minimum (blue line) air temperatures during the crop cycle. (2b) Trend of $ET_o$ during the crop cycle; (2c) Cumulative water supply along the crop cycle. The Grey line represents water supplied by rain. Blue (100%), green (50%), and red (25%) lines represent the amounts of the water provided in the three irrigation treatments.

**Experiment 2:**

During the crop cycle, maximum temperatures ranged between 24,4 and 36,4°C, with an average maximum temperature of 30°C. Minimum temperatures ranged between 9,1 and 20.2°C, with an average minimum temperature of 17,3°C **(Fig. 6-3a)**. Air temperature were used to estimate the $ET_o$ using the HS equation. The trend of $ET_o$ across the growing season is shown in figure 3b **(Fig. 6-3b)**. Plants under control treatment (100%) received a total (useful rain + irrigation) 558 mm of water ($HS_{100}$), plants under 50% irrigation treatment received a total of 338 mm of water ($HS_{50}$), and plants under 25% irrigation treatment received a whole 228 mm ($HS_{25}$) **(Fig. 6-3c)**.




**(a)**

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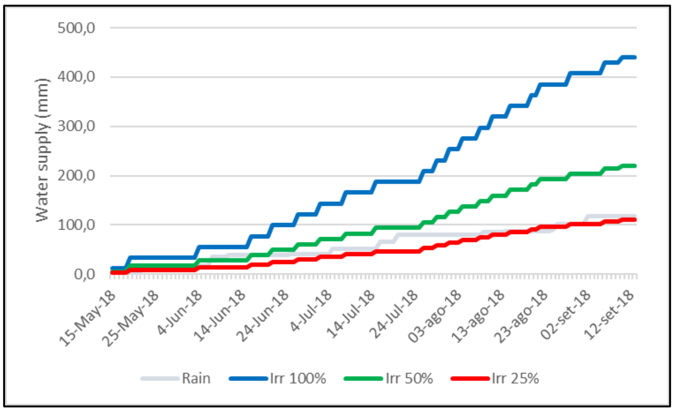



**(c)**

**Figure 6-3.** (3a) Maximum (red line) and minimum (blue line) air temperatures during the crop cycle; (3b) Trend of $ET_o$ during the crop cycle (3c); Cumulative water supply along the crop cycle. The Grey line represents water supplied by rain. Blue (100%), green (50%), and red (25%) lines represent the amounts of the water provided in the three irrigation treatments.

### *6.3.2 Yield, average fruit weight and WUE*

### *Experiment 1*

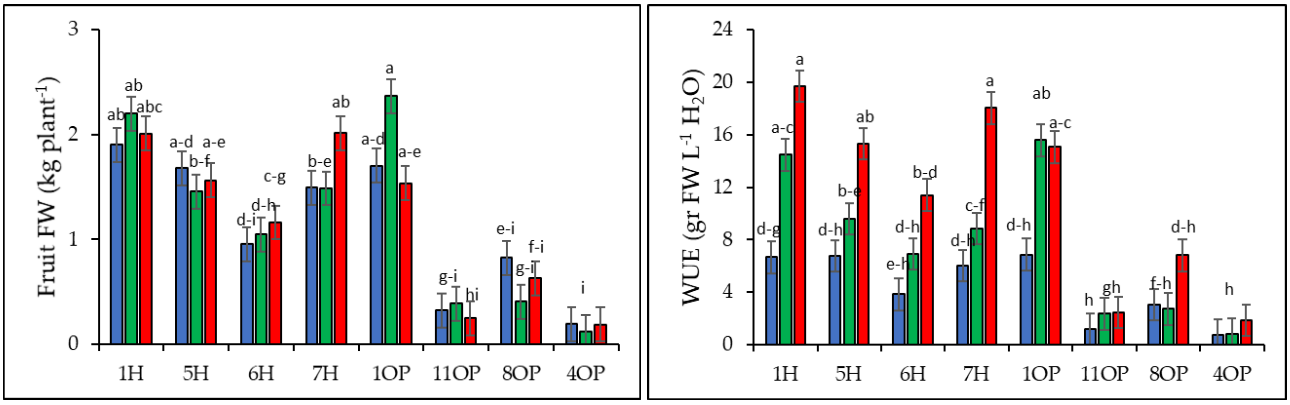
In figure 6a, were fruit fresh weight is reported, different behaviours can be observed according to the tomato variety. Black Cherry variety obtained the highest yield (2.36 kg plant$^{-1}$) when irrigation treatment $HS_{50}$ was adopted. High fruit fresh weight was also obtained from variety Kirill (1H) (average of 2.03 kg plant$^{-1}$), where no significant effect of irrigation treatment was observed. Interesting is the yield obtained from the Paki (7H) variety under irrigation treatment 25% (2.01 kg plant$^{-1}$) **(Figure 6-6a)**. Fruit number has been affected only by varieties. The higher number of fruit has been obtained by the OP cultivars (except for Yellow Pear Shaped variety) **(Table 6-1)**. Average fruit weight has been affected both by water treatment and varieties. Tomatoes grown under $HS_{100}$ showed the higher values of average fruit weight while the lowers ones were obtained in plant grown under $HS_{25}$ water treatment **(Table 6-2)**. Concerning Hybrid varieties, the hybrid Kirill (H1) showed the higher average fruit weight while not significant difference has been noted among other varieties except for Mexikanische Honigtomate (4OP) that obtained the lower values. Water use efficiency (WUE) was different in the tomato varieties, and significant interaction with the water level was observed **(Figure 6-6b)**. Regarding hybrid varieties, the hybrid Kirill (1H), Paki (7H), Strillo (5H) showed a higher WUE when the $HS_{25}$ water level was applied with 19.7, 18.0, and 15,3 g of Fruit FW $L^{-1}$, respectively **(Figure 6-6b).** Remarkable is the case of the open-pollinated variety Black Cherry (11OP) that obtained no significant differences between the irrigation treatment $HS_{50}$ and $HS_{25}$ (15,5 and 15,0 g of Fruit FW $L^{-1}$, respectively) **(Figure 6-6b).**

**Table 6-1.** Fruit number plant$^{-1}$ and average fruit weight (g fruit$^{-1}$) as affected by irrigation treatment in tomato. Different letters indicate significant differences at Tukey HSD test ($P \leq 0.05$). Data are means of the three replicates. Significance codes: *, significant at $P \leq 0.05$; **, "Ns" = not significant. $HS_{25}$ = recovery of 25% ETc calculated by Hargraves-Samani equation; $HS_{50}$ = recovery of 50% ETc calculated by Hargraves-Samani equation; $HS_{100}$ = recovery of 100% ETc calculated by Hargraves-Samani equation.

| **Water treatments** | **Irrigation** | **Fruit number plant$^{-1}$** | **Average fruit weight** |
|---|---|---|---|
| | **(mm)** | **(n)** | **(g fruit$^{-1}$)** |
| **$HS_{100}$** | 539 | 311 (a) | 16.7 (a) |
| **$HS_{50}$** | 315 | 304 (a) | 13.6 (ab) |
| **$HS_{25}$** | 230 | 283 (a) | 11.8 (b) |
| **mean** | **-** | Ns | * |

**Table 6-2**. Effect of varieties on productive parameters of tomato. Different letters indicate significant differences at Tukey HSD test ($P \leq 0.05$). Data are means of the three replicates. Significance codes: ***, significant at $P \leq 0.001$. (1H=Kirill; 5H=Srillo; 6H=Lobello; 7H=Paki; 1OP= Black Cherry; 11OP= Yellow Pear Shaped; 8OP= Dattelwein; 4OP=Mexikanische Honigtomate)

| **Variety** | **Fruit number** | **Average fruit weight** |
|---|---|---|
| | **(n plant$^{-1}$)** | **(g fruit$^{-1}$)** |
| **1H** | 187 (c) | 28.4 (a) |
| **5H** | 240 (bc) | 13.37 (bc) |
| **6H** | 231 (bc) | 14.2 (bcd) |
| **7H** | 264 (bc) | 17.6 (b) |
| **1OP** | 353 (ab) | 12.5 (bcd) |
| **11OP** | 194 (c) | 15.09 (bc) |
| **8OP** | 435 (a) | 7.33 (cd) |
| **4OP** | 439 (a) | 5.10 (d) |
| **mean** | *** | *** |




*(a)* *(b)*

**Figure 6-6:** Effect of interaction between irrigation treatment and variety on fruit fresh weight (a) and water use efficiency (b) of tomato. FW=Fresh weight; WUE=Water Use Efficiency (gr FW l-1 $H_2O$). Vertical bars indicate SE; different letters indicate significant differences with P≤0.05. Data are means of the three replicates. Red bare = recovery of 25% ETc calculated by Hargraves-Samani equation ($HS_{25}$); Green bare = recovery of 50% ETc calculated by Hargraves-Samani equation ($HS_{50}$); Blue bare = recovery of 100% ETc calculated by Hargraves-Samani equation ($HS_{100}$). 1H=Kirill; 5H=Strillo; 6H=Lobello; 7H=Paki; 1OP= Black Cherry; 11OP= Yellow Pear Shaped; 8OP= Dattelwein; 4OP=Mexikanische Honigtomate

### *Experiment 2*

Yield were affected by water treatments and varieties **(Table 6-3 and 6-4)**, but no interaction between the two factors was observed. Irrigation affected yield, but significant differences were detected only between $HS_{25}$ and the other two irrigation treatments. In $HS_{25}$ treatment, yield was the lowest with a reduction of 13,5% compared to the means among the other water treatments (3.18 kg FW plant$^{-1}$) **(Table 6-3)**. Fruit numbers has been affected only by cultivar treatment showing the higher number of fruit in the open-pollinated varieties, specifically 8OP, 4OP, and 1OP that produced 461, 448, 358 fruit per plant$^{-1}$, respectively, compared to the hybrid one. The average fruit weight (g fruit$^{-1}$) has been affected both by water treatments and varieties. The higher average fruit weight has been obtained by the tomatoes grown under $HS_{50}$ and $HS_{100}$ with an average of 14.9 and 14.4 g per fruit while the significant lower value as been showed by treatment $HS_{25}$ (table 3). The variety named Kirill (H1) showed the higher average fruit weight and significant difference has been observed compared with the other varieties. The lower value has been observed by the Dattelwein (8OP) and Mexikanische Honigtomate (4OP) **(Table 6-4)**. Finally, water use efficiency (WUE) was affected by the tomatoes varieties, and significant interaction with the water level was observed. Hybrid Kirill (1H) and open-pollinated variety Black Cherry (1OP) showed the higher WUE when the $HS_{25}$ water level was applied with 37,0 and 35,3 g of Fruit FW L$^{-1,}$ respectively **(Figure 6-7a)**.

**Table 6-3.** Fresh Fruit weight (kg plant$^{-1}$)and Yield (Mg-ha$^{-1}$) as affected by irrigation treatment in tomato. Different letters indicate significant differences at Tukey HSD test (P≤0.05). Data are means of the three replicates. Significance codes: *, significant at P≤0.05; **, "Ns" = not significant. $HS_{25}$ = recovery of 25% ETc calculated by Hargraves-Samani equation; $HS_{50}$ = recovery of 50% ETc calculated by Hargraves-Samani equation; $HS_{100}$ = recovery of 100% ETc calculated by Hargraves-Samani equation.

| **Water treatments** | **Irrigation** | **Fruit FW** | **Fruit number plant$^{-1}$** | **Average fruit weight** |
|---|---|---|---|---|
| | **(mm)** | **(kg plant$^{-1}$)** | **(n)** | **(g fruit$^{-1}$)** |
| **$HS_{100}$** | 558 | 3.20 (a) | 307 (a) | 14.4 (ab) |
| **$HS_{50}$** | 338 | 3.17 (a) | 295 (a) | 14.9 (a) |
| **$HS_{25}$** | 228 | 2.75 (b) | 289 (a) | 13.0 (b) |
| **mean** | - | ** | Ns | * |

**Table 6-4**. Effect of varieties on productive parameters of tomato. Different letters indicate significant differences at Tukey HSD test ($P \le 0.05$). Data are means of the three replicates. Significance codes: ***, significant at $P \le 0.001$. (1H=Kirill; 5H=Srillo; 6H=Lobello; 7H=Paki; 1OP= Black Cherry; 11OP= Yellow Pear Shaped; 8OP= Dattelwein; 4OP=Mexikanische Honigtomate)

| Variety | Fruit FW | Fruit number | Average fruit weight |
|---|---|---|---|
| | **(kg plant$^{-1}$)** | **(n plant$^{-1}$)** | **(g fruit$^{-1}$)** |
| **1H** | 4.46 (a) | 192 (c) | 24.5 (a) |
| **5H** | 2.68 (cd) | 234 (bc) | 12.17 (bc) |
| **6H** | 3.66 (bc) | 230 (bc) | 13.9 (bc) |
| **7H** | 3.92 (b) | 238 (bc) | 15.5 (b) |
| **1OP** | 4.22 (a) | 358 (ab) | 11.8 (c) |
| **11OP** | 2.24 (de) | 190 (c) | 14.4 (bc) |
| **8OP** | 2.28 (de) | 461 (a) | 6.47 (d) |
| **4OP** | 1.80 (e) | 448 (a) | 4.52 (d) |
| **mean** | *** | *** | *** |

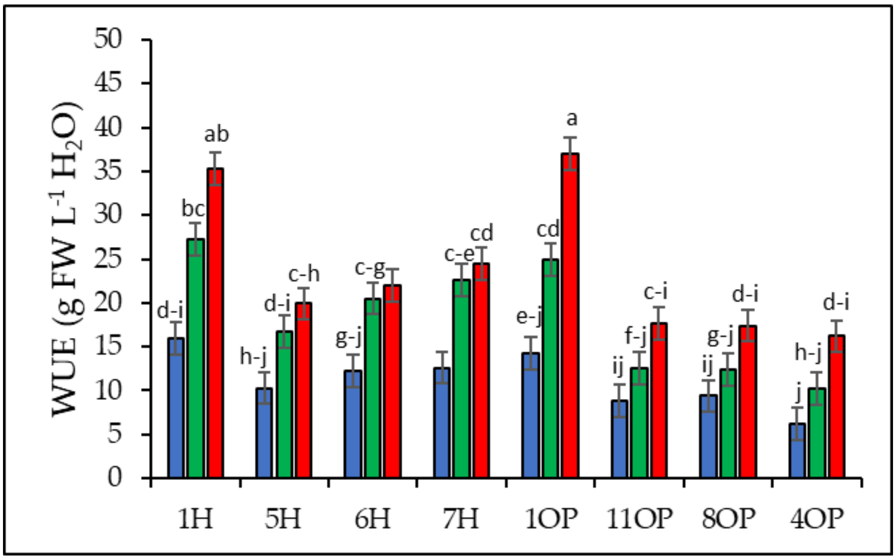



**Figure 6-7:** Effect of interaction between irrigation treatment and variety on water use efficiency. WUE=Water Use Efficiency (g FW l$^{-1}$ $H_2O$). Vertical bars indicate SE; different letters indicate significant differences with $P \le 0.05$. Data are means of the three replicates. Red bare = recovery of 25% ETc calculated by Hargraves-Samani equation ($HS_{25}$); Green bare = recovery of 50% ETc calculated by Hargraves-Samani equation ($HS_{50}$); Blue bare = recovery of 100% ETc calculated by Hargraves-Samani equation ($HS_{100}$), (1H=Kirill; 5H=Srillo; 6H=Lobello; 7H=Paki; 1OP= Black Cherry; 11OP= Yellow Pear Shaped; 8OP= Dattelwein; 4OP=Mexikanische Honigtomate).

## 6.4 Discussion

The application of different irrigation treatments significantly affected yield of tomatoes. This experiment's main result is that it is possible to obtain a satisfactory tomato yield by restoring with irrigation only a fraction of estimated crop evapotranspiration (50% of $ET_c$ estimated by HS equation) but the right choice of variety is crucial.

In the first experiment, the interaction between irrigation and variety treatment was observed. With regards to the hybrid varieties, higher yield has been obtained by Kirill (H1) variety with a 2.03 kg plant$^{-1}$of fresh weight, and concerning open-pollination varieties, Black Cherry (1OP) variety obtained 2.36 kg plant$^{-1}$. In both cases, $HS_{50}$ irrigation treatment was adopted. The higher yield obtained by Kirill (H1) variety was mainly due to the higher average weight per fruit obtained, while the highe number of fruit allows high yield for Black Cherry (1OP) variety.

In the second experiment, the reduction of irrigation water volume (50% of $ET_c$) was not significantly different from the yield obtained restoring 100% of $ET_c$. The highest yield was related to both water treatments $HS_{100}$ and $HS_{50}$ (3,20 and 3,17 kg plant$^{-1}$, respectivelyand was observed adopting the cultivar Kirill (H1) which produced 4,46 kg plant$^{-1}$. It is interesting to highlight that yield obtained by Hybrid Kirill (H1) cultivar is not significantly different from the one achieved adopting the open-pollinated OP variety named Black Cherry (1OP), which produced an average yield of 4,22 kg plant$^{-1}$ corresponding to 59,1 Mg ha$^{-1}$. The results obtained are according to various research on similar topics. Ortiz *et al*. (1994), in a study comparing nine tomato cultivars open-pollinated with six tomato hybrids, observed that on average, the hybrids had significantly higher yields and fruit weight than the open-pollinated genotypes. Moreover, with specific regard to open-pollinated cultivars, he found that the fruit yield range from 2.7 and 89.8 Mg ha$^{-1}$ (Ortiz *et al*., 1994).

The average fruit weight (g fruit$^{-1}$) has been affected by water treatments and varieties and higher values has been obtained when tomatoes were grown under the two higher water treatments $HS_{100}$ and $HS_{50}$ obtaining 14,4 and 14,9 g fruit$^{-1}$, respectivtly. Similar trend has been reported also by Lovelly *et al*. (2017), in an experiment carried out on tomato in Meditarrean area wherein the average fruit weight obtained was greatly lower in the lower water treatments (35.0 g) than the other water treatments applied (66.8 g on average) (Lovelly *et al*., 2017).

Moreover, open pollinated varieties and hybrids exhibited significant variability in average fruit weight. Within OP varieties, higher average fruit weight (g fruit$^{-1}$) has been observed in hybrid Kirill (1H) variety while for OP varieties the higher value has been obtained by Yellow Pear Shaped (11OP) and Black Cherry (1OP) with 14.4 and 11.8 g fruit$^{-1}$. The higher variability obtained in this study regarding average fruit weight showed conformity with the findings of several workers (Kumar *et al*., 2007).

According to the results obtained it is possible to affirm that the hybrid Kirill (1H) and the open-pollinated cultivar Black Cherry (1OP) can be considered genotypes suitable to be cultivated within proximity agriculture activities. The yield was often below 4kg plant$^{-1}$ in the other open-pollinated lines, suggesting their low adaptability to the local environment.

The Genotypes × Water treatment interaction was significant ($P \leq 0.05$) only for water use efficiency **(Figure 6-7).** Water use efficiency increased from control conditions when irrigation water was reduced, reaching values above 35 g L$^{-1}$ $H_2O$ in both Hybrid Kirill (1H) and Black Cherry OP (1OP) cultivars. A similar WUE trend was observed by Patanè *et al*. (2011) in tomatoes crops grown under semi-arid Mediterranean areas.

### 6.5 Conclusions

The experiment highlights the importance of adopting proper irrigation management associated with selecting appropriate plant genotypes to improve productivity and water use efficiency for tomatoes production in Mediterranean areas. It is possible to affirm that accurate irrigation management associated with selected tomato varieties increases yield and improves the WUE of tomato production. This research points out that the irrigation management returning 50% of ETc calculated by using HS method, combined with the hybrid Kirill (1H) and the Open-Pollinated-Black Cherry (1OP), variety, resulted in efficient water use and satisfactory yields.

## CHAPTER 7 - Comparative study of three low-tech soilless systems for the cultivation of geranium (*Pelargonium zonale*): a commercial quality assessment.

This chapter is based on the journal paper:

*Brentari, L., Michelon, N., Gianquinto, G., Orsini, F., Zamboni, F., & Porro, D. (2020). Comparative Study of Three Low-Tech Soilless Systems for the Cultivation of Geranium (Pelargonium zonale): A Commercial Quality Assessment. Agronomy, 10(9), 1430. https://doi.org/10.3390/agronomy10091430*

**Abstract:** The study aims to evaluate the feasibility of simplified hydroponics for the growth of rooted cuttings of geranium (*Pelargonium zonale*) for commercial purposes in local farms in Northern Italy. Tested systems included a control where soilless system on substrate (peat) (T-1), usually adopted by local farmers, was compared against an open-cycle drip system on substrate (peat) (T-2), and a Nutrient Film Technique system (T-3). For commercial features, assessed parameters included flowering degree (flowering timing, numbers of inflorescences plant$^{-1}$, number of flowers inflorescence$^{-1}$), numbers of leaves plant$^{-1}$, number of branches plant$^{-1}$, final height of plant and the aesthetic-commercial assessment index. Assessed parameters also included fresh and dry weight, SPAD Index, the water consumption and the water use efficiency (WUE). The soilless systems typology significantly affected rooted cuttings growth, commercial features and WUE. The adoption of an open-cycle drip system (T-2) resulted in a significant improvement of all the crop commercial characteristics as compared with other treatments, making plants more attractive for the market. The water consumption was higher in T-2 as compared with T-1 and T-3, but it allowed for the highest fresh weight, and therefore also the highest WUE. The results indicate that the typology of soilless system significantly enhances the commercial characteristics of geranium.

**Keywords:** *Pelargonium zonale*, low-tech soilless cultivation system, commercial quality.

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### 7.1. Introduction

The global gardening pots market size was valued at USD 1.7 billion in 2018. A growing interest in gardening is expected to remain a favourable factor for industry growth (Size *et al.*, 2019). In Italy, the cultivation of cut flowers and potted ornamentals in both greenhouses and open field accounts for a relevant share of the market. In 2017, out of the 2.5 billion euros associated with the national floricultural and ornamental crop sector, about 1.15 billion euros are associated with flower production and potted plants. The Italian cut flowers and potted ornamental sector accounts for 27’000 companies involved, for a total of 100’000 workers and almost 29’000 hectares of farmland overall occupied. When considering only figures for the ornamental seedling production, 2’000 farms for a total area of 1’500 hectares are also found in Italy (MiPAAF, 2017).

Ornamental plants are typically characterized by a fast growth rate and by a large consumption of both nutrients and water, which should be of elevated quality given the limited salt tolerance of these plant species (Pardossi *et al.*, 2009). Furthermore, farmers generally tend to overwater these crops, with the consequence that ornamental plants generally present low water use efficiency (WUE) values. Accordingly, despite the existing variability among ornamental species in terms of water and fertilizer requirements (Pardossi *et al.*, 2004a), the sector generally accounts for high environmental impact due to the losses of both water and fertilizers (Pardossi *et al.*, 2009). In this scenario, the increasing awareness of environmental pollution caused by agriculture, the scarcity of resources such as water, the need to reduce the production costs, and the growing demand for healthy foods are forcing operators to move towards more sustainable cropping techniques. In greenhouse cultivation, the adoption of soilless culture coupled with techniques such as fertigation, drip irrigation, integrated plant protection and climate control, can provide a high-quality product with efficient use of resources, e.g. water, also increasing the potential yield (Pardossi *et al.*, 2004b; Fernández *et al.*, 2018), as well as decreasing nutrient losses (Van Os *et al.*, 2008). Soilless culture can be defined as “any method of growing plants without the use of soil as a rooting medium, in which the inorganic nutrients absorbed by the roots are supplied via the irrigation water” (Savvas *et al.*, 2013). The soilless systems are classified according to the presence and type of substrate, to the irrigation system, and to the nutrient solution (NS) management, namely the re-use or not of the leaching fraction (Savvas *et al.*, 2013), which results respectively in the so-called "closed" or "open" loop systems. In open-loop systems, an excessive amount of NS (120-150% of actual water requirements) is supplied to avoid salt accumulation in the substrate, and the leaching fraction is not re-used and commonly released into the environment. In closed soilless systems, on the other hand, water supply is generally higher (150-170% of daily water requirements), but the leaching fraction is reused after being disinfected (Incrocci *et al.*, 2004). Accordingly, water and fertilizer saving (which translates in both environmental and economic benefits), are the main advantages of closed systems. However, closed systems require more complicated NS management that ultimately result in higher equipment and management costs. Primarily, the higher risks of pest outbreak (mainly root diseases), require for the disinfection of the leached fraction. Moreover, controlling nutrients and non-essential ions in the recirculating NS becomes more difficult, especially in the case of saline waters or high concentration of non-essential or scarcely absorbed ions (e.g., $Na^+$ and $Cl^-$) (Incrocci *et al.*, 2004). Overall, it is acknowledged that closed systems show a better WUE, at the expenses of possible yield decay in response to salt build-up in the root zone as compared to open systems (Pardossi *et al.*, 2004b; Hardgrave, 2993; Lopez *et al.*, 2013). Classification of soilless systems may also be done according to those that feature the presence of a solid inorganic or organic medium, that offers support to the plants, and systems without substrate (water based soilless systems), where the bare roots of plants lie directly in the NS (Savvas *et al.*, 2013) Different features characterize the two groups of systems. Soilless systems on substrate are surely the most popular systems for cut flowers and pot ornamentals (Malorgio *et al.*, 2004). Water-based soilless systems are, on the other hand, associated with reduced environmental impact and costs related to the substrate disposal. However, in water-based soilless systems, the resilience to stresses (e.g. drought) is affected by the absence of a buffer offered by the substrate, and a considerably higher risk of outbreak of root-borne diseases may also be experienced (Wortman, 2018).

In soilless systems, fertilization is performed administering a NS containing macro and micronutrients, generally through different types of irrigation systems (drip irrigation, sub-irrigation, or overhead system). Such fertigation can be continuous or discontinuous.

Based on these assumptions, the current research aims to comparatively assess three low-tech soilless systems for the cultivation of geranium (*Pelargonium zonale*), targeting the identification of the system that would allow for optimal commercial production and improvement of WUE.

## 7.2. Materials and Methods

### *7.2.1. Location*

The experiment was conducted in a greenhouse covered with polyethylene within a commercial farm located in Vigolo Vattaro, Province of Trento, Northern Italy, 46°00′ N, 11°19′ E, at an altitude of 725 m a.s.l. Plants were grown under natural light conditions. The local climate, according to Köppen's classification, is Cfb type (Eccel *et al*., 2015), which is a mesothermic climate, with the absence of a dry season and cool summer with temperature during the hottest month falling below 22 °C. The experiment was conducted from March 25$^{th}$ to June 2$^{nd}$ 2017.

### *7.2.2. Treatments and Experimental Design*

Three low-tech soilless systems were compared, namely:

- T-1 (farm system with substrate, **Figure 7-1**): 30 rooted cuttings were grown on 0.95 L pot ($Ø_1$ 9 cm, $Ø_2$ 13 cm, h 10.8 cm), each featuring eight bottom holes, filled with a mixture of two different peats with a 1:1 volume ratio mixture (peat A: Geotec srl, Adria, Italy, dry bulk density = 0.15 g $cm^{-3}$, total porosity = 92%; peat B: Tercomposti S.p.A., Calvisano, Italy, dry bulk density = 0.10 g $cm^{-3}$, total porosity = 95%). The 30 pots were placed on a greenhouse bench, arranged in 3 rows with 10 pots each. Plants were manually watered using a 15 L watering can, as usually done in the local farms, daily supplying 100% of water evapotranspiration. The leaching fraction of water was tending to 0%. The rooted cuttings were fertilized only three times in total with granular fertilizer solubilized in water to have each time a concentration of 2.08 g $L^{-1}$.

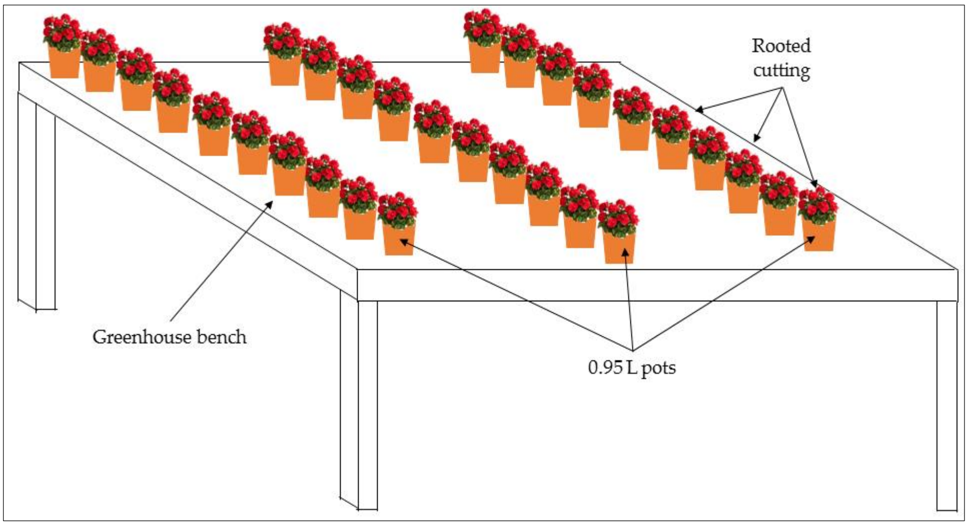



**Figure 7-1.** T1, farm system with substrate. Schematic representation of the growing system used.

- T-2 (Open-cycle drip system with substrate, **Figure 7-2**): 30 rooted cuttings were grown on 0.95 L pot ($Ø_1$ 9 cm, $Ø_2$ 13 cm, h 10.8 cm), with eight bottom holes, filled with a mixture of two different peats with a 1:1 volume ratio mixture (peat A: Geotec srl, Adria, Italy, dry bulk density = 0.15 g $cm^{-3}$, total porosity = 92%; peat B: Tercomposti S.p.A., Calvisano, Italy, dry bulk density = 0.10 g $cm^{-3}$, total porosity = 95%). The 30 pots were arranged in three rows with 10 pots each. Rows consisted of three plastic troughs measuring 1.50 m in length, 12 cm in width and 6 cm in depth with a rectangular section and and displaying a slope of about 1% to allow collecting the drained NS. The pots were placed inside the plastic troughs. The rooted cuttings were watered only with the NS by the drip irrigation system, daily supplying 130% of daily water requirement (leaching fraction of about 30%). The system was further integrated with a 210 L NS reservoir tank located at the bottom of the plastic troughs, a submerged pump (Comet Elegance, Germany) with a flow rate of 10 L $min^{-1}$ and a pressure of 0.5 bar, a 15 L upper tank located at 130 cm high to receive the pumped NS, a drip irrigation system equipped with non-self-compensating emitters (2.4 L $h^{-1}$ nominal flow rate), one for each pot, and a 30 L reservoir tank for collecting the drainage. The leaching fraction was not reused, and T-2 was managed as an open system. Given that from the upper tank to the drippers the NS descended only by gravity, the actual flow rate of the drippers (0.66 L $h^{-1}$, as measured before the experiment started) was lower than their nominal flow rate. Accordingly, the correct amount of NS to be introduced in the system was determined through a programmable electronic timer that activated the pump.

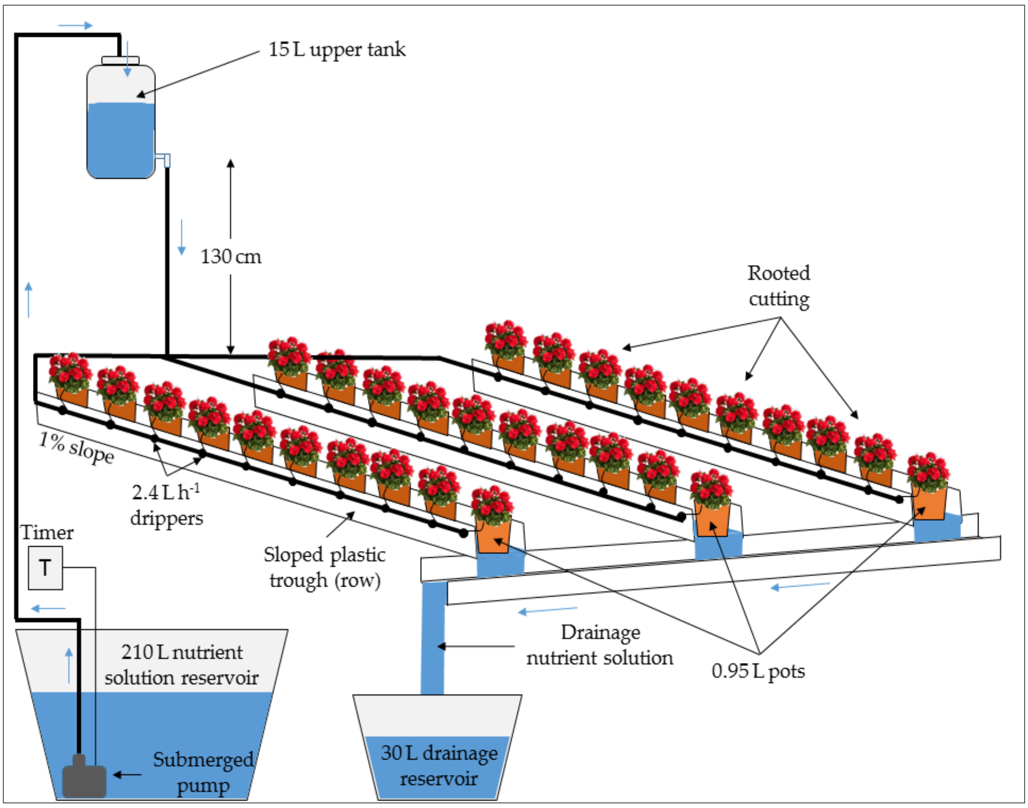



**Figure 7-2.** T-2, open-cycle drip system with substrate. Schematic representation of the growing system used.

- T-3 (Nutrient Film Technique system, **Figure 7-3**): the system adopted the Nutrient Film Technique (NFT), and featured a closed soilless system with a thin layer of around 1-2 mm of NS flowing through sloped watertight troughs wherein the roots lie. 30 rooted cuttings were arranged in 3 rows consisting of 3 plastic troughs measuring 1.50 m in length, 12 cm in width and 6 cm in depth with a rectangular section and a slope of about 1%. The plastic covers featured holes, where the rooted cuttings were placed. T-3 was also composed of a 210 L NS reservoir located at the bottom of the plastic troughs and a submerged adjustable flow pump (Newa Jet, Italy) that pumped the NS in the plastic troughs.

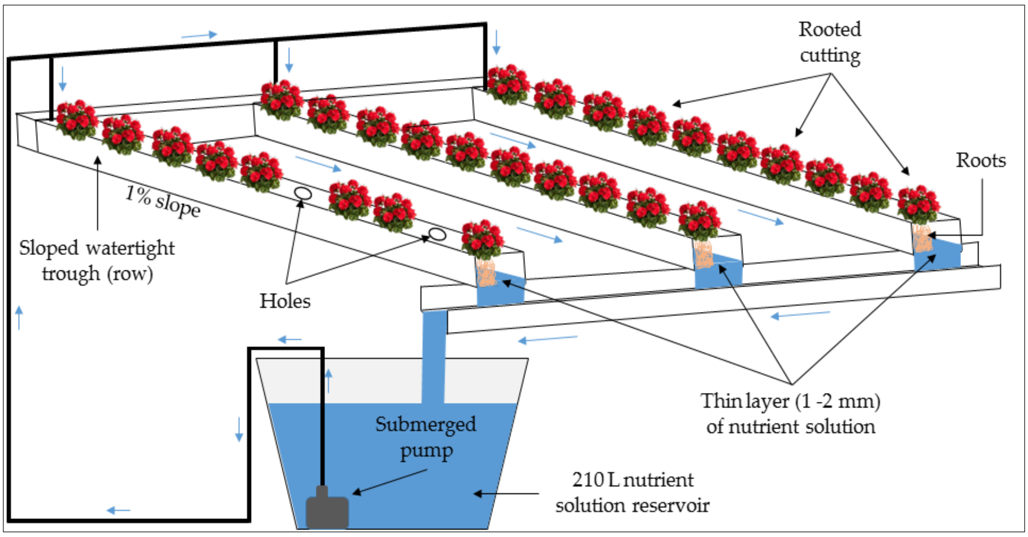



**Figure 7-3.** T-3, Nutrient Film Technique system. Schematic representation of the growing system used.

All the 90 rooted cuttings were arranged in rows with 10 plants each, with 15 cm between rooted cuttings and 42 cm between rows, resulting in a planting density of about 16 plants m$^{-2}$, following common commercial practices. Three replicate plots for each treatment (rows), composed of ten rooted cuttings each (n=30), were arranged in a randomized complete block design.

*7.2.3 Plant Material and Crop Management*

At the beginning of the trial, rooted cuttings were selected to have uniform plant material (4 cm height and 3 leaves) among the 90 individual plants used for the experimentation. T-1 (control) was managed following traditional practices from local farmers. It was irrigated only with water once every 2 days from the 1st to the 7th week, and once a day from 8th to 10th week, by hand. T-1 was fertilized only three times (discontinuous fertigation, on April 4th, April 22nd, and on May 12th), with a granular fertilizer (Manna Lin A, Mannafert V., Bolzano, Italy). Granular fertilizer was solubilized in water to have a 2.08 g $L^{-1}$ concentration for a total amount of 50.50 g applied. Manna Lin A is composed of 7% $N\text{-}NO_3$, 13% $N\text{-}NH_4$, 5% $P_2O_5$, 10% $K_2O$, 2% MgO, 0.025% B, 0.005% Cu, 0.06% Fe, 0.025% Mn, 0.0025% Mo, 0.02% Zn. The microelements were supplied as chelates.

Unlike T-1, in T-2 and T-3 a continuous fertigation was adopted, using the same NS. The composition of macronutrients of full strength NS was: 10.00 mM $NO_3^-$, 1.00 mM $NH_4^+$, 2.00 mM $H_2PO_4^-$, 5.01 mM $K^+$, 4.00 mM $Ca^{2+}$, 1.50 mM $Mg^{2+}$, 3.53 mM $SO_4^{2-}$. A mixed fertilizer for micronutrients was used, with the following full strength NS: 20.00 μM $Fe^{3+}$, 0.63 μM $Cu^{2+}$, 4.29 μM $Zn^{2+}$, 13.88 μM $B^{3+}$, 19.66 μM $Mn^{2+}$, 0.42 μM $Mo^{6+}$. For all fertigation treatments, NS was prepared using fresh water (pH = 8.00, EC = 359 μS $cm^{-1}$ at 20°C). The final EC of full strength NS ranged between 1829 and 1963 μS $cm^{-1}$ and pH ranged between 5.5 and 6.2. During the first week, in T-2 and T-3, a lower strength NS for macronutrients was used (T-2 top-fertilized by watering can) (EC = 1021 μS $cm^{-1}$, pH = 5.5, 5.4 mM $NO_3^-$, 0.50 mM $NH_4^+$, 1.0 mM $H_2PO_4^-$, 2.5 mM $K^+$, 2.0 mM $Ca^{2+}$, 0.97 mM $Mg^{2+}$, 0.75 mM $SO_4^{2-}$) to allow the roots to adapt to the new growing environment before using the full strength NS. The EC of leaching fraction was measured every week in both T-2 and T-3 treatment.

T-2 fertigation scheduling took into account the leaching fraction measurement, having drainage around 30% per day as a target. It changed during the crop cycle and ranged from 1 irrigation every 3 -5 days at the beginning to 2 irrigations per day at the end of the trial. The NS volume provided for all pots ranged from 3.6 L during the 2nd week to 78.9 L during the 10th week, corresponding to the flowering stage. In T-3, the NS was continuously supplied from sunrise to sunset, by submerged adjustable flow pump with a measured flow rate for every plastic trough of 1.83 L $min^{-1}$.

Inside the greenhouse, temperature and relative humidity were monitored every 15 minutes by GEMINI data logger Tinytag Plus 2. The greenhouse temperature ranged between 12 and 33°C, and day/night humidity from 30 to 85%, respectively.

*7.2.4. Sampling and analysis*

In the first week, EC, pH, the drained volume of T2, volume of leftover NS in the 210 L reservoir tank of T3, its EC and pH were daily measured after the sunset. During the trial, on April 22nd and on May 13th, 100 L of fresh NS each were added to the T-2 and T-3 reservoir tanks. EC, pH, and total volume were measured again after the additions. From 2nd week to the 10th week, all these parameters were measured weekly. EC was measured by Adwa AD31 Waterproof EC/TDS Tester and pH was measured by Artiglass IP67 pocket pH Tester. All testers were weekly calibrated.

Progressive and final plant heights, determined as the distance from the surface of the medium to the top of the plant, for all the 90 rooted cuttings were measured. To evaluate the flowering timing and its quality, the starting date of appearance of inflorescences and their numbers per plant, together with dates of beginning and full flowering were recorded in all 90 rooted cuttings. Furthermore, in three plants per replicate, weekly counts of the number of fully-grown leaves was performed, as well as counts of the number of flowers of the first inflorescence and number of branches.

The estimation of leaf chlorophyll concentration was performed at the end of the trial through a non-destructive measurement with SPAD-502 (Konica-Minolta, Japan). Measures were taken on the leaf nearby the oldest inflorescence from each of the 90 rooted cuttings. The Minolta SPAD meter (Soil Plant Analysis Development) used indirectly measures chlorophyll content in a non-destructive manner. SPAD values were determined by measuring the ratio of light transmitted through the leaf at a red wavelength (650 nm) and an infrared wavelength (940 nm).

At the end of the experiment, all the 90 plants were divided into leaves (leaves with petioles), trunks, roots, and inflorescences. Plant organs were weighed for the fresh and dry weight (after drying in a ventilated oven at 105°C for 48 hours).

Furthermore, at the end of the experiments, an aesthetic-commercial assessment of all 90 plants was done. For each rooted cutting, three parameters (vegetative growth, foliage compactness, general aspect) were evaluated by assigning a score from 1 to 5, giving to the score 3 the threshold value for the marketability. Whenever at least one of the three parameters received a score below 3, the rooted cutting was evaluated as not marketable. The aesthetic-commercial assessment was performed by the local farmer in a randomized way without being aware of the specific treatments.

*7.2.5. Statistical analysis*

For phenological data regarding the flowering degree (appearance of inflorescences, flowering start, and full flowering) and fully-grown leaves, no statistical analysis was applied, but only kinetic behaviors in relation to the treatment were shown. For all other measured parameters, the effect of treatment was evaluated through analysis of variance (ANOVA) on the data arranged according to the different replications for the number of inflorescences plant$^{-1}$, number of flowers inflorescence$^{-1}$, final height of the plant, number of branches plant$^{-1}$, SPAD indexes, water contents of organs, aesthetic commercial assessments, fresh weight, total water consumption and water use efficiency. All data were statistically processed using Systat software package (Systat Software, California, USA).

### 7.3. Results

*7.3.1. Climate and nutrient solution monitoring during the experiment*

During the experiment, inside the greenhouse, a data logger was used to measure temperature and humidity every fifteen minutes. Maximum air temperature ranged between 14.7 °C and 39.0 °C, with an average of 32.2 °C. Minimum air temperature ranged between 8.2 °C and 20.7 °C, with an average of 12.1 °C. The average daily temperature was 18.7 °C. The daily maximum relative humidity ranged between a minimum of 50.0 % and a maximum of 93.3 %, with an average of 83.9 %. The daily minimum relative humidity ranged between a minimum of 16.5 % and a maximum of 85.6 %, with an average of 31.7 %. The average daily humidity was 65.3 %. During the experiment, the mean value of daily global radiation, outside the greenhouse, was 15.87 MJ m$^{-2}$ day$^{-1}$ in April and 20.25 MJ m$^{-2}$ day$^{-1}$ in May.

A NS was applied only in T-2 and T-3 treatments, with periodical control of both EC and pH. During the first week, in which a lower strength NS (EC = 1021 μS cm$^{-1}$ and pH = 5.5) was used, EC of the leaching fraction ranged between 1026 μS cm$^{-1}$ and 1040 μS cm$^{-1}$, while the pH ranged between 5.5 and 5.8. From the second week, when a full strength NS (EC ranged 1829 to 1963 μS cm$^{-1}$ and pH ranged 5.5 to 6.2) was used, EC of leaching fraction ranged between 2171 μS cm$^{-1}$ and 3923 μS cm$^{-1}$, while the pH ranged between 5.8 and 6.5.

*7.3.2. Date of the appearance of inflorescences*

The starting date of appearance of inflorescences was not affected by the soilless systems (16-17 16 days after transplanting) (**Figure 7-4a**). Concurrently, T-2 and T-3 showed a more extended period (3-4 days) to conclude this phase as compared to T-1 (**Figure 7-4a**).

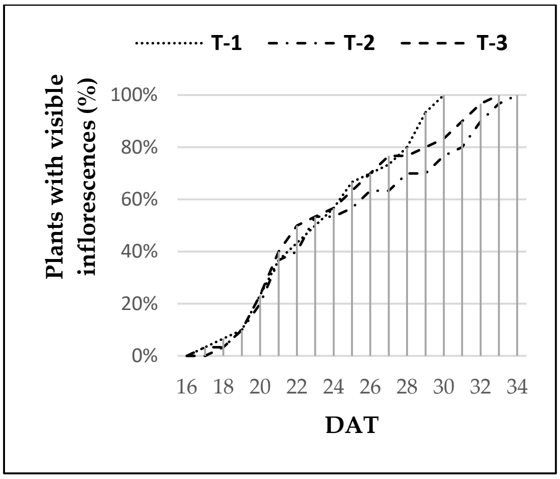
*7.3.3. Date of flowering start*

The three soilless systems affected the date when the flowering started. As compared with T-1, flowering started six and four days earlier, respectively in T-3 and T-2 (**Figure 7-4b**). Flowering was concluded between 64 and 66 days in all treatments, independently from the growing system.

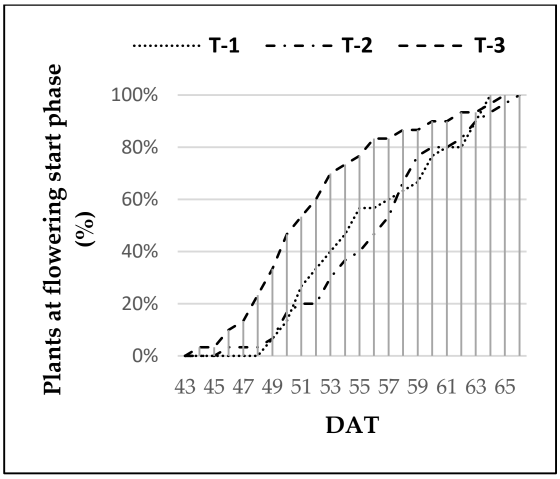
*7.3.4. Date of full flowering*

There were no differences between T-1 and T-2 treatments either in terms of date of starting of the full flowering phase (58 days after transplanting) and in terms of flowering duration (14 days) (**Figure 7-4c**).

Conversely, full flowering was anticipated by about six days and lasted five days longer under the T-3 treatment (**Figure 7-4c**).




(a)

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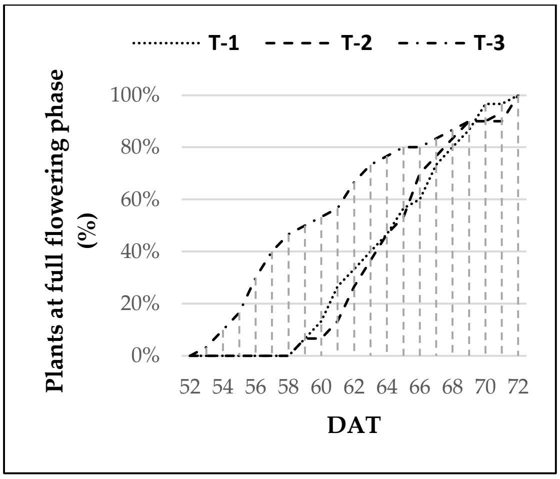
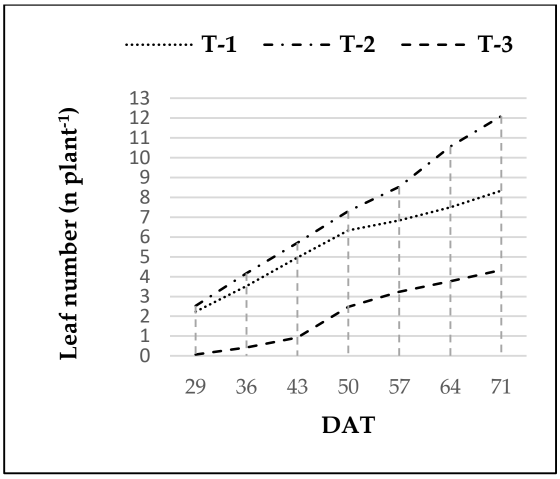



(c)




(d)

**Figure 7-4.** Effect of growing systems on *Pelargonium zonale*. (**a**) Plants with inflorescences just visible, (**b**) plants at flowering start phase, (**c**) plants at full flowering phase, and (**d**) leaf number. T-1 = farm system with substrate, T-2 = open-cycle drip system with substrate, T-3 = Nutrient Film Technique, DAT = Days After Transplanting.

*7.3.5. Biometrical parameters*

All biometrical parameters were significantly affected by treatments (**Table 7-1**), with highest values always associated with T-2 and lowest values found in plants grown under T-3. The plants' height was also affected by treatment (**Table 7-1** and **Figure 7-5**): at the final assessment, T-2 had higher values than T-1, which in turn was significantly higher than T-3.

**Table 7-1.** Mean *Pelargonium zonale* biometrical responses to growing systems. Within-columns mean values followed by different letters are significantly different by Tukey test, with significance (***) for p≤0.001. T-1 = farm system with substrate, T-2 = open-cycle drip system with substrate, T-3 = Nutrient Film Technique.

| Treatment | Inflorescences (n plant$^{-1}$) | Flowers (n inflorescence$^{-1}$) | Branches (n plant$^{-1}$) | Plant height (cm) |
|---|---|---|---|---|
| T-1 | 10.63 b | 96.33 b | 5.33 b | 11.66 b |
| T-2 | 13.67 a | 143.11 a | 8.33 a | 15.13 a |
| T-3 | 6.00 c | 64.67 b | 2.78 c | 9.41 c |
| mean | *** | *** | *** | *** |

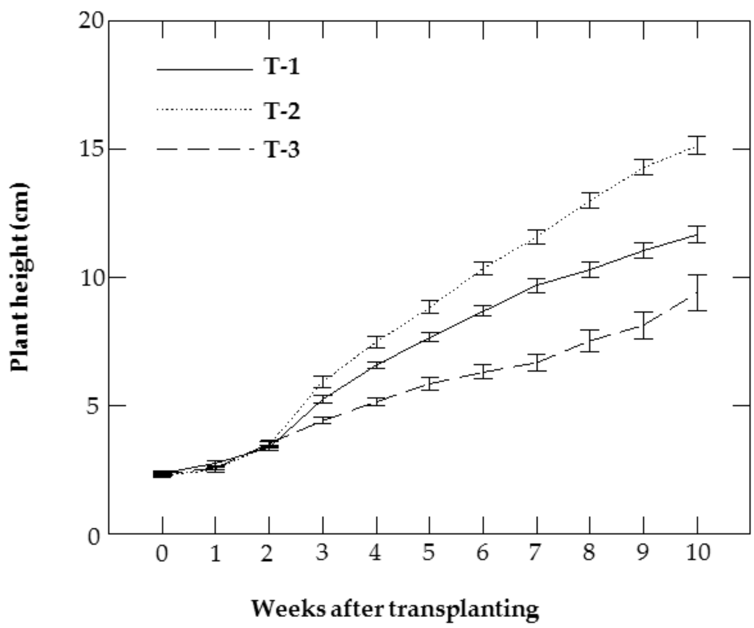



**Figure 7-5.** Height of *Pelargonium zonale* plant during growing period in response to the growing system used. Mean values ± standard error. T-1 = farm system with substrate, T-2 = open-cycle drip system with substrate, T-3 = Nutrient Film Technique.

*7.3.6. Number of leaves*

The three soilless systems affected the number of fully-grown leaves, which was the highest in T-2 (**Figure 7-4d**). In general, T-1 and T-2 treatments resulted in a different crop kinetic behavior as compared to T-3.

*7.3.7. Leaf chlorophyll*

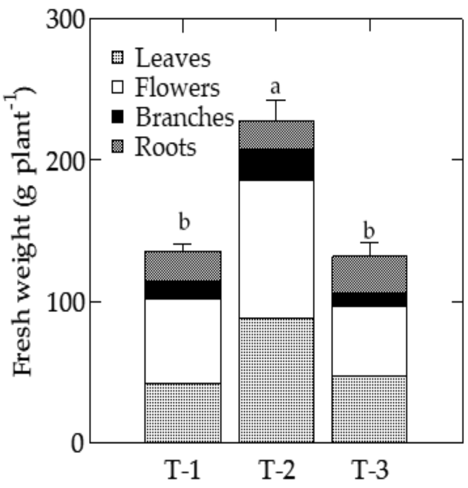
Leaf greenness of plants (SPAD values) was affected by treatment. Higher SPAD values were detected in rooted cuttings grown in T-3 treatment as compared with plants grown in T-1 and T-2 (**Table 7-2**).

**Table 7-2.** SPAD values of *Pelargonium zonale* in response to the growing system used. Within-columns mean values followed by different letters are significantly different by Tukey test, with significance at p≤0.001 (***). T-1 = farm system with substrate, T-2 = open-cycle drip system with substrate, T-3 = Nutrient Film Technique.

| Treatment | SPAD value |
|---|---|
| **T-1** | 47.16 c |
| **T-2** | 54.88 b |
| **T-3** | 65.63 a |
| **mean** | *** |

*7.3.8. Fresh and dry weight*

The three soilless systems affected both fresh (**Figure 7-6a**) and dry (**Figure 7-6b**) weight, which were the highest in T-2 and the lowest in T-3 and T-1. Leaves, flowers, and branches fresh weights had similar behavior of total biomass, presenting highest values in T-2 as compared with T-1 and T-3, while the fresh weight of roots was not affected by treatment (Figure 6a). Among dry weights (**Figure 7-6b**), different behaviors were found across organs. Plants grown under T-2 presented the highest leaf and flower dry biomass as compared to T-1 and T-3. On the other hand, higher dry biomass of both branches and roots were associated with T-1 and T-2 as compared with T-3.



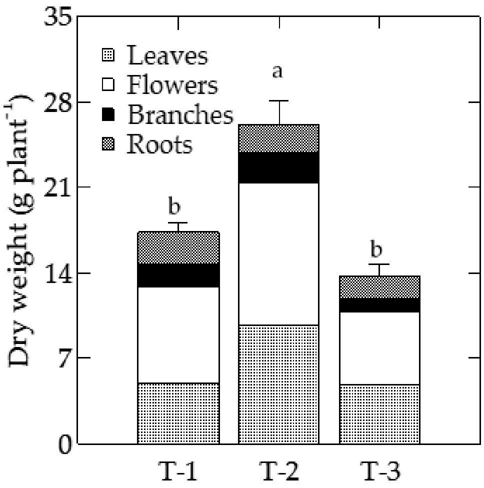




**Figure 7-6.** Effect of treatment on *Pelargonium zonale*. (**a**) Biomass total/plant (fresh weight) in relation to treatment and relative partitioning into different organs. Means values ± standard error for total biomass. (**b**) Biomass total plant$^{-1}$ (dry weight) in relation to treatment and relative partitioning into different organs. Mean values ± standard error for total biomass. T-1 = farm system with substrate, T-2 = open-cycle drip system with substrate, T-3 = Nutrient Film Technique.

Treatment affected the water contents of different organs (**Table 7-3**): in particular, T-3 showed higher values than T-1, except for flowers where the difference was not significant. T-1 always presented the lowest levels, while T-2 had an intermediate behavior, with high values for both flowers and branches, and lower for roots. It is interesting to note that roots of T-3 plants showed the highest values of water contents.

**Table 7-3.** Water contents **(%)** of *Pelargonium zonale* organs in response to the growing system used. Within-columns mean values followed by different letters are significantly different by Tukey test, n.s. = not significant; * = significance for $p \leq 0.050$ and $p \geq 0.010$; *** = significance for $p < 0.001$. T-1 = farm system with substrate, T-2 = open-cycle drip system with substrate, T-3 = Nutrient Film Technique.

| Treatment | Leaves (%) | Flowers (%) | Branches (%) | Roots(%) |
|---|---|---|---|---|
| T-1 | 88.28 b | 86.90 b | 84.76 b | 87.55 b |
| T-2 | 89.06 ab | 87.76 a | 89.46 a | 87.93 b |
| T-3 | 89.68 a | 87.58 ab | 89.26 a | 93.22 a |
| mean | *** | * | *** | *** |

*7.3.9 Aesthetic-commercial assessment*

T-3 always had the lowest values for all investigated parameters. T-2 showed the best scores in all the parameters evaluated, except for the vegetative growth, in which T-1 had the highest score as the absolute value, even if statistical analysis did not detect any significant difference as compared to T-2 (**Table 7-4**).

**Table 7-4.** Aesthetic-commercial assessment of *Pelargonium zonale* in response to the growing system used. Within-columns mean values followed by different letters are significantly different by Tukey test, with significance for $p < 0.001$ (***). MV is the arithmetic mean between Vegetative growth, Foliage compactness and General aspect values. T-1 = farm system with substrate, T-2 = open-cycle drip system with substrate, T-3 = Nutrient Film Technique.

| Treatment | MV | Vegetative growth | Foliage compactness | General aspect |
|---|---|---|---|---|
| **T-1** | 4.02 a | 4.17 a | 3.80 b | 4.10 a |
| **T-2** | 4.27 a | 4.13 a | 4.53 a | 4.13 a |
| **T-3** | 3.30 b | 2.98 b | 3.67 b | 3.28 b |
| **mean** | *** | *** | *** | *** |

*7.3.10 Water consumption and the water-use efficiently (WUE)*

The comparison of the three treatments revealed significant differences as regards the biomass produced, the water consumption (leaching fraction included) and the related WUE values (**Table 5**). In particular, T-2 differed from the other two for its most considerable vegetative development. Total water consumption revealed significantly different values among the three treatments: T-2 showed the highest value, T-3 the intermediate ones, and T-1 the lowest ones. The calculated values of WUE, therefore, showed the highest values in T-2, and the lowest ones in T-3.

**Table 7-5.** Total biomass (fresh weight), total water consumption and WUE of *Pelargonium zonale* in response to the growing system used. Within-columns mean values followed by different letters are significantly different by Tukey test, with significance for $p < 0.001$ (***). T-1 = farm system with substrate, T-2 = open-cycle drip system with substrate, T-3 = Nutrient Film Technique, FW = fresh weight; TWC = Total water consumption; WUE = Water use efficiency.

| Treatment | Plant FW (g plant$^{-1}$) | TWC (L plant$^{-1}$) | WUE (g FW L$^{-1}$ $H_2O$) |
|---|---|---|---|
| **T-1** | 132.22 b | 7.50 c | 17.63 a |
| **T-2** | 220.95 a | 10.11 a | 21.85 a |
| **T-3** | 113.34 b | 8.68 b | 13.07 b |
| **mean** | *** | *** | *** |

### 7.4. Discussion

The adoption of different soilless cultivation systems significantly affected the growth (including flowering, fresh and dry weight) and the commercial characteristics (number of inflorescences per plant, number of flower per inflorescence, number of branches per plant and number of leaves) of geranium grown in a greenhouse, in Northern Italy. As also reported by Rouphael and Colla (Rouphael *et al*., 2009), the optimal concentration of fertilizer solutions for greenhouse crops may be affected by irrigation method, because it influences the accumulation of nutrients in the growing medium, which in turn affects the nutrient uptake by plants. For example, Cardarelli (Cardarelli *et al*., 2012) reported that when averaged over NS concentration, the number of geranium flowers per plant was significantly (27%) higher with sub-irrigation than with drip-irrigation.

The growth of rooted cuttings of geranium continues until full bloom, when they are ready for sale. Given the characteristics of the market in the area where the trial was conducted, where farmers generally supply local retailers, a gradual flowering could help producers. However, T-1 and T-2 showed no differences (**Figure 7-4**), displaying both a 14-day flowering window (from May 23 to June 5). T-3, on the other hand, showed a much more scalar flowering (20 days, from May 17 to June 5) and earlier than T-1 and T-2 (**Figure 7-4**). Despite this, T-3 did not develop adequate commercial characteristics for the market. Furthermore, some of the rooted cuttings of T-3 treatments have highlighted a delayed growth demonstrating stress conditions, which may have caused the flowering pattern. As a matter of fact, according to Riga *et al*. (2012), stress conditions in geranium can influence the flowering timing, anticipating the opening of the flowers.

The application of different cultivation systems, to which three different fertigation managements are associated, significantly affected all the plant commercial features. T-2 showed the highest number of inflorescences (13.67 inflorescences plant$^{-1}$), followed by T-1 and T-3, where 10.63 and 6.00 inflorescences plant$^{-1}$ were observed, respectively (**Table 7-1**). T-2 showed significant differences from both T-1 and T-3, and T-1 from T-3. T-2 also showed the highest number of flowers per inflorescence (143.11 flowers inflorescence$^{-1}$), followed by T-1 and T-3, where values of 96.33 and 64.67 flowers inflorescence$^{-1}$ were observed, respectively. No significant differences were observed by comparing T-1 and T-3 (**Table 7-1**). Regarding the vegetative behavior (number of fully grown leaves at the end of the experiment, number of branches plant$^{-1}$ and final height of plants), also considered commercial characteristics, T-2 always showed the highest values, demonstrating a better efficiency of this treatment, also confirmed by fresh and dry weight results (**Figure 7-6a** and **Figure 7-6b**). Overall, T-1 and T-2 developed adequate leaf mass for marketing, whereas T-3 showed insufficient development. Cardarelli (Cardarelli *et al*., 2012), reported that the net assimilation of $CO_2$ of geranium was significantly affected by the irrigation systems with the highest values recorded with the drip-irrigation. The mean value of the number of fully-grown leaves (**Figure 7-4d**), at the end of the experiment, was 12.10 in T-2, followed by 8.33 in T-1 and 4.33 in T-3. Concerning the number of branches plant$^{-1}$, T-2 developed 8.33 number of branches plant$^{-1}$, followed by T-1 and T-3, where the value of 5.33 and 2.78 number of branches plant$^{-1}$ were observed, respectively (**Table 7-1**). T-2 showed significant differences from both T-1 and T-3, and T-1 from T-3. The final height of plants was 15.13 cm in T-2, followed by T-1 with a value of 11.66 cm e T-3 with a value of 9.41 cm. T-2 showed significant differences from both T-1 and T-3, and T-1 from T-3. Moreover, regarding the growth trend, as reported in **Figure 7-5**, it is possible to see that just after two weeks after transplanting, treatment significantly modified the rate of growth until the final assessment. During the first two weeks, plants had a similar trend due to low temperatures registered, which strongly depressed growth.

Regarding the SPAD values, T-1 had the lowest values (47.16) and differed from both T-2 and T-3, which had respectively values of 54.88 and 65.63, which in turn were significantly different (**Table 7-2**) (Wang. *et al*., 2012). These behaviors reflected management of fertilization: in fact, when only three fertilizer supplies were provided (T-1) the lowest values were recorded, while for other treatments (T-2 and T-3), in which the concentration of nutrient (nitrogen in particular) was constantly kept, SPAD values were always high. T-3 presumably had too elevated SPAD values, confirmed by the worst performances, while T-2 reached good SPAD levels, suggested to have more equilibrated leaf greenness (Wang *et al*., 2012). In previous evidences, in geranium, SPAD values were linearly correlated with total chlorophyll in fresh tissue. For example, in geranium "Ringo Deep Scarlet", there is this correlation: SPAD = 14.96 + 37.30*chlorophyll content (mg g$^{-1}$ of dried tissue), $r^2 = 0.95$ and $p < 0.001$ (Smith *et al*., 2004). In this experiment, the high SPAD values of T-2 and T-

3 are attributable to the high nutrient concentration of NS provided. This is confirmed by EC values of leaching fraction, always showing higher values compared to EC of NS applied. EC values of leaching fraction fluctuated between 2171 μS $cm^{-1}$ and 3923 μS $cm^{-1}$. The fact that the percentage of leaching fraction has always been sufficient (around 30%) (Enzo *et al.*, 2001) and that no particularly high temperatures were experienced during the experiment may have resulted in the use of a too concentrated NS, thus suggesting that the use of a less concentrated NS should be recommended. This was also confirmed by the fact that during the first week, when a lower concentration of the NS was used, the EC of the leaching fraction did not increase as compared to the EC of NS supplied.

The visual assessment (aesthetic-commercial assessment) confirmed that the rooted cuttings of T-2 reached the best score, except for vegetative growth, and developed the best characteristics for the market (**Table 7-4**). Only one rooted cutting of T-2 treatment scored 2, and therefore was considered unmarketable because of an excessive asymmetry of the shape of the canopy. In T-3 treatments, 50% of the plants reached a MVscore below 3, mainly since they showed a reduced growth. All of these plants also showed roots darkening. In particular, 7 plants scored below 3 in one of the 3 parameters, 6 plants in two parameters, and 2 plants in all parameters. The roots darkening and the stunted growth could be due to the reuse of the non-sterilized leaching fraction, favoring the spread of root pathogens to the whole system. Indeed, spreading of root-borne diseases may occur, thus sterilization of the solution must be provided to avoid pathogens outbreak (Savvas *et al.*, 2013).

The application of different cultivation systems, to which three different fertigation managements are associated, also affected both the water consumption and the WUE (**Table 7-5**). Regarding the water consumption, T-2 showed the highest value (10.11 L $plant^{-1}$), followed by T-3 and T-1 with 8.68 and 7.50 L $plant^{-1}$, respectively. T-2 showed significant differences from both T-1 and T-3, and T-1 from T-3. Despite these results, T-2 showed the highest value of WUE (21.85 g $L^{-1}$), followed by T-1 and T-3 with 17.63 and 13.07 g $L^{-1}$, respectively. No significant differences were observed by comparing T-2 and T-1 (**Table 7-5**). It should be considered, however, that when converting the T-2 treatment into a closed system, the values could significantly improve (Voogt *et al.*, 1997; Rouphael *et al.*, 2004). In this case, the consumption of the NS would be lower (thanks to recycling ot the drained solution), if compared with the other two treatments (Rouphael *et al.*, 2004).

However, it is important to underline that in this scenario (closed system) the changing relationships between the nutrients in the drained solution need to be carefully considered, since they constitute an aspect that could influence the development of the rooted cuttings. Closed systems show a better water use efficiency, despite a slightly lower yield due to salt build-up in the root zone as a consequence of degradation of NS quality compared to the open systems (Pardossi *et al.*, 2004b; Hardgrave, 1993; Lopez *et al.*, 2013). In some cases, according to Savvas *et al.*, /2013) "switching over to closed cultivation systems does not seem to restrict crop yield or product quality". Anyway, given that in the context considered the farms often integrate their income with other crops, the drained fraction can also be used in open-air crops (Van Os *et al.*, 1991).

**7.5. Conclusions**

The experiment shows that it is possible to enhance the commercial characteristics of geranium, making it more attractive for the market and improving the fertigation management associated with the cultivation systems. In particular, the adoption of a cultivation system with continuous fertigation on the substrate (peat) with drip irrigation can enable to obtain more attractive plants for the market. Moreover, this strategy improves water use efficiency, which could also be further improved with the adoption of a closed system. Modernization in the cultivation system and fertigation management may help to improve the commercial features of geranium even without using high technologies currently still not economically sustainable for most of the often family-run farms operating in the cut flowers and pot ornamentals sector in Trento province.

# CHAPTER 8 – General discussion and conclusions

This section addresses the main conclusions of this dissertation based on the researches objectives defined in Chapter 1.

**Objective 1: Assess the management of natural resources in the urban vegetable gardens with particular reference to irrigation water management and WUE.**

This research has proven that the awareness and management skills of urban horticulturists of Teresina City still need to follow up and technical assistance to guarantee the proper soil and water management for vegetable production in urban areas. It has been analyzed the production performance and water use efficiency simultaneously. According to the results obtained on main crop production (lettuce, coriander, and green onion), it is possible to affirm that the yield obtained (in the period covered by the survey) are satisfactory and are in line with the productions reported in several studies. The aspect that should be considered is related to the WUE values obtained in all the comunities gardens investigated. The WUE values obtained are very low compared with values obtained in several studies on vegetable production carried out in similar context adopting accurate irrigation water management. The main reason for obtaining such low values could be imputable to the growers' limited knowledge of cultivation's agronomic aspects. Another aspect to consider is the high values of phosphorus and potassium soil content due to the high quantities of goat manure distributed in the growing plots. The high amount of organic matter in the soil determines the increase of the water retention capacity of the soil that, associated with high daily irrigation volumes (even during the rainy season), causes saturation of macro and micropores. This could favoure the proliferation of fungal diseases that according to growers' opinion determines up to 50% of production lossis. The introduction of accurate water irrigation strategies to improve soil and water use is a crucial aspect to consider. Close collaboration between local research centers (for instance, EMBRAPA, Local Universities) and technical assistance agencies (SDR, EMATER) must be implemented. A tentative intervention strategy that could be adopted to ensure the proper know-how transfer to urban gardens' beneficiaries is illustrated below. The proposed action plan has been designed for the Teresina case study, and it must be adapted according to each context. The suggested steps should be the following:

**Step1: Inception phase and need assessment**

Define priorities and alliances between different local institutions (EMBRAPA, Universidade Federal do Piauì, Universidade Estadual do Piauì, Municipality of Teresina through SDR). Identify the priorities to be addressed within urban gardens. Our survey showed clearly the gaps in the soil and water management for vegetable production in Teresina's urban community gardens.

**Step 2: Memorandum of Understanding (MoU)**

The development of a Memorandum of Understanding between the partners defining the roles of each is essential. EMBRAPA and local universities could play the leading role in carrying out targeted scientific research on the needs defined during phase 1. Moreover, these organizations could take responsibility for carrying out the training of the trainers targeting the Rural Development Department (SDR) agriculture technicians, which will guarantee the knowledge transfer to the beneficiaries of the urban gardens.

**Step 3: Scientific research activities**

In this phase, the Research Institutes must carefully organize the scientific experiments to meet the community gardens' technical priorities (identified in phase 1). Experiments design and the technologies adopted in the trials must be carefully planned to validate the data from the scientific perspective and replicate them. In this case, the research could be organized inside the research institution campus, and the qualification of the institutions mentioned above guarantee a substantial experience. On the other hand, whether other contexts cannot guarantee a correct scientific research approach will be necessary to involve external institutions (for example, UNIBO - DISTAL) to strengthen experimental methodology and management. The experimental campus could also work as a training center and, through the Farmers Field School approach, ensure the transfer of results and methodology adopted in the research to SDR institution staff.

**Step 4: development of demonstration horticulture farm**

At this stage, the institute responsible for carrying out technical assistance (specifically the Municipal SDR) should set up demonstration trials in a strategic and easily accessible area for horticulturists involved in urban gardens. The development of this activity will be necessary to validate the results obtained by the experiments carried out in research centers, in contexts with similar environmental and agronomical features of the urban gardens. Once it is proven that the innovative methodologies and technologies adopted are working correctly in a similar context, the beneficiaries will be encouraged to adopt it. In such a demonstration site, it will be possible to organize by SDR staff periodic technical and practical training for the beneficiaries adopting the "learning by doing" approach wherein beneficiaries could deepen their experience on several technical aspects.

**Step 5: Validation of the innovative methodology and technologies within the urban communities' garden of Teresina**

This phase will allow the beneficiaries to introduce and validate the concepts learned in phase 4 in their gardens. Technical assistance will be essential to ensure that the beneficiaries adequately adopt the new technologies. According to my personal experience gained in more than ten years in international cooperation projects, a large number of beneficiaries jeopardize their production due to minimal issues (e.g. clogging of irrigation pipe due to limited mantenance). These constrains can often be easily overtaken if beneficiaries are timely supported by adequate technical assistance and followed up regularly. For this reasons, the local municipality should consider and include the technical assistance program for the urban gardens in the yearly economic balance and own public policies. Teresina's case study is an excellent example of this approach. In Teresina, the main issue is to improve the methodology of technical assistance carried out by SDR staff and bring within the garden innovation from an agronomic perspective. Moreover, the technical assistance must be carried out both through the experienced and qualified agronomists and technicians, who regularly visit the community gardens and through key persons identified within each garden. The key person (so-called community garden extension officer) should be one of the beneficiaries of community gardens and characterized by a dynamic attitude with good learning and communication skills. The community garden extension officer will receive specific training from the technical assistance institute staff and connect the community garden and the technical assistance agency.

**Step 5: Irrigation Water committee establishment**

In each community garden, a specific water management committee should be established. It could be made of 3 to 5 members (among them, the key person identified for carrying out the technical assistance and representatives from the vegetable growers), depending on the community garden's size. It will represent the whole garden, and its main tasks will be:

- → Ensure proper maintenance of the water facilities;
- → Govern and monitor the use of water;
- → Assist the staff of technical assistance agency during the periodic technical assistance;

A set of rules governing the purpose of the water facilities and their use should be agreed upon and approved by the committee.

The above-described proposal will be illustrated through the Theory of Change tool **(figure 8-1)**

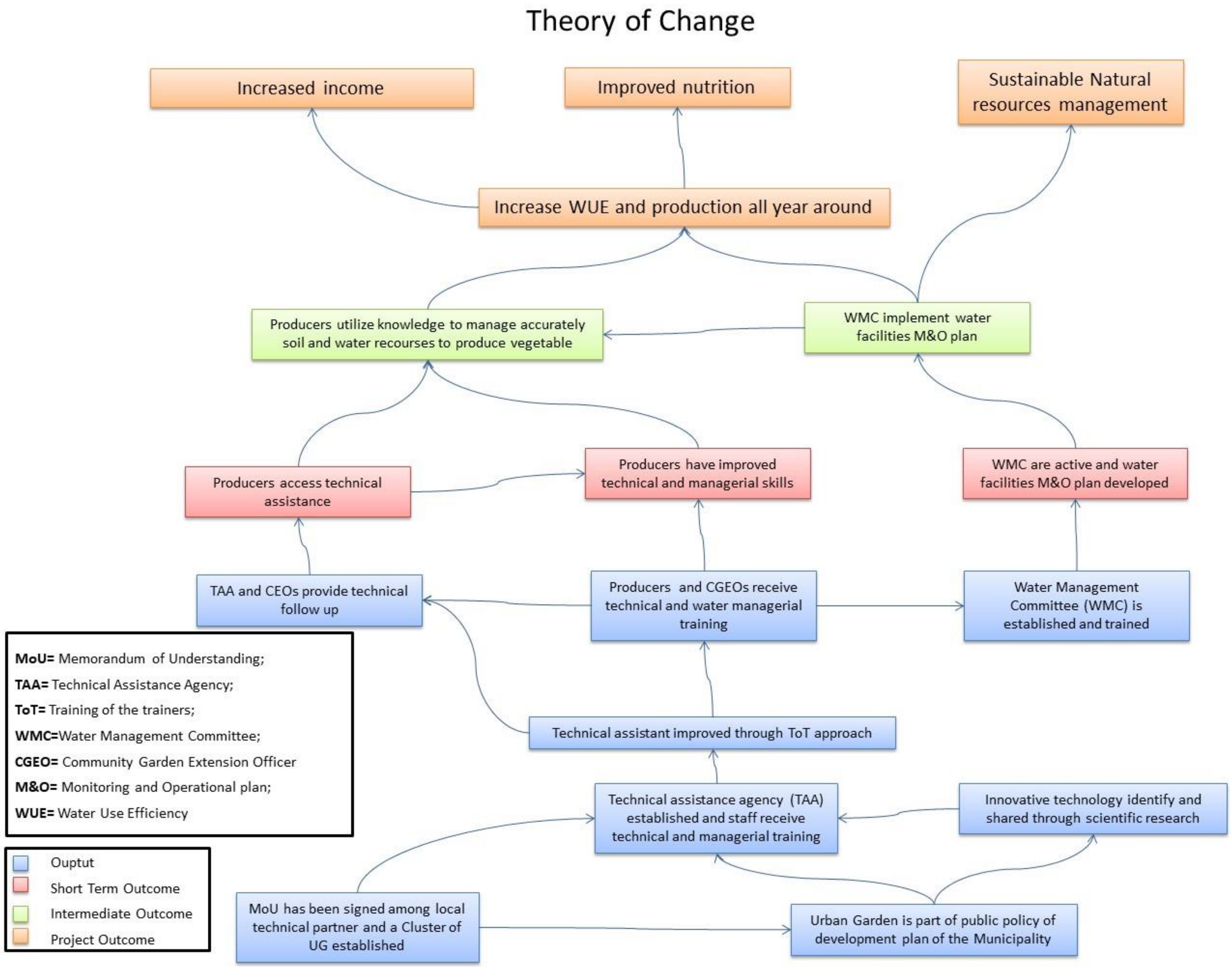



**Figure 8-1:** The Theory of Change (ToC) proposed articulating and explaining how a project's change process regarding urban gardens could occur.

**Objective 2: Use of different substrates and nutrient solution concentration for the production of Lettuce and Chinese cabbage seedlings in a semi-arid environment in central Myanmar**

In chapter 3, we have seen how important is the good management of seedlings to contribute to get good horticultural production. The research highlighted the following finding:

- Growth (fresh weight and leaf morphology) and physiological parameters (stomatal conductance, leaf temperature, SPAD units) of lettuce's seedling are significantly affected by the adoption of different substrates and different nutrient solutions;
- The experiments point out that it is crucial to identify and adopt a proper substrate and nutrient solution to obtain suitable quality lettuce seedling for transplanting;
- The HM-mixed substrate (composed of 50% carbonized rice husk and 50% of mature cattle manure) combined with $NS_{1.2}$ (Nutrient solution characterized by an EC of 1.2 dS $m^{-1}$) applied to the seedling as fertilization allowed to obtain the best lettuce transplant quality.
- Carbonized rice husk has proven to be a useful natural resource for seedling growth due to its positive agronomical features. Therefore, biochar practice should be stimulated to increase vegetable local quality seedling production wherein rice husk is available.
- The adoption of proper nutrient solution salinity is crucial to getting quality seedling.

**Objective 3: Identify the appropriate water management strategies for vegetable production in semi-arid climate characterized by severe water scarcity.**

The study aimed to investigate the effect of different irrigation strategies and soil organic mulching on the water use efficiency and yield of lettuce grown in the semi-arid areas of Central Dry Zone, Myanmar.
The research highlighted the following technical aspects:

→ The adoption of different irrigation strategies significantly affects both the productive and physiological parameters of lettuce production.

→ The adoption of accurate irrigation water management makes it possible to obtain a high yield of lettuce by restoring only a fraction of estimated crop evapotranspiration.

→ The Hargreaves-Samani method for estimating potential evapotranspiration, apparently overestimates the $ET_o$ compared to the Penman-Monteith method (8-14% more). Nevertheless, It proves to be efficient and suitable for central dry zone, Myanmar during the dry season. The consequence more frequent water supplies during the crop cycle probably leads to more uniform hydration of root zone, which, combined with the soil's mulching, allowed adequate control of the soil temperature, better use of nutrients and minor infestation of weeds, and a higher yield.

→ The reduction of irrigation water (50% of ETc) allows to obtain either the highest yield or yield comparable to the restitution of 100% ETc in all the experiments.

→ Lettuce plants prove to give a good production even under limited water availability determining a profitable increase of WUE

→ The use of mulching for lettuce vegetable production in semi-arid environmental conditions is crucial to improve the soil micro-environment around the root zone and promote soil moisture conservation, contributing to increasing both the quantitative and qualitative parameters of production.

According to this research, it is possible to affirm that accurate irrigation management associated with drip irrigation systems and mulching technology increases yield and improves the WUE of lettuce production in the semi-arid climate condition. Under-water limiting conditions, irrigation management returning 50% of ETc resulted in efficient water use and higher yields. Moreover, the irrigation strategies introduced in this research could be, in my opinion, easily applied by urban horticulturists as long as it guarantees adequate training, organization, and technical assistance. If introduced in urban gardens with a collective and not individual approach, the strategies applied in this research could be affordable not only from a technical but also from an economic point of view. It is clear that, as mentioned several times within this thesis, an interdisciplinary approach and appropriate dissemination activities will be essential to guarantee that improved water management methodology and technology for agriculture will be put in place adequately by local institutions and farmers.

**Objective 4: Assess the viability of SSC system for the production of lettuce compared to traditional on soil cultivation techniques in tropical environments, considering yield, water use efficiency, and the overall physiological plant response.**

This study aimed to assess the simplified soilless culture's (SSC) viability for lettuce production compared to traditional on-soil cultivation techniques in two tropical areas, considering both productivity and physiological plant response. The main findings are the following:

- → The simplified soilless system in tropical areas allows to increase the lettuce yield, determining an increase of +35% in NE-Brazil and +72% in Central Dry Zone-Myanmar compared to the traditional cultivation system.
- → The adoption of the SSC system enables a reduction of water use by 76% and 59% in NE-Brazil and Central Dry Zone, Myanmar, respectively, as compared to on-soil production,
- → SSC allowed a significant increase in WUE by 7.7 and 2.7 times than conventional on-soil production in NE-Brazil and Central Dry Zone, Myanmar, respectively.

The crop variety selection and the adoption of appropriate technical devices, such as the orientation of the garden and different concentrations of the nutrient solution in SSC (two factors considered in the experiments), can maximize the crop performance both from productivity and physiological perspective. These aspects must be taken into account by growers to adapt the cropping system to the climatic conditions and season. We can consider that three main seasons can be identified in the areas where the experimentation has been carried out: the rainy season, with limited solar radiation and high humidity; cold, dry season with no rainfall, high radiation, and mild air temperatures; and a third season characterized by the absence of rain, very low humidity, and very high air temperatures. The results obtained from these experiments allow us to consider and give some indications to the growers to allow them to produce continuously all year round. For instance, during the rainy season, it is recommended to use varieties adapted to lower solar radiation and nutrient solution with higher electro conductivity values (e.g. 1.8 dS $m^{-1}$) since the evapotranspiration rate is low and the nutrient solution, since the system is a simplified one, can be diluted by the rain that goes into the SSC system. In dry season, it is recommended to adopt varieties resistant to higher radiation and the nutrient solution concentration adopted should be reduced to 1.2 dS $m^{-1}$ (Fecondini *et al.*, 2009b, Michelon *et al.*, 2020a).

Nevertheless, it is possible to affirm that SSC's adoption can increase yield and reduce lettuce's water consumption compared to traditional on-soil grown crops. These main findings could be beneficial mainly in those contexts characterized to have poor soil quality, unfavorable climate, and limited access to water and land by many people living in both rural area and urban and peri-urban areas of large cities.

**Objective 5: Assess drought stress affects yield and water use efficiency in hybrid and open-pollinated lines of tomato (*Solanum lycopersicum* L.)**

This study aimed to evaluate drought stress effects on yield and WUE of open-pollinated tomato cultivars as compared to the commercial hybrid. The main findings of this study are:

- → It is possible to obtain a satisfactory tomato yield by returning with irrigation only a fraction of estimated crop evapotranspiration.
- → Different irrigation treatments' application significantly affected growth, yield of tomatoes'.
- → The irrigation management returning 50% of ETc combined with the hybrid variety named Kirill (1H) and the Black Cherry (1OP), open-pollinated variety, resulted in efficient water use and satisfactory yields.

This experimentation further pointed out the need to increase biodiversity within urban gardens by enhancing native vegetable species (open-pollinated) introduction and promotion that adapt to local contexts more easily. Besides, native species could reduce production costs for horticulturists, allowing them to produce their vegetable seeds. The promotion of heirloom species should be stimulated in gardens, at least for family consumption, and contribute to food security.

**Objective 6: Assess simplified soilless systems to improve ornamental plants' cultivation, targeting the identification of appropriate cropping systems to optimal commercial production and maximization of the WUE.**

The study evaluates the feasibility of the simplified hydroponics/ soilless system for ornamental species' growth for commercial purposes. The main findings are the following:

- → Hydroponic and soilless systems can be valuable tools to contribute to ornamental plants' cultivation even in urban areas.
- → An accurate SSC selection for ornamental plants' production must be carefully carried out since different systems' adoption significantly affects the plants' product performance.
- → The application of different cultivation systems significantly affected the plant commercial features, and the visual valuation. In the experiment, the open-cycle drip system(T-2) reached the best score and developed the market's best characteristics.
- → The experiment shows that it is possible to enhance geranium's commercial characteristics, making it more attractive for the market and improving the cultivation systems' fertigation management.

To contribute to urban gardens' environmental sustainability, the promotion of biodiversity within the garden is needed. Indeed, urban agriculture could have a vital role in regulating and habitat ecosystem services. In Europe, such an approach is quite well established. In a survey on UA projects in ten European countries (Pölling *et al*., 2016a), it was observed that about half of the considered cases promoted biodiversity preservation by cultivating more than thirty crop types and varieties. Small and widely diversified urban crop systems could increase the vegetative complexity of the cities and can have positive effects on animal biodiversity, providing suitable habitats for invertebrates (Halaj *et al*., 2000; Sperling and Lortie, 2010), birds (Andersson *et al*., 2007) and mammals (Baker and Harris, 2007). The introduction and promotion of ornamental plants in the urban garden could allow both environmental and economic benefits for the families to integrate their income through the plants' direct sale. Moreover, increasing biodiversity within the garden could also facilitate the pest and disease management of the main crops.

## CHAPTER 09: Suggestions for further research

As presented in part 1 of this dissertation, there are two scenarios concerning urban agriculture. In the global north context, the future of UA (proximity farming) will rely on its integration into the newly emerging city model that takes different names from "smart cities," "sustainable cities", "green cities," and "circular economy cities." In the developing country, UA has an essential role to play in addressing urban food security problems and income generation activities for vulnerable population.

Moreover, the current COVID19 health emergency has highlighted how fragile is the situation of thousands of families concerning food security in many countries of the world (both in the global north and south). Providing facilitated access to proper nutrition to the world's population requires significant raw material production and food processing changes. The COVID19 emergency has further demonstrated that there is still an uneven distribution and access to food that let a significant part of the world's population in a state of food insecurity. Likely, many initiatives related to vegetable family production in rural and urban environments will contribute to food sovereignty. Among these initiatives, the promotion of household or community home gardens will probably be one of the main approach for contribute to increase the livelihood level of people currently living both in urban, peri-urban of big cities and remote rural areas worldwide.

Therefore, it will be essential to manage these initiatives paying particular attention to the management of natural resources to ensure sustainable use. Governmental and research institutions will have a crucial role, and the pattern illustrated in Chapter 8 with the Theory of Change should be considered. Governments must develop strategies to implement tailored public policies concerning food security topics, guaranteeing the efficient use of natural resources in rural and urban areas considering big farmers and middle and small scale farmers.

Moreover, I would like to stress that such activities must be accompanied by an experimental component involving local and international research institutions.

Around this central topic, the resulting main research lines are proposed:

### 9.1. Future research on irrigation water use for vegetable production

9.1.1 Simplified strategies for improved Water Use Efficiency (WUE) of vegetable production within proximity agriculture

As presented throughout the dissertation, water use efficiency is one of the major concerns associate to crop production in urban and remote rural areas.

- The WUE experiments conducted in this dissertation in the tropical areas were carried out during the dry season, which coincides with no rainfall. Thus, it is necessary to carry out similar experiments in tropical areas during the **rainy season** also. In this case, not only WUE should be considered but also the **precipitation use efficiency (PUE)** and evaluate the effect on production. The research could investigate the effect of different irrigation strategies (also combined with crop residue management practices) on the precipitation water storage efficiency, water use efficiency, and yield of vegetables grown during the rainy season in tropical areas.
- One of the limitations found in urban gardens is the low familiarity of farmers in irrigation systems management. We have seen how, in the case study of Teresina, the Department of Rural Development (SDR) of the municipality of Teresina encouraged the use of drip irrigation systems among the community gardens (Chapter 2). However, it has been proven to be challenging to manage and maintenance by the beneficiaries. Instead, the micro-aspersion irrigation system management seems to be more accessible and more affordable by beneficiaries. The research topic proposed could aim to study the feasibility of using **micro-sprinkler systems** as an alternative to the drip irrigation system for vegetable production within proximity agriculture context. Therefore, micro-sprinkler could be

compared with the drip irrigation system and with traditional irrigation systems usually adopted by the local farmers and focus on water use efficiency and vegetables grown by adopting the different irrigation strategies.

- As reported in chapter 4 of this dissertation, the Hargraves-Samani formula can be suggested as a method to estimate $ET_0$, mainly where the availability and access of climate data are limited, such as the Central Dry Zone, Myanmar. However, even in small-scale farmers, the adoption of simplified innovation in **diagnostic tools and sensors** to improve water use efficiency for vegetable production and facilitate irrigation schedules should be promoted. Modern technology makes currently available in the market simplified and affordable systems capable of detecting soil moisture at different points and different depths, making it possible to map the volumetric content of water accurately and optimally manage irrigation strategies. All management operations could occur through a web interface, accessible from any smartphone. This experimentation could aim to identify suitably (from an economical and management perspective) diagnostic tools and soil moisture sensors to define the proper irrigation schedule within proximity agriculture context.

9.1.2 Irrigation Water quality. Use of saline water and purified urban wastewater

- As reported several times in this thesis, agriculture is the most important economic activity involved in water resource consumption. Globally it uses 70% of available resources, a percentage that can reach 85-95% in developing countries (FAO, 2006). These quantities, which are not sufficient to fully meet the needs of crops, will diminish more and more due to increasing competition with civil and industrial uses and climate change. As consequance the agricultural sector is frequently the addressee of water of suboptimal quality intended as water whose chemical, physical, and biological properties deviate from those considered normal for agricultural use. Particular importance for the agricultural sector is saline water and purified civil and agro-industrial wastewater. Accordingly, further research should consider for vegetable production in proximity agriculture context these water sources for irrigation. For example, Gianquinto (2015) reported that in some locations in Myanmar's Dry zone (Myingyan and Taungtha Townships, Mandalay Region), the water available for irrigation is characterized by high salinity, becoming a limiting factor for local agricultural production (Gianquinto, 2015).

  Regarding the high **salinity of water**, the following research could be promoted:

- Studies on alternative tools or devices allowing the optimization of the irrigation managed using saline water (e.g., zeolite filters or water evaporators, which provide for the evaporation of the saline/polluted the subsequent condensation of the steam with the production of pure water).
- Use of compost to mitigate the adverse effects of salinity of irrigated water on soil and plants;
- The adoption of the technique called "Leaching Requirement." It consists of applying a quantity of water higher than the water volume needed to bring to the field water capacity the soil's layer occupied by the plant's root systems. The extra water moves below the root zone and leaching from the latter the solutes brought with the previous irrigation.
- Test and introduce in those contexts with limiting agronomic factors, species, and varieties that are high yielding, drought-resistant, and early maturing (e.g., asparagus, kale, New Zealand spinach, arugula). New Zealand Spinach (*Tetragonia tetragonioides*) could be a fascinating plant to study in such contexts (Gianquinto, 2015). It is a leafy groundcover known as Botany Bay spinach, Cook's cabbage, sea spinach, and tetragon (Fig. 34). The leaves are thick and rich in manganese, Vitamin A, Vitamin B6, Vitamin C, and Vitamin K. The plant is a halophyte and grows well in the saline ground. It has been proven to be especially salt removal, with the ability to accumulate ions $Na^+$ and $Cl^-$ and improve water drainage (Wilson *et al*., 2000). It is grown for the edible leaves and can be used as food or for ground cover. As some of its names signify, it has similar flavor and texture properties to spinach and is cooked like spinach. It can be found as an invasive plant in North and South America and has been

cultivated along the East Asian rim. It thrives in hot weather, and few insects will bother it (Gianquinto, 2015).

Concerning the **reuse of wastewater**, the following are the suggested research:

- Especially in arid and semiarid regions, purified urban wastewater can be a sustainable source of water supply for the agricultural sector, as it can meet the irrigation needs of crops while saving significant volumes of primary resources (Pedrero *et al*., 2020). The nutritional value of this water source should also be taken into account. Urban wastewater can contain macro (N, P, K, Ca, Mg and S) and micronutrients (B, Zn, Mn, Mo, Fe, Cu) in variable quantities depending on the source and the treatments to which they are subjected, and therefore also represent a fertilizer solution (Vivaldi *et al*., 2019). Adopting such a resource implicates the need to monitor toxic substances present in water to prevent potential risks to human health and the environment. Therefore, it is suggested to carry out experiments comparing different irrigation water (for example, rainwater, saltwater, wastewater) to cultivate vegetables in urban and rural environments and adopting both soil-based and soilless systems.

9.1.3 Improve the agronomic aspect related to Simplified Soilless systems

Simplified Soilless Culture system (SSC) is a suitable option for landless families living in urban and rural areas to grow their fresh vegetables. SSC should be proposed and implemented in several contexts to contribute to facing the issue of food insecurity. As observed in Chapter 5, the adoption of SSC named "Garrafas pet system", proven the potential to improve access to fresh vegetables for people living in vulnerable areas such as the case-study of Teresina city in Brazil and the Central dry zone of Myanmar illustrated in this dissertation. Nevertheless, more research is needed to make the system easier to replicate and accessible to more people worldwide. Therefore, the following agronomic strategy should be considered in future research:

- Demonstrate the feasibility of using alternative nutrient solutions considering both the adoption of mineral fertilizer and organic fertilizer (for example, compost tea) and evaluate its effect on qualitative and quantitative vegetable parameters. In both cases, the nutrient solution should be a standard nutrient solution that could be used on all crops;
- There are needs to identify robust growing media for use in SSC according to the local context, and that can also act as a buffer to reduce stress in crops in case of limiting growing conditions such as nutrient/ water shortage or where energy is available to run the system, energy outages. The following researches are reccomended:

  - The carbonized rice husk adopted as a growing media in the "Garrafas pet" system is proven to be suitable for SSC due to its adequate porosity that avoids water stagnation and facilitates root growth within the substrate. Moreover, since the substrate before using is carbonized, it is less prone to develop fungal diseases. Nevertheless, the methodology currently adopted to carbonize the rice husk could be a limiting factor for farmers adopting this substrate. Further research should be addressed towards finding alternative methods for organic husk carbonization by adopting more practical and faster pyrolysis systems than the method currently adopted.

  - To mitigate the relatively high pH of carbonized rice husk, which could negatively affect plant growth, could be considered to mix it with perlite. According to Awad *et al*., 2017, using a mixed substrate composed of Perlite and Rice husk Biochar (ratio of 1:1) can give up to 3 times greater yield, suggesting that an alternative substrate combination could be beneficial (Awad *et al*., 2017).

- Since rice husk pyrolysis is necessary for substrate processing and production, it could be used also to produce Pyroligneous Acid (PA) The condensation of PA does not require excessive changes or extra costs. Several studies observed promising results in agriculture adopting PA since it has antimicrobial, antioxidant, pesticidal and plant growth enhancing properties (Grewal *et al*., 2018; Steiner *et al*., 2008). The utilization of PA could play a fundamental role in improving simplified hydroponic systems performance.

- To detect, quantify, and characterize all city/community/ village wastes and specifically those derived from food production that could be used (after proper processing) as a substrate. It should include other organic wastes like crop biomass, the reuse of agricultural (such as row coconut fiber, groundnut shells, or shredded corn stems) and industrial waste by-products (such as from olive mills, breweries wineries, and paper mills) as new feedstock for growing media can allow the generation of circular economies. They can enable the use and replication of SSC by smallholders.

To further promote replication of SSC, these topics should be developed through proper scientific research:

- Test alternative SSC system to produce a wider number of vegetable species. A suitable system is the hydroponic bag systems (Abidjan system and Morris system). The bags are mostly suitable when the soil quality is low so that it can be easily corrected by soil amendment (for example, manure and zeolite). Zeolites are microporous, aluminosilicate minerals. Based on their high ion-exchange capacity and water retention, natural zeolites have been used extensively in Japan as amendments for sandy soils. Zeolites have the properties to act as slow-release fertilizers and to retain and control moisture in soils. Zeolites (mainly clinoptilolite and chabazite) can selectively hold nutrients such as ammonium and potassium in their structure for long periods, thereby increasing fertilizers' efficiency reducing the total cost of fertilization. Zeolites act as water moderators, in which they will absorb up to 55% of their weight in water and slowly release it under the plant's demand. Using clinoptilolite tuff as a soil conditioner, the Agricultural Improvement Section of the Yamagata Prefectural Government, Japan, reported significant increases in the yields of wheat (13 to 15%), eggplant (19 to 55%), apples (13 to 38%), and carrots (63%) when from 4 to 8 tons of zeolite was added per acre (about 1 to 2 kg $m^{-2}$). Zeolite could be used directly in the soil, testing soil application distributing zeolites along the row where vegetable seeds will be placed and an amendment for substrate adopted in the hydroponic system.
- It is also crucial for the SSC system to test and introduce, species, and varieties that are high yielding, drought-resistant, and early maturing (e.g., asparagus, kale, New Zealand spinach, arugula). Test different approaches to reduce water salinity by, for example mixing low-quality water (pond or well water) with high-quality water (roof/rainwater) or introducing zeolite filters;
- As reported in chapter 5, the lettuce yield obtained in the upper part of the SSC system was significantly higher than the one observed in the lower part of the system. Future trials should test the effectiveness of adding supplementary hydraulic pipes with emitters in the middle of the system to standardize the production within the "Garrafas pet" system **(Figure 9-1)**.

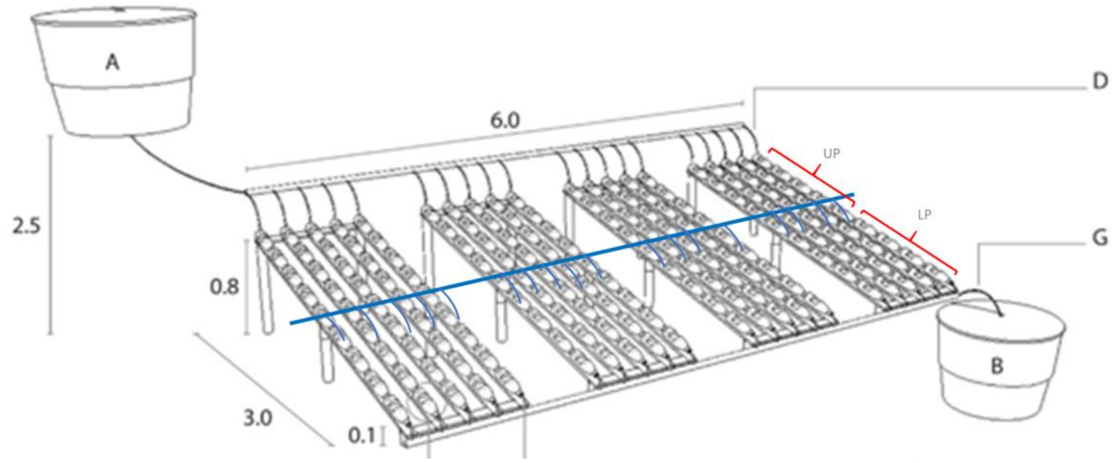



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**Figure 9-1:** Schematic drawing of the growing system used, with measures (in meters) adopted. Blueline represents the additional hydraulic pipes with emitters of which the efficiency of distribution of the nutrient solution in the lower part of the system should be tested and evaluated. The excess nutrient solution is then drained to a recollection pipe (F), which is connected (G) to the drainage tank (B). UP= Upper position; LP=Lower position. Images of the systems in the cities of (b) Teresina (Piaui, Brazil) and (c) NayPyiTaw (Myanmar).

Future studies should focus also on adapted varieties with better organoleptic characteristics and better nutritional content (lycopene, vitamins, carotenes, etc.). Open-pollinated species should be promoted mainly in remote areas wherein market access is problematic for many families. Further experimental trials should evaluate the production performance and, at the same time, appraise the nutritional aspects of the crops themselves.

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