Impact Assessment of Pomegranate Cultivation Using Reclaimed Wastewater

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Please cite this paper as:

Giungato, P., Rana, R.L. and Tricase, C.,2023. Impact Assessment of Pomegranate Cultivation Using Reclaimed Wastewater. In: R. Pamfilie, V. Dinu, C. Vasiliu, D. Pleșea, L. Tăchiciu eds. 2023. *9th BASIQ International Conference on New Trends in Sustainable Business and Consumption.* Constanța, Romania, 8-10 June 2023. Bucharest: ASE, pp. 464-471

DOI: 10.24818/BASIQ/2023/09/051

Abstract

The approval of national specific legislative acts and the subsequent elaboration of the regional Water Protection Plans have raised attention on reclaimed wastewater as an abundant usable resource for irrigation or industrial purposes in the Apulia region. Among interesting cultivation pomegranate represent a commodity with niche market share among consumers paying attention to healthy way of life. In the present paper the objective of evaluating the environmental impact and nutritional efficiency of this resource was achieved by comparing 3 treatment scenarios: a) Irrigation with conventional water and fertilization capable of satisfying 100% of the expected nutritional requirements; b) Irrigation with reclaimed urban wastewater and fertilization capable of satisfying 100% of the expected nutritional requirements and c) Irrigation with refined urban waste water and fertilization capable of satisfying 50% of the expected nutritional requirements. The methodology to evaluate the impact assessment was the Life Cycle Assessment. Findings indicate the reclaimed wastewater scenario as the lowest impacting due to electricity consumption for the pumping system of the irrigation infrastructure of pomegranate. Fertirrigation of pomegranate using reclaimed wastewater with 50% lower fertilization does not satisfy the nutrient needs and this supplement should be commensurate to the reclaimed wastewater nutrient content. Results provide to stakeholders the sustainable decision support and this represent the practical implication of this study. Moreover the case study represents an original subject both for the crop, fertirrigation and the location choice of the cultivation and the methodology used.

Keywords

Pomegranate, smart water, Life Cycle Assessment, wastewater reclamation, hydroponic cultivation, Apulia.

DOI: 10.24818/BASIQ/2023/09/051

Introduction

The pomegranate is one of the oldest fruits known to man whose origin is uncertain although, according to the famous Russian phytogeography, Nikolaj Vavilov, it should come from an area between Asia Minor, Trans-Caucasian Asia, Iran and the high peaks of Turkmenistan (Holland, Hatib and Bar-Ya'akov, 2009). From that region over the centuries thanks to trade routes, it has spread throughout the world. Currently has been re-evaluated thanks to scientific studies on its nutritional and medicinal properties. According to the most widespread botanical classification, the pomegranate belongs to the order of Myrtales and to the family of Lythraceae. The Punica genus is commonly divided into three species: *Punica granatum* L. and *P. protopunica Balf.* F. and *P. nana* L. (Khadivi et al., 2020). Punica granatum is the species cultivated for agricultural and commercial purposes. Generally, fruit is consumed directly as a fresh product as well as fresh juice. However, recently, an increasing demand for processed products such as, alcoholic drinks, juices, jams, dehydrated seeds, and extracts from its different parts of the plants, is starts worldwide. The intraspecific variability is very high: more than 500 subspecies of pomegranate have been counted in the world. Nevertheless, the main cultivars now widespread in the world thanks to their agronomic and organoleptic characteristics of the fruit are the 'Wonderful' of American origin, and “Mollar de Elche”, native of Spain (Tinebra et al., 2021). From a commercial point of view, the pomegranate fruits are divided into three types mainly based on the taste, such as: sweet, bitter-sweet and acidic. The consistency of the seed is also an important characteristic, which the sweet varieties, with softer seeds, are the ones most in demand on the market (Melgarejo Moreno et al., 1999). Thanks to its nutritional characteristics, the pomegranate fruit can be considered a functional food since it can have a positive effect on the health consumer. Therefore, the pomegranate tree and its fruit are considered as a kind of "natural pharmacy", from which numerous medicinal products can be obtained. Indeed, studies have shown that different parts of the plant, including the flowers, have therapeutic activities to treat cancer, dysentery, diabetes, liver or blood circulation problems (Rana and Ingrao, 2014). Regarding the agronomic characteristic, pomegranate is a rustic tree, which grows in soils poor in nutrients, although it prefers deep soils rich in organic matter and fresh. It does not tolerate soils with a high quantity of clay and heavy ones, because pomegranate is subject to water stagnation and root asphyxia. From a climactic point of view, the pomegranate prefers temperate-warm and subtropical climates. Moreover, although pomegranate is a tree resistant to long periods of drought, commercial production requires an intensive irrigation scheme, which prevents principally the fruit splitting and improves the yield of fruits. In the last fifteen years, the production and consumption of pomegranates has increased considerably on a global scale. Two factors have mainly influenced this phenomenon: a) the greater dissemination of information among consumers on the healthy properties of the fruit b) the development of new varieties, which are more productive and with better organoleptic characteristics of the fruit. In 2021 the world surface dedicated to the cultivation of pomegranate trees is more than 300,000 hectares and in terms of volume, the industry produced a total of 3.0 million tons, up from 2.8 million tons in 2020. The leading producers globally are India and China followed by Iran, Turkey, Afghanistan, the US, Iraq, Pakistan, Syria and Spain. In 2021 the global pomegranate fruit market was valued at USD 24.8 Billion and is expected to reach USD 33.86 Billion by 2026 (APEDA, 2021; Skyquest, 2022).

Review of the scientific literature

Introduced in the seventies as a scientific methodology suitable for comparing the environmental performance of different packaging systems (PET bottles, glass, and aluminum cans), LCA (Life Cycle Assessment) became widespread in the eighties and nineties (Heijungs and Guinée, 1992; Guinèe, 2002) as an analytical environmental management tool applicable to any process, product or service "system" to identify its relative load and environmental impact. The standardization of the methodology with the standards of the ISO 14044 series, based on the guidelines drawn up by SETAC (Society of Environmental Toxicology and Chemistry) has further increased its diffusion and scientific value by eliminating the subjectivity character which was the main criticism leveled at the instrument. About LCA used for the analysis of the environmental impacts of urban wastewater treatment systems there is a large literature on the subject: Roeleveld since 1997 pointed out the critical most impacting phases in classical wastewater treatment plants in The Netherland, as pollution discharge in the effluent and sludge production (Roeleveld et al., 1997). Tillmam et al. (Tillman, Svingby and Lundstròm, 1998) performed a comparative life cycle assessment of two alternatives in municipal planning treatment of wastewater: the existing waste water treatment (classical mechanical, biological and chemical treatment phases) was compared with the first one consisting of pretreatment, anaerobic digestion or drying of the solid fraction and treatment of the liquid fraction in sand filter beds and the second one consisting on urine used as fertilizer, faeces digested or dried, before used in agriculture and grey water treated in filter beds all out of the buildings; in both the alternatives the total environmental impacts of the alternatives was lower with respect to the traditional scenario. Lundin et al., investigated the existing conventional wastewater treatment system with one in which urine is handled separately and the one in which black water is treated in a liquid composting process: the separation alternative system demonstrate lower emissions to water and more efficient recycling of nutrients Nitrogen and phosphorous to agriculture, avoiding the production mineral fertilizers (Lundin, Bengtsson and Molander, 2000). Particularly relevant for this study the conclusions of Kärrman and Jönsson who demonstrated the irrigation of energy forest with biologically treated wastewater was the best option to reduce discharges of nitrogen, cadmium, lead, and mercury to water, to improve recycling of nitrogen and phosphorus to arable land and to limit flows of heavy metals to arable land (Kärrman and Jönsson, 2001). Iterative procedures were performed to assess the environmental sustainability of an urban water system and to empirically define the most important indicators for the system being studied (Lundin and Morrison, 2002), combination of anaerobic digestion and agricultural land application were the most environmentally friendly wastewater sludge treatments scenario (Suh and Rousseaux, 2002). The reuse of treated wastewater for agricultural purposes and the choice of the best environmental friendly disinfection technology (UV disinfection, membrane filtration, and heat drying) has been studied (Tchobanoglous et al., 2002) as the cost criteria for selection of the best municipal wastewater treatment systems (Tsagarakis, et al., 2003; Tsagarakis, et al., 2000). Two most impacting categories were eutrophication (pollutant load at the watercourse discharge, mainly NH_3, PO_4) and terrestrial ecotoxicity (emissions to soil of Cr, Hg and Zn, when the sludge is used for agricultural application), (Hospido, et al., 2004). LCA methodology has been also applied in strategic planning of large complex systems composed of water supply and wastewater treatment of a large urban area like Sidney (Lundie, Peters and Beavis, 2004), California (Stokes and Horvath, 2006) and Walloon Region (Belgium) (Renzoni and Germain, 2007), Galicia (Spain) (Gallego, Hospido, Moreira and Feijoo, 2008). The effects of impact assessment methods in wastewater treatment LCA were investigated resulting in good agreement between CML 2000, Eco Indicator 99, EDIP 96, EPS and Ecopoints 97 except for human toxicity, as large discrepancies resulted among the impact assessment methods utilized (Renou et al., 2008).

Research methodology

The methodology applied in this work is the Product Life Cycle Assessment (LCA), standardized by the standards of the ISO 14000 series (ISO 14040, 2006; ISO 14044, 2006) capable of providing useful indications in the case of Life Cycle Engineering. For the realization of the LCA study, the LCA OpenLCA open-source software and the Ecoinvent 3.7 database were used (Giungato et al., 2021; Giungato et al., 2023). To achieve this final objective, the research activity was divided into three implementation objectives: Definition of the aims and scope of investigation, Inventory analysis, Evaluation of the environmental impacts of the analyzed systems, Interpretation of the results. The purpose of this case study is to analyze the environmental benefits of the irrigation reuse of urban wastewater for pomegranate irrigation, in particular to establish which is the most suitable choice from an environmental point of view for irrigation. The following scenarios were considered: Scenario 1: fertirrigation reuse after tertiary treatment of effluents from a primary and secondary urban waste treatment plant, which provides for an integrated treatment of disinfection using UV and sodium hypochlorite combined with flocculation in an accumulation and treatment tank. Scenario 2: it is a scenario in which there is no reclamation of treated urban wastewater but fertirrigation takes place by direct pumping powered by the electricity grid in wells around the area. Primary data relative to the inventory analysis of the reclamation process, the UV lamps were from previous works (Apisitpuvakul, et al., 2008; Giungato and Guinèe, 2010). The construction and dismantling impact of the plant were considered negligible with respect to the use phase according to literature in similar cases (Pillay, Friedrich and Buckley, 2002). Functional unit of the system is the provision of 1,000 m^3 of water for irrigation which complies with limits stated for reusing of the water, provided from an accumulation basin, in which a sedimentation process, followed by UV and sodium Hypochlorite disinfection, useful to reduce the bacteria concentration of E. coli from values 1,000 to less than 10 UFC (Unity Forming Colony) is performed. CML 2001 baseline characterisation factors were used (Guinèe, 2002) for nine relevant impact categories. In the traditional scenario, groundwater was pumped from a deep of the well 70 m, energy consumed was 1,3 kWh/m^3. For the reclaimed water scenario primary treatment consisted of a coagulation and flocculation of suspended solid particles, followed by sedimentation and a post treatment with sodium hypochlorite and UV irradiation, depending on the bacterial content of the influent. Chemicals for flocculation (Akifloc) were modeled from secondary data of hydrochloric acid and aluminum hydroxide reactions as NaClO, from the Ecoinvent 3.7 database).

Results and discussion

As depicted in figure 1, in all the impact categories considered in this study, the reclaimed water performs better with respect to water extracted from a well by a pumping station. This suggests the use of fertirrigation using reclaimed water will be always the best option to consider in reducing the environmental impact of the cultivation. In all the impact categories the most impacting process is the production of electricity by the Italian energy mix.

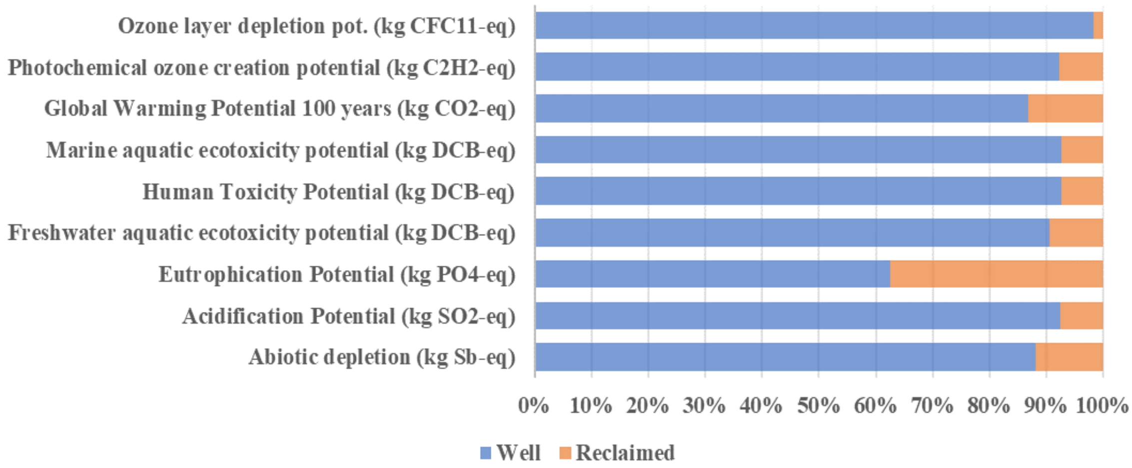

Figure no. 1. Results of the Life Cycle Impact assessment of the comparative LCA, between irrigation from well and reclaimed water, per functional unit

Strategies for the reuse of reclaimed urban wastewater, in addition to being aimed at recovering a natural resource allowing for savings, in an area particularly subject to drought phenomena and saline intrusion, also allow to exploit the nutrient content by avoiding the consumption of mineral extraction or synthetic fertilizers. The objective of evaluating the nutritional efficiency of this resource was achieved by comparing 3 treatment scenarios:

a) Irrigation with conventional water and fertilization capable of satisfying 100% of the expected nutritional requirements;

b) Irrigation with refined urban waste water and fertilization capable of satisfying 100% of the expected nutritional requirements;

c) Irrigation with refined urban waste water and fertilization capable of satisfying 50% of the expected nutritional requirements.

Each year, the plants subjected to treatments a) and b) received 70 g of N, 60 g of K_2O and 80 g of P_2O_5 (equivalence per hectare: 84 kg of N, 72 kg of K_2O and 96 kg of P_2O_5); the plants receiving fewer units of fertilizer (treatment c) received 35g of N, 30g of K_2O and 40 g of P_2O_5 (equivalence per hectare: 42 kg of N, 36 kg of K_2O and 48 kg of P_2O_5). From the data in table 1, in which concentration of nutrients were reported, excluding nitrites which are in negligible concentrations, it is possible to calculate the N and P_2O_5 content added in scenario c), shown in table 2. The environmental advantage that can be obtained from the use of reclaimed wastewater with advanced tertiary treatment is represented by the avoided impact for the production of 9.25 g of nitrogen from nitrogenous fertilizers and 4.76 g of PO_4^{3-} from phosphate fertilizers. This value converted to P_2O_5 with the conversion factor (0.7473) gives the value of 3.56 g. Instead of being industrially synthesized or extracted from mines, with high energy consumption, these nutrients are supplied directly from purified wastewater, treated with advanced tertiary treatments (flocculation and disinfection). However, fertirrigation of pomegranate using reclaimed wastewater and a reduced quantity of fertilizers, does not satisfy the nutrient provided in the scenario (a) and (b) and this represents the main issue of this solution. The fertilizer quantities supplied with the wastewater added to those of scenario (c) result in a lower value in nitrogen and P_2O_5 compared to the traditional scenarios. The irrigation with reclaimed wastewater and traditional fertilization capable of satisfying 100% of the expected nutritional requirements, were the best possible options, reduction of the fertilization will result in a corresponding reduction of nutrients and will reduce yield per hectare of the crops.

Table no. 1. Chemical-physical characteristics of the water: Fresh Water, FW; Reclaimed Water, RW, used during the experimental test, mean and standard deviation of pH, electrical conductivity and concentration of the main ions and elements

	FW		RW	
	Mean	**Standard dev.**	**Mean**	**Standard dev.**
pH	7.20	0.34	6.83	0.41
El. Cond. (µS/cm)	503.20	66.40	1563.10	258.78
B (mg/L)	0.11	0.01	0.13	0.03
Ca (mg/L)	33.42	5.68	75.33	6.55
Cu (mg/L)	<0.01	-	0.22	0.16
Fe (mg/L)	0.01	-	0.17	0.09
K (mg/L)	10.39	1.34	25.10	4.93
Mg (mg/L)	14.08	1.74	25.07	4.45
Mn (mg/L)	0.13	0.01	0.24	0.04
Na (mg/L)	47.71	5.45	187.85	38.55
P (mg/L)	<0.1	-	2.57	1.27
Zn (mg/L)	0.02	0.01	0.87	0.70
F^- (mg/L)	0.35	0.04	0.26	0.03
Cl^- (mg/L)	47.48	5.15	282.06	59.48
NO_2^- (mg/L)	<0.1	-	<0.1	-
Br^- (mg/L)	0.10	0.01	0.87	0.22
NO^{3-} (mg/L)	1.66	0.42	43.42	43.51
PO_4^{3-} (mg/L)	<0.1	-	5.05	2.81
SO_4^{2-} (mg/L)	59.93	6.82	335.79	95.05

Table no. 2. Average nutrient ion concentration (mg/L), liters administered, g of nitrogen and PO_4^{3-} of the reused waters in scenario (c)

Nutrient	**Mean conc. (mg/L)**	**Volume (L)**	**g N or PO_4^{3-} in the Reclaimed Water**
N as NO_3^-	43.42	943	9.25
P as PO_4^{3-}	5.05	943	4.76

Conclusions

Reclaimed wastewater is of increasing importance in the circular economy strategy both at the national and regional level, as an abundant usable resource for irrigation or industrial purposes. Moreover, interesting autochthonous cultivations like pomegranate are gaining share in the niche market of consumers paying attention to a healthy way of life. Fertirrigation of pomegranate with reclaimed water coming from a urban wastewater treatment system, is an interesting challenge, provided an assessment of the environmental impact of different scenarios were made. In the present paper the objective of evaluating the environmental impact of this resource was achieved by comparing a scenario of fertirrigation with reclaimed water and a scenario of irrigation with traditional groundwater extracted from a well. On the other hand, the objective of evaluating the nutritional efficiency of this resource was achieved by comparing 3 treatment scenarios: a- Irrigation with conventional water and fertilization capable of satisfying 100% of the expected nutritional requirements; b- Irrigation with refined urban waste water and fertilization capable of satisfying 100% of the expected nutritional requirements; c- Irrigation with refined urban waste water and fertilization capable of satisfying 50% of the expected nutritional requirements. Findings of LCA indicate the reclaimed wastewater scenario as the lowest impacting due to the huge electricity consumption for the pumping system of the traditional irrigation infrastructure of pomegranate. Fertirrigation of pomegranate using reclaimed wastewater and reduction of fertilization does not satisfy the nutrient needs, resulting in a decrease of the yield per hectare of the cultivation. The application of the principles of the circular economy in this case has been successful in preserving water as a natural resource but the fertirrigation of pomegranate or other crops, with the reclaimed wastewater, do not satisfy the nutrients needs of the crop. The importance of the proposed research relies in the provision to the stakeholders, of a reliable decision support system, capable of point out the pros and cons of the applicative choices of the principle of circular economy. The most important limitations of this proposal, reside in the need to have accurate data and in a wide time interval sometimes incompatible with the timing of political decisions. Possible applications and extensions of the research will be the choice of sustainable supplement to the reclaimed water to support the provision of nutrients necessary to achieve the same yield per hectare obtained in the traditional scenario of irrigation with both conventional groundwater and fertilization. This supplement should be commensurate to the reclaimed wastewater nutrient content.

Acknowledgement(s): the author P.G. would acknowledge the Minister of University for funding this research by FFABR2017 grant.

References

Agricultural and Processed Food Products Export Development Authority (APEDA), 2021. *Market Intelligence Report for Pomegranates.* [pdf] Available at: https://agriexchange.apeda.gov.in/Weekly_eReport/Pomegranate_Report.pdf [Accessed 6 April 2023].

Apisitpuvakul, W., Piumsomboon, P., Watts, D. J., Koetsinchai, W., 2008. LCA of spent fluorescent lamps in Thailand at various rates of recycling, *Journal of Cleaner Production* 16(10), pp.1046-1061. https://doi.org/10.1016/j.jclepro.2007.06.015.

Gallego, A., Hospido, A., Moreira, M.T. and Feijoo, G., 2008. Environmental performance of wastewater treatment plants for small populations. *Resources, Conservation and Recycling*, 52(6), pp.931–940. https://doi.org/10.1016/j.resconrec.2008.02.001.

Giungato, P. and Guinèe, J., 2010. Life Cycle Assessment of an Urban Wastewater Tertiary Treatment Plant. In: *Proceedings Lcafood2010*. Bari, 22-24 September, vol. 2, p. 384-389, BARI: University of Bari Aldo Moro, ISBN: 978-88-88793-29-0.

Giungato, P., Moramarco, B., Rana, R.L. and Tricase, C., 2023. Carbon footprint of FFP2 protective facial masks against SARS-CoV-2 used in the food sector: effect of materials and dry sanitisation. *British Food Journal*. [online] https://doi.org/10.1108/BFJ-09-2022-0773.

Giungato, P., Rana, R.L., Nitti, N., Cavallari, C. and Tricase, C., 2021. Carbon Footprint of Surgical Masks Made in Taranto to Prevent SARS-CoV-2 Diffusion: A Preliminary Assessment. *Sustainability*, 13(11), p.6296. https://doi.org/10.3390/su13116296.

Guinée, J.B. ed., 2002. *Handbook on life cycle assessment: operational guide to the ISO standards*. Eco-efficiency in industry and science. Dordrecht Boston: Kluwer Academic Publishers.

Heijungs, R. and Guinée, J.B. eds., 1992. *Environmental life cycle assessment of products*. Leiden: Centre of Environmental Science.

Holland, D., Hatib, K. and Bar-Ya'akov, I., 2009. Pomegranate: Botany, Horticulture, Breeding. In: J. Janick, ed. *Horticultural Reviews*. Hoboken, NJ, USA: John Wiley & Sons, Inc. pp.127–191. https://doi.org/10.1002/9780470593776.ch2.

Hospido, A., Moreira, M.T. and Feijoo, G., 2008. A comparison of municipal wastewater treatment plants for big centres of population in Galicia (Spain). *The International Journal of Life Cycle Assessment*, 13(1), pp.57–64. https://doi.org/10.1065/lca2007.03.314.

Hospido, A., Moreira, M.T., Fernández-Couto, M. and Feijoo, G., 2004. Environmental performance of a municipal wastewater treatment plant. *The International Journal of Life Cycle Assessment*, 9(4), p.261. https://doi.org/10.1007/BF02978602.

ISO, 2006. *ISO 14040:2006—Environmental Management—LCA—Principles and Framework*, [online] International Organization for Standardization. Available at: <https://www.iso.org/standard/37456.html> [Accessed 6 April 2023].

ISO, 2006. *ISO* 14044:2006—*Environmental Management—LCA—Requirements and Guidelines*, [online] International Organization for Standardization. Available at: <https://www.iso.org/standard/38498.html> [Accessed 6 April 2023].

Kärrman, E. and Jönsson, H., 2001. Normalizing impacts in an environmental systems analysis of wastewater systems. *Water Science and Technology*, 43(5), pp.293–300.

Khadivi, A., Mirheidari, F., Moradi, Y. and Paryan, S., 2020. Morphological variability of wild pomegranate (Punica granatum L.) accessions from natural habitats in the Northern parts of Iran. *Scientia Horticulturae*, 264, p.109165. https://doi.org/10.1016/j.scienta.2019.109165.

Lundie, S., Peters, G.M. and Beavis, P.C., 2004. Life Cycle Assessment for Sustainable Metropolitan Water Systems Planning. *Environmental Science & Technology*, 38(13), pp.3465–3473. https://doi.org/10.1021/es034206m.

Lundin, M. and Morrison, G.M., 2002. A life cycle assessment based procedure for development of environmental sustainability indicators for urban water systems. *Urban Water*, 4(2), pp.145–152. https://doi.org/10.1016/S1462-0758(02)00015-8.

Lundin, M., Bengtsson, M. and Molander, S., 2000. Life Cycle Assessment of Wastewater Systems: Influence of System Boundaries and Scale on Calculated Environmental Loads. *Environmental Science & Technology*, 34(1), pp.180–186. https://doi.org/10.1021/es990003f.

Melgarejo Moreno, P., Hernández Garcia, F., Martínez Nicolàs, J. J., Martínez, J., Sánchez, M., Martínez Valero, R., 1999. Il melograno, *L'Informatore Agrario*, 22, pp.37-41.

Pillay, S.D., Friedrich, E. and Buckley, C.A., 2002. Life Cycle Assessment of an industrial water recycling plant, *Water Science and Technology*, 46(9), pp.55-62.

Rana, R. and Ingrao, C., 2014. *Il melograno*, 1, pp.1-116, Bari: Wip Edizioni, ISBN: 9788884593320.

Renou S., Thomas J.S., Aoustin E. and Pons M.N., 2008, Influence of impact assessment methods in wastewater treatment LCA. *Journal of cleaner production*, 16(10), pp.1098-1105.

Renzoni, R. and Germain, A., 2007. Life Cycle Assessment of Water: From the pumping station to the wastewater treatment plant (9 pp). *The International Journal of Life Cycle Assessment*, 12(2), pp.118–126. https://doi.org/10.1065/lca2005.12.243.

Roeleveld P.J., Klapwijk A., Eggels P.G., Rulkens W.H., van Starkenburg W., 1997. Sustainability of municipal wastewater treatment. *Water Science and Technology*, 35(10), pp.221–228.

Skyquest, 2022. *Global Pomegranate Market*, [online] Available at: <https://www.skyquestt.com/report/pomegranate-market> [Accessed 6 April 2023].

Stokes, J. and Horvath, A., 2006. Life cycle Energy assessment of alternative water supply systems. *The International Journal of Life Cycle Assessment*, 11(5), pp.335-343.

Suh, Y.J. and Rousseaux, P., 2002. An LCA of alternative wastewater sludge treatment scenarios. *Resources, conservation and recycling*, 35(3), pp.191-200.

Tchobanoglous, G., Burton, F.L., Stensel, H.D., and Metcalf & Eddy, Inc eds., 2002. *Wastewater engineering: treatment and reuse*. 4. ed., internat. ed., [Nachdr.] ed. McGraw-Hill series in civil and environmental engineering. Boston, Mass.: McGraw-Hill.

Tillman, A.M., Svingby, M. and Lundstròm, H., 1998. Life cycle assessment of municipal wastewater systems. *International Journal of Life Cycle Assessment*, 3(3), pp.145–157.

Tinebra, I., Scuderi, D., Sortino, G., Mazzaglia, A. and Farina, V., 2021. Pomegranate Cultivation in Mediterranean Climate: Plant Adaptation and Fruit Quality of 'Mollar de Elche' and 'Wonderful' Cultivars. *Agronomy*, [online] 11(1), p.156. https://doi.org/10.3390/agronomy11010156.

Tsagarakis, K.P., Mara, D.D. and Angelakis, A.N., 2003. Application of cost criteria for selection of municipal wastewater treatment systems. *Water Air Soil Pollution*, 142(1–4), pp.187–210.

Tsagarakis, K.P., Mara, D.D., Horan, N.J. and Angelakis, A.N., 2000. Small municipal wastewater treatment plants in Greece. *Water Science and Technology*, 41(1), pp.41–48.