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A life cycle assessment of biosolarization as a valorization pathway for tomato pomace utilization in California

Thomas L. Oldfield [a,*], Yigal Achmon [b], Kristen M. Perano [c], Ruth M. Dahlquist-Willard [d], Jean S. VanderGheynst [e], James J. Stapleton [f], Christopher W. Simmons [b], Nicholas M. Holden [a]

[a] UCD School of Biosystems and Food Engineering, University College Dublin, Belfield, Dublin 4, Ireland
[b] Department of Food Science and Technology, University of California, Davis, CA 95616, United States
[c] Department of Biological and Environmental Engineering, Cornell University, Ithaca, NY 14850, United States
[d] University of California Cooperative Extension, Fresno County, Fresno, CA 93710, United States
[e] Department of Biological and Agricultural Engineering, University of California, Davis, CA 95616, United States
[f] Statewide Integrated Pest Management Program, University of California, Kearney Agricultural Research and Extension Center, Parlier, CA 93648, United States

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A B S T R A C T

The California tomato processing industry produced circa 388,856 t of tomato pomace in 2014. While currently used for animal feed, tomato pomace could be utilized for biosolarization. Primary Energy Demand (PED) and Global Warming Potential (GWP) equivalent emissions were calculated for two valorization pathways: (i) feed for cattle; and (ii) biosolarization. In order to make these two valorization pathways comparable three management options were analyzed whereby each part of the system was satisfied, i.e. a pest management sub-system and a cattle feed sub-system. The management options were (1) tomato pomace used for cattle feed and soil pest control using fumigant Telone II and herbicide glyphosate; (2) tomato pomace used for cattle feed and soil pest control using solarization; (3) alternative cattle feed (cottonseed, canola pellets and wheat straw) and soil pest control using biosolarization with tomato pomace. Options 2 and 3 result in a reduction of GWP and PED. Among management options, the GWP ranged from 64–98 kg CO_2-e and 1502–2250 MJ for PED per t of pomace. The majority of impacts were beyond the tomato processors' immediate control, therefore encouraging the diversion of tomato pomace to biosolarization may be desirable. Total savings per annum for biosolarization could be as large as 7.7 M kg CO_2-e and 203,000 GJ annually.

1. Introduction

The extensive use of pesticides in modern agricultural systems is essential in order to manage pests that transmit infectious diseases and compete for resources. Approximately 2.5 Mt of pesticides are used worldwide, with over 450 Kt used in the United States of America (USA) each year (Alavanja, 2009). Until recently, Methyl bromide (MeBr) was the most widely used pesticide, however in accordance with the Clean Air Act (EPA, 2016) its use has been banned due to its negative effect on human health and depletion of the ozone layer (UNEP, 1992). The prohibition of MeBr has spurred innovative new designs and formulations of pesticides by manufacturers and researchers to meet the global demand for pest control in agriculture. Alternative and sustainable integrated pest management strategies need to have a low environmental impact, be cost effective (Lichtfouse et al., 2009), and ideally, they should only be toxic to the target organisms (Ros et al., 2008).

One alternative approach to chemical pesticides use is solarization; a hydrothermal process of disinfesting soil of agricultural pests. Solarization is accomplished by covering moist soil with clear plastic sheeting, leading to passive solar heating and pest inactivation through a combination of physical, chemical, and biological mechanisms (Stapleton, 2000). Solarization has been shown to be beneficial and practical (Özhan Boz, 2009), in particular for strawberry (Yildiz et al., 2010) and legume cultivation (Linke et al., 1991), and in smaller farming operations (Stapleton et al., 2008). However,

* Corresponding author.
E-mail address: thomas.oldfield@ucdconnect.ie (T.L. Oldfield).

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there are barriers preventing its widespread use. Solarization demands strict scheduling to coincide with the warmest period of the year, and it suffers from variable efficiency (Stapleton, 2000). The addition of a soil amendment with organic matter extends solarization to the process known as biosolarization, and has been shown to enhance pest-inactivating conditions (Achmon et al., 2016; Simmons et al., 2013) while contributing to the mitigation of the aforementioned barriers. Biosolarization and solarization research to date has focused on the technical aspects of the technology with an emphasis on comparing the pest control efficacy to conventional pesticides (Özhan Boz, 2009; Achmon et al., 2016; Simmons et al., 2013). Typically, the soil amendment used in biosolarization is an agricultural by-product or residue. The use of agricultural by-products and residues for waste valorization processes is seen as an opportunity to displace fossil alternatives (Lin et al., 2013) and falls within the mandate of the bioeconomy, whereby non-renewable products are replaced with renewable alternatives.

One location where the adoption of biosolarization is ideal due to its climate and significant agricultural industry is the state of California (CA), USA. Annually, CA produces large quantities of fruit processing residues (Morning Star, 2014) and also requires soil pest management for a significant area of agricultural land (Epstein and Zang, 2014). Solid residues from fruit processing are a promising biosolarization organic amendment because they are rich in organic compounds and have limited alternate uses (Achmon et al., 2016). Pomace consists mainly of skins, seeds and residual pulp that remain after the fruit has been disrupted and pressed. Achmon et al. (2016) identified that for biosolarization, tomato pomace gave the best result, while white grape pomace performed less effectively and red grape pomace was far less suitable.

Research has been carried out on tomato processing in CA (Brodt et al., 2013), but did not include options for the management of tomato pomace. In 2007, about 260,000 t (fresh weight) of tomato pomace was produced by the California tomato processing industry (Matteson and Jenkins, 2007), which had increased to approximately 388,856 t (fresh weight) by 2014 (Morning Star, 2014). The majority of agricultural by-products are incorporated by dairy farmers into their feed rations (Silva-del-Río et al., 2010), and tomato pomace has been successfully used as a component of the ration in some California dairies (Cassinerio et al., 2015). If tomato pomace were to be diverted to biosolarization, an ideal location would be the San Joaquin Valley, one of CA's major eggplant cultivation regions (Aguiar, 2016), and where many of the tomato processors operate. Eggplant is often harvested in the summer in this region, leaving the fields fallow during the warmer months that are ideal for biosolarization. This also corresponds to the tomato-processing season and thus the availability of pomace. Several pesticides are typically used (CEPADPR, 2016) to control soil borne pests in eggplant fields. These factors make eggplant production an ideal target for alternative pest management technologies like biosolarization.

Life cycle assessment (LCA) is a technique that quantifies the potential environmental impact and resource consumption of a product, system or service from cradle to grave (ISO, 2006). The LCA method can be employed to assess the environmental impact of utilizing tomato pomace for biosolarization. To date no LCA has been published on solarization, biosolarization, or tomato pomace management; however, LCA studies have been carried out that look at the valorization of wasted food products, food residues and crop residues (San Martin et al., 2016; Gassara et al., 2011). The approach taken by both San Martin et al. (2016) and Gassara et al. (2011) was to consider these organic materials as wastes (wasted vegetables and apple pomace, respectively) that would have otherwise been sent to landfill, hence they omitted the upstream impact and only considered the recovery phase. For simplicity, this study followed the same established approach. Such studies considered competing valorization pathways, but did not expand the systems so that value-added products produced where comparable, and all parts of the system were equally satisfied.

The objective of the study was to evaluate the implications, in terms of global warming impact and fossil energy consumption, of utilizing tomato pomace for biosolarization rather than as a component of livestock diets in the context of soil fumigation prior to eggplant crop establishment in California.

2. Materials and methods

2.1. Life cycle assessment

A LCA study was carried out based on ISO 14040 standard (ISO, 2006) and the four stages were followed (1) goal and scope definition; (2) inventory analysis; (3) impact assessment; and (4) interpretation. GaBi v.6 software (Thinkstep, 2016) was used for modelling. The Centrum voor Milieuwetenschappen (CML) 2001 baseline methodology (Guinee et al., 2002) was used without normalisation or weighting, and included the environmental impact global warming potential (GWP, kg CO_2-e) and primary energy demand (PED, MJ).

2.1.1. Goal and scope definition

The goal of the study was to calculate baseline environmental data for utilizing tomato pomace as a substrate for biosolarization, from the perspective of waste management/valorization as compared to use as an animal feed ingredient.

The reason for undertaking this study was to support strategic decision-making and the audience was assumed to be the scientific community, tomato processors, regulators and farmers.

Two valorization pathways for tomato pomace (Table 1) were identified for California: (i) feed for cattle (the business as usual option); and (ii) biosolarization. In order to make these two valorization pathways comparable three hypothetical management options were constructed whereby each part of the system was satisfied, i.e. a pest management sub-system and cattle feed sub-system. The management options were (1) tomato pomace used for cattle feed and soil pest control using the fumigant Telone II and herbicide glyphosate; (2) tomato pomace used for cattle feed and soil pest control using solarization; (3) alternative cattle feed (cottonseed, canola pellets and wheat straw) and soil pest control using biosolarization with tomato pomace.

2.1.1.1. Option 1: business-as-usual (BaU), tomato pomace for cattle feed and pest control with chemical fumigant. Option 1 represents BaU (Fig. 1), whereby tomato pomace is transported from 19

Table 1
Physiochemical characteristics of Tomato Pomace, Cottonseed (whole, with lint), Canola Pellets and Wheat Straw (given as % dry weight except where noted); (Beef Magazine, 2010).

Constituent	Tomato pomace	Cottonseed	Canola pellets	Wheat straw
Fat	10.6	19.4	2	1.8
Protein	23	23	41	3
Carbohydrate	3.78	–	–	–
Fibre	50	37	19	57
Ash	6	5	8	8
Water[a]	77	9	10	9
Nitrogen	3.68	3.68	6.56	0.48
Phosphorus	0.59	0.64	1.14	0.06
Potassium	3.6	1	1.1	1.3
Carbon (total)	55.3	–	–	–

[a] Fresh weight.