Scientific Bulletin. Series F. Biotechnologies, Vol. XXVI, No. 1, 2022
ISSN 2285-1364, CD-ROM ISSN 2285-5521, ISSN Online 2285-1372, ISSN-L 2285-1364

ECO-EFFICIENCY AND TECHNO-ECONOMIC ANALYSIS OF *TRICHODERMA* BASED PLANT BIOSTIMULANT UTILISATION ON TOMATOES CULTIVATED IN A CONSERVATION FARMING SYSTEM

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Abstract

Conservation agriculture is a farming system that includes no-tillage and coverage of the soil with plant residues. Despite many advantages, there are also drawbacks of such conservative systems. Plant residues promote the development of soil-borne pathogens and delay early crop development stages. Bioproducts based on microbial plant biostimulant strains were applied to compensate for the drawbacks of the conservation farming system. This paper evaluates the eco-efficiency and the economic benefits of using plant biostimulant Trichoderma strains as a plant residues treatment. To determine eco-efficiency, we used a Life-Cycle Analysis approach. We calculate the gross margin based on average yields and available statistical costs for outputs (tomatoes) and inputs for economic benefits estimation. The application of Trichoderma-based plant biostimulant bioproducts significantly increased the yield by 16.03%. The greenhouse gas (GHGs) production calculation reveals that the biostimulant application to plant residues reduced GHGs emissions per production unit. The yield increase compensates for the additional costs of the bioproducts. The gross margin is higher in the conservation farming system, which utilizes Trichoderma plant biostimulants.

Key words: *conservation farming, plant residues, Trichoderma-based plant biostimulants, eco-efficiency, gross-margin.*

INTRODUCTION

Industrial vegetables, produced in intensive field-grown systems, have a low phytonutrient content, a high risk of contamination with agrochemicals residues (pesticides, nitrates/ nitrites), and are less attractive for the consumers to their lower organoleptic characteristics (García-Mier *et al.*, 2013). Intensive monocultures reduce biodiversity due to weeding and high chemical inputs (Frison *et al.*, 2011).

The conditions for field-grown tomatoes in Romania are similar to those from semi-arid Mediterranean areas (Alexe *et al.*, 2015; Ronga *et al.*, 2017). From May till August, the growing season is characterized by low precipitation (well below 200 mm in the last decade) and high temperature - reaching 40°C (Paltineanu *et al.*, 2007). In such conditions, field-grown tomatoes are exposed to water and heat stress in the critical phenological phases (Voican *et al.*, 1995). The farming system is characterized by a massive application of agricultural inputs - water (up to 600 m^3ha^{-1}), fertilizers, and plant protection products (Dima *et al.*, 2020).

To compensate for these drawbacks, sustainable and low-input systems were proposed. Organic farming reduces the utilization of chemical inputs and increases the vegetables' edible yield (Tuomisto *et al.*, 2012). However, the cost of organic vegetable production is high, and the environmental impact per unit of product is sometimes higher than in intensive agriculture (Ronga *et al.*, 2019). A typical example is phosphorus eutrophication of the continental water bodies, promoted by the extensive use of organic fertilizers in organic farming. To ensure proper nitrogen fertilization, an excess of phosphorus is introduced into the soil, negatively impacting eutrophication (Möller *et al.*, 2018).

A low-input, sustainable production system for fresh-marked tomatoes and other vegetables was developed with cover crop mulches (Abdul-Baki *et al.*, 2002; Teasdale & Abdul-Baki, 1997). This system involves using winter annual legume hairy vetch (HV; *Vicia villosa* L. Roth) both as a cover crop and as a mulch source for vegetable transplants cultivation (Campiglia *et al.*, 2010). It was shown to reduce soil losses, maintain high soil fertility, lower production costs, and maintain yield and product quality (Abdul-Baki *et al.*, 1996).

When is used as a cover crop, the winter hairy vetch simulates nitrogen fixation and nutrient recycling, reduces soil erosion and compaction, and supplements organic soil matter (Butler *et al.*, 2016; Muchanga *et al.*, 2020). When the cover crop is converted into mulch, plant residues covering the soil reduce weed seed germination, increases the nitrogen content in the soil, reduces water loss, and acts as a controlled-release growth-promoting pool - nutrients for cultivated plants and biologically active compounds that modulate agronomically valuable physiological processes (Massantini *et al.*, 2021).

It was demonstrated that when the tomatoes plants are cultivated in this HV farming plant, the expression of several genes related to nitrogen assimilation and ethylene signaling is up-regulated compared to those grown on black polyethylene (BP) mulch (Kumar *et al.*, 2004). HV farming system enables a metabolic system in tomatoes somewhat akin to higher polyamine-accumulating transgenic fruit with higher phytonutrient content (Neelam *et al.*, 2008). The positive responses of tomatoes to a hairy vetch cover crop observed in the field seem to be mediated by physiological cues other than the additional N provided by the vetch cover crop (Fatima *et al.*, 2016; Fatima *et al.*, 2012). Our hypothesis was that the polyamines released from the HV mulch modulate microbiome and plant physiology (Oancea, 2011)

The HV farming system has several drawbacks: (*i*) stimulation by plant residues of the soil-borne plant pathogens (Kerdraon *et al.*, 2019; Van Agtmaal *et al.*, 2017); (*ii*) lower soil temperature compared to bare soil, which could affect the development of the vegetables transplants during springs (Hobbs *et al.*, 2008); (*iii*) reduced bioavailability of nitrogen due to the increase of soil carbon pool (Ranaivoson *et al.*, 2017); (*iv*) low mechanical stability of vegetable mulch, which reduces the weeding ability (Sicuia *et al.*, 2011).

To compensate for these negative aspects of the high residues vegetable farming system, our group proposed using hydrogelified and film-forming formulation of microbial plant biostimulants based on *Trichoderma* (Oancea *et al.*, 2017). *Trichoderma* antagonize the development of the soil-borne plant pathogens (Hewedy *et al.*, 2020) and activate tomatoes plant defense against various foliar pathogens (Fernández *et al.*, 2014; Gomes *et al.*, 2017), aphids (Coppola *et al.*, 2019), and nematodes (Poveda *et al.*, 2020). Due to their production of bioactive compounds, *Trichoderma* increases nutrient uptake and nutrient use efficiency and stimulates plant growth (López-Bucio *et al.*, 2015). The tackifier and the film-forming adhesives increase mulch mechanical stability and weeding efficiency (Oancea *et al.*, 2016).

This paper aims to evaluate eco-efficiency through a life cycle impact assessment targeted on carbon footprint/climate change impact and the economic benefits of using plant biostimulant *Trichoderma* strains as a plant residues treatment.

MATERIALS AND METHODS

Study area, farming system, and yield. This study focuses on field-grown tomatoes in the Romanian plain, in the following farming system: bare-soil intensive system, HV- mulch system, *Trichoderma* plant biostimulant + HV mulch system. The yields used in this study are those reported already in our previous studies (Oancea *et al.*, 2017; Sicuia *et al.*, 2011), ranging from 67.5 to 82.3 tones.ha^{-1}.

System description. The system boundary of the Life Cycle Analysis (LCA) performed in this study is cradle-to-gate, respectively, during the farming phase. Such farming phase includes tomato transplant production, soil fertilization/ mulching, transplant replication, plant protection treatments, including weeding, irrigation, and harvesting. In the case of the HV system, the farming phase also included the hairy vetch establishment costs. HV mulch system is a low-input system. Fertilizer, weeding, and irrigation are reduced by around 25% on average comparing with the intensive system/ In the HV + *Trichoderma* biostimulant mulch system, the need for plant protection treatment is reduced by 40%, according to our previous studies (Sicuia *et al.*, 2011), due to activation of the plant innate immunity. Figure 1 illustrates the studied farming system and its boundary.

Life cycle inventory. Data used for the LCA study were collected from the data source (EcoInvent) and recently published inventory from peer-review articles (Pineda *et al.*, 2021). Trichoderma production and formulation data were collected from the peer-reviewed paper regarding cellulase production using selected *Trichoderma* strains. The data were adapted to the optimal biosynthesis conditions of the plant biostimulant strains used in our studies (Zamfiropol-Cristea *et al.*, 2017).

Figure 1. The cradle to gate system boundary was used for the Life Cycle Analysis performed in this paper

Life cycle impact assessment. The eco-efficiency can be evaluated as the environmental burden, spotlighted by the LCA specific indicators, such as carbon footprint/climate change impact, damage to continental water bodies, acidification potential, impact on human health. HV farming reduces erosion and nitrate leakage (Rice *et al.*, 2002). Therefore, damage to the continental water bodies and acidification potential were not calculated. Plant biostimulants and hairy vetch mulch cultivation enhance field-grown tomatoes' quality (Dima *et al.*, 2020; Hong *et al.*, 2000). The main LCA indicator which was considered in this paper was the carbon footprint. The carbon footprint was made by modeling bare-soil intensive system, HV- mulch system, *Trichoderma* plant biostimulant + HV mulch system in the GaBi software (Sfera Solutions, Leinfelden-Echterdingen, Germany). The chosen approach was the attributional LCA. The energy grid was considered the Romanian grid.

Techno-economic analysis. For the field-grown tomatoes in bare soil intensive farming system, the water consumption for irrigation was considered 600 m^3ha^{-1}. The fertilization was considered NPK 8:11:23, 500 $kg.ha^{-1}$ and one foliar treatment with 2 $liters.ha^{-1}$, with a 3:1:1 type NPK fertilizer, with microelement, including selenium (Dima *et al.*, 2020). The considered plant protection treatments were: bactericides against tomatoes bacterial disease (*Xanthomonas* spp., *Pseudomonas* spp.); fungicides against fungal foliar diseases (*Phytophthora infestans, Alternaria solani, Septoria lycopersici, Leveillula taurica*), against fungal vascular diseases (*Fusarium* spp., *Verticillium* spp.) and gray mold, *Botrytis cinerea* control; insecticides against *Tuta absoluta* and *Helicoverpa armigera*; pre-emergent herbicides for weed control. For the HV mulch system, the consumption of fertilizers, herbicides, and irrigations is lower by 25%. In the HV + *Trichoderma* biostimulant mulch system, the need for plant protection treatment was reduced by 40% (Sicuia et al., 2011). For both HV mulch systems, the winter cover crop's costs during the fall were considered. According to the cost, which is reimbursed for establishing the winter cover crop according to agro-environmental support, this cost was estimated to be 128 euro per ha.
To determine the costs for the production of *Trichoderma* hydrogelified and film-forming formulation, the model of *Trichoderma* cellulase production costs was used (Olofsson *et al.*, 2017). This model was combined with our data regarding optimal biosynthesis conditions for our plant biostimulant strain (Zamfiropol-Cristea *et al.*, 2017). Mass energy balance, capital costs/investment amortization, material consumption were estimated in Aspen Plus v8.0 software (Aspen Technology, Cambridge, MA, USA). All calculated costs and income were expressed in euros.

RESULTS AND DISCUSSIONS

The data used for calculation of carbon footprint of the three systems, bare-soil intensive system, HV- mulch system, *Trichoderma* plant biostimulant + HV mulch system analyzed in this paper, are presented in Table 1. These data were validated by publication as peer-reviewed papers (Oancea *et al.*, 2016; Oancea *et al.*, 2017; Sicuia *et al.*, 2011).

Similar data were used for other LCA studies focused on the assessment of the carbon footprint/climate change impact of the tomatoes farming system, both in protected systems and open-field systems (Garofalo *et al.*, 2017; Pineda *et al.*, 2021; Ronga *et al.*, 2019; Zarei *et al.*, 2019). The resulted values related to carbon footprint for each type of farming system analyzed in this paper are presented in Figure 2.

As we already mentioned, one of the main differences in the HV-mulch system comparing to bare-soil intensive systems is tillage (Campiglia *et al.*, 2010). However, fuel consumption is not significantly reduced in the HV mulching system because of other mechanized works - establishment of the winter cover crops, termination of the hairy vetch, and conversion to mulch by roller-crimper. The reduced carbon footprint is due mainly to the reduced production of greenhouse gases (CO_2, CH_4, N_2O) due to soil coverage and nitrogen immobilization (Massantini *et al.*, 2021).

Table 1. The data used for the calculation of the carbon footprint of the three analyzed farming systems for field-grown tomatoes

	Unit	Bare soil	HV-mulch	HV-mulch + *Trichoderma*
Outputs to the Technosphere				
Tomato fruits yield	tones	82.324	67.538	79.696
Inputs from the environment				
Water	m^3	600	450	450
Inputs from Technosphere				
Transplants production				
Seeds	number	50,000	50,000	50,000
Peat based substrate	m^3	2.53	2.53	2.53
Fertilizer (Calcium nitrate, superphosphate, potassium sulphate)	kg	4.75	4.75	4.75
Amendment (calcium carbonate)	kg	2.25	2.25	2.15
Heating fuel	kg	264	264	264
Tomato fruit production – open field				
Mineral fertilizer NPK 8:11:2	kg	500	400	400
Foliar fertilization	kg	2	2	2
Trichoderma plant biostimulants	kg	0	0	4
Plant protection products		12,70	9.52	7.62
Electricity (irrigation)	kWh	14.10	10.57	10.57
Diesel (tillage, transplantation, harvesting)	kg	46.50	0	0
Diesel (hairy vetch establishment, hairy vetch termination, transplantation, harvesting)		0	52.5	52.5
Lubricant	kg	3.50	3.80	3.80
Outputs to the environment				
Emissions to air				
CO_2	kg	198,958.20	146,451.85	138,656.42
CH_4	kg	23.25	12.26	12.46
N_2O	kg	1.39	1.08	0.92

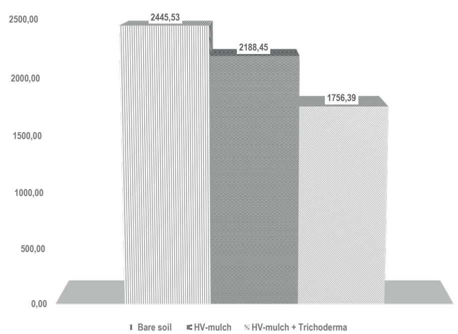

Figure 2. The carbon footprint, as equivalent kg CO_2 per tone of tomatoes fruits for the three farming systems studied - bare soil, HV-mulch, HV-mulch + *Trichoderma* plant biostimulants

Another difference that contributes significantly to the carbon footprint is the lower plant protection product consumption. Other studies also underlined this difference. Reduction of plant protection product utilization benefits also from other environmental indicators (Guo *et al.*, 2021; Ntinas *et al.*, 2017; Ronga *et al.*, 2019).

The techno-economic analysis for the three farming systems is presented in Table 2. The results demonstrated that the *Trichoderma* plant biostimulant application on mulch enhances the HV-system's profitability - mainly due to increased yield. Similar results related to the gross margin decreases in the hairy vetch low-inputs farming systems were also reported for other semi-arid areas (Delate *et al.*, 2012; Leavitt *et al.*, 2011). It seems that the benefits of nitrogen and water storage are lower in semi-arid regions, especially during this period of climate change (Muchanga *et al.*, 2020)

Table 2. The techno-economic analysis for the three farming systems studied - bare soil, HV-mulch, HV-mulch + *Trichoderma* plant biostimulants

Incomes										
Tomatoes fruits yield per ha	kg	82324	0.11	9055.6	79696	0.11	8766.5	67538	0.11	7429.18
Subvention per ha	€	1.00		1410	1.00		1538.00	1.0		1538.00
Total				**10465.64**			**10304.56**			**8967.18**
										Direct costs
Seeds	Nr	50000.00	0.02	1000.00	50000.0 0	0.02	1000.00	50000.0 0	0.02	1000.00
Transplant production costs	Nr	50000.00	0.03	1500.00	50000.0 0	0.03	1500.00	50000.0 0	0.03	1500.00
Hairy vetch establishment and mulching	Nr	0.00	0.00	0.00	1.00	128.0 0	128.00	1.00	128.0 0	128.00
Fertilizers (soil)	kg	500.00	0.45	225.00	400.00	0.45	60.00	400.00	0.45	60.00
Fertilizer (foliar)	kg	2.00	16.50	33.00	2.00	16.50	33.00	2.00	16.50	33.00
Plant protection products	kg	12.70	30.50	387.35	9.52	30.50	290.36	7.62	30.50	M232,41
Trichoderma bioproduct	kg	0.00	0.00	0.00	4.00	12.75	51.00	0.00	0.00	0.00
Irrigation	m^3	600.00	0.75	450.00	450.00	0.75	337.50	450.00	0.75	337.50
Diesel	kg	46.50	1.05	48.83	52.50	8.00	8.00	52.50	1.01	8.00
Lubricant	kg	3.50	18.50	64.75	3.80	18.50	70.30	3.80	18.50	70.30
Direct working force	h	12.00	5.50	66.00	15.00	5.50	82.50	16.00	5.50	88.00
Others direct costs		1.00	48.00	48.00	1.00	48.00	48.00	1.00	28.00	28.00
Total				**3822.93**			**3608.66**			**3485.21**
Goss margin EUR per ha				**6642.72**			**6695.90**			**5481.97**

Low-input farming systems, such as organic farming or HV-farming, have a general environmental impact lower when expressed per production area unit, i.e., ha (Tuomisto *et al.*, 2012; Zarei *et al.*, 2019). However, due to lower production, the environmental impact is sometimes higher than in intensive agriculture (Ronga *et al.*, 2017). Therefore, yield increase was suggested for the low-inputs systems, especially in the semi-arid area (Delate *et al.*, 2012; Ronga *et al.*, 2019), to improve the eco-efficiency.

Our proposed systems, involving applying the *Trichoderma* plant biostimulant as a hairy vetch mulch treatment to compensate for the drawbacks of the traditional HV-mulch farming systems, increase the yield and the gross margin. At the same time, retain the benefits of the HV-system related to soil health and fertility (Butler *et al.*, 2016; Muchanga *et al.*, 2020), as our previous work demonstrated (Oancea *et al.*, 2017).

CONCLUSIONS

The low-input farming system of tomato cultivation into the hairy vetch mulch was improved by utilizing the treatment with a plant biostimulant *Trichoderma* strain. This strain was included in the hydrogelified and film-forming formulation.

Life cycle assessment demonstrates a significant reduction of the carbon footprint. This reduction was almost 30% compared to the bare-soil intensive farming system and more than 20% compared to the traditional HV farming system. The yield increase compensates for the additional costs of the bioproducts. The gross margin is higher in the conservation farming system, which utilizes *Trichoderma* plant biostimulants.

ACKNOWLEDGEMENTS

The research leading to these results has received funding from the NO Grants 2014-2021, under Project RO-NO-2019-540 "Integrated use of the next generation plant biostimulants for enhanced sustainability of field vegetable high residue farming systems STIM 4+", contract no. 14/2020.

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