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COVERING PLASTIC FILMS IN GREENHOUSES SYSTEM: A GIS-BASED MODEL TO IMPROVE POST USE SUISTAINABLE MANAGEMENT

Monica C.M. Parlato, Valenti Francesca^{*}, Simona M.C. Porto

¹Department of Agriculture, Food and Environment, University of Catania, Building and Land Engineering Section Via S. Sofia 100, 95123, Catania, Italy

*Corresponding author: francesca.valenti@unict.it

Keywords: plastics waste management; land management; sustainability; GIS modelling; spatial index.

2 COVERING PLASTIC FILMS IN GREENHOUSES 3 SYSTEM: A GIS - BASED MODEL TO IMPROVE POST 4 USE SUSTAINABLE MANAGEMENT

6 Abstract

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7 Yearly, in Europe, more than 1 million tonnes of plastic materials are used in 8 agricultural activities. Among the possible applications, plastic films for protected 9 cultivation practices are highly used worldwide because of the significant advantage 10 deriving from the shortening of the growing period. However, in the absence of a 11 correct policy disposal of plastic films, environmental degradation could take place 12 with serious ecological and economic consequences.

In this study, a geographical information system (GIS) - based model to locate and quantify the yearly amount of agricultural plastic waste (APW) coming from cropshelter coverage used in greenhouses system was put forward and was applied in a study area located in southern Italy, highly characterised by protected cultivation practices.

Firstly, the areas with the highest density of crop shelters were mapped, then a suitable index to determine APW amount was computed and applied to obtain heat maps related to covering plastic films. Finally, sensitivity analyses were carried out by varying thickness, lifetime, and density of the covering films of the greenhouses, located in the considered samples. The index ranged between 976 kg ha⁻¹yr⁻¹ and, 2,484 kg ha⁻¹yr⁻¹.

24 The results showed that the density of greenhouses and tunnels-greenhouses is 25 still elevated nearby the coastline, highlighting that the guidelines of the territorial 26 plan of the Province of Ragusa concerning the displacement of protected crops from 27 the coast to the internal rural areas were disregarded. Moreover, the GIS-based model 28 results could provide basic information for the analysis of the environmental impact 29 due to transportation of APW. Therefore, these results could offer a suitable tool to 30 improve the correct disposal management of covering plastic films and the related 31 recycle policy.

Keywords: plastics waste management; land management; sustainability; GIS
 modelling; spatial index.

34

35 **1 Introduction**

In accordance with the main Global policies of environmental sustainability, in 2015 the European Commission adopted a Circular Economy Action Plan (CEAP) concerning actions to improve Europe's transition from a linear economy towards a circular one as well as to promote a sustainable economic grown.

40 The European CEAP foresees actions covering the whole economic cycle from
41 the production process to waste management, measure for the market of secondary raw
42 materials and a revised legislative proposal on waste.

The main objective of the revised legislative framework on waste, entered into force in July 2018, is the reduction of waste by improving disposal management, recovery and reuse rate (Directive (EU) 2018/849). This legislative framework is providing a clear and stable policy to improve long-term investment strategies focusing on prevention, reuse and recycling rates.

48 The conversion of waste into new raw material is an important aspect of 49 increasing resource efficiency and closing the loop in a circular economy framework. 50 In particular, actions on plastic waste are identified by CEAP as priority. Nowadays, 51 plastic pollution is considered one of the biggest environmental concerns due the long-52 life material (plastic can take hundreds or thousands of years to be decomposed) and 53 because more than 85% of plastic waste ends up in landfills. Yearly, in Europe about 54 26 million tons of plastic waste are generated and their recycling rate is less 30%, a 55 great loss for both economy and environment. Worldwide, as it occurs in other 56 production sectors, also for agricultural activities the use of plastic materials being 57 increasing too. Each year, the world consumption of agricultural plastic materials is 58 about 6,5 million tons (Scarascia-Mugnozza et al., 2012) and more than 1 million tons 59 in Europe. A large amount of this plastic material is plastic film for covering protected 60 crops or mulching soil, the rest is used for irrigation piping, packaging, and containers 61 for fertilizers.

62 Since 1950's the use of plastic films as covering materials for greenhouses 63 developed quickly and it is still growing. Currently protected cultivations are 64 increasing worldwide with about 1,600,000 ha of greenhouses and walk-in tunnels (Espí et al., 2006) of which 405,000 ha are greenhouses widespread in Europe,
(mainly in Spain, Italy and France). In Europe, Almeria, in the south of Spain, is the
region with the greatest concentration of greenhouses in the world, it is known as the
'Sea of Plastic' (Aguilar M. et al, 2016).

69 Plastic covering films shorten the growing period, defend crops from 70 environmental risks, such as bad weather conditions, birds and parasites, and create 71 microclimate favourable to plant growth (Ahemd et al., 2016; Demetres Briassoulis et 72 al., 2013a; Kyrikou and Briassoulis, 2007).

On the other hand, the increased diffusion of protected crops generates a large amount of agricultural plastic waste (APW) that requires a properly collection, disposal and recycling process. Among the different types of APW collected and directed for recycling, a huge amount is constituted by plastic films used to cover greenhouses, mainly represented by low density polyethylene (LDPE), ethylene vinyl acetate (EVA), polypropylene (PP) or polyethylene (PE).

In 2011 the APW recovering rate in Europe was around 46% and the mechanical recycling rate was about 23% (European commission (DGE), 2011). In some geographical areas, where recovery and reuse processes for plastic wastes are not foreseen, plastic films are left illegally on the margins of cultivated fields, on illegal dumps, or even burned. Their abandonment close to water courses could cause groundwater pollution or an obstacle to the natural flow of water with dramatic consequences such as flooding.

Yearly, in Italy more than 350,000 tons of agricultural plastic materials are used (Picuno et al., 2012) and most of them, that are used as covering films, must be frequently replaced due to their early deterioration caused by exposition to atmospheric agents. For this reason, a correct disposal policy is crucial to avoid environmental pollution.

APW recycling could reduce pollution and prevent economical losses and environmental impacts due to the development of greenhouse cultivation system. In this regard, land conservation policies should include also guidelines for the sustainable management of APW in order to reduce soil and water consumption, soil and aquifers chemical contamination and, organic matter soil decrease (Díaz-Palacios-Sisternes et al., 2014; Picuno et al., 2011; Vox et al., 2016).Therefore, the main aim of 97 this study is to improve post-use sustainable management of greenhouses covering 98 films. Post-use management takes into account the execution of different steps for the 99 disposal or for recycling of agricultural plastic covering film, such as: APW 100 localization and quantification, APW collection, APW transport to landfill or recycling 101 industries, APW processing in order to obtain secondary raw material (e.g. plastic 102 granules).

103 This research study focused on the first step of post-use management of APW which is 104 crucial in order to put forward a method for a sustainable disposal management and 105 recycling process of APW. Since, Geographic Information System (GIS) tools have 106 been considered as an appropriate platform for environmentally related issues (Valenti 107 et al., 2018) and have been applied for both assessing, quantifying and site-location 108 analysis, in this study a GIS-based model was developed for collecting, organizing, 109 analysing, and visualizing geographical data related to APW. The data coming from 110 the developed model could be adopted by local authorities as input for strategic 111 territorial planning and monitoring.

112 **2** Materials and methods

113 **2.1** Case study

114 From the analyses of the greenhouses cultivation system in Italy (Table 1), it 115 emerges that Sicily is the region with the greatest percentage and surface of protected 116 cultivation. The spread of the greenhouse cultivation system in Sicily began in the 117 early sixties of the last century thanks to the flexibility and the lightness of plastic 118 films for the covering of crops that allowed the creation of very simple building 119 structures for the production of vegetables. Since the development of protected 120 cultivation took place very quickly, the surface covered by greenhouses between 1960 121 and 1965 reached about 700 ha from almost insignificant values. The amount of crop 122 shelters in Sicily has been increased progressively during 70^s, and it is still in growth.

Among the Sicilian provinces, Ragusa has the highest concentration of protected crops (Table 2) with a covered surface of about 470,000 ha which is nearly 68% of the regional total and is distributed as follows: 58.7 %, for tomato; 33.6%, for other vegetables; and 6.7% for flowers and ornamental plants (ISTAT, 2010). Therefore, the GIS-based model described in this study was applied to the province of Ragusa (Figure 1).



Figure 1 – Italy, Sicily and province of Ragusa

138	Table 1 – Incidence	of greenhouse	cultivation system	in the Italian regions.
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Italian regions	Total cultivated surface (TCS)	Greenhouse (GHS	surface
	[ha]	[ha]	[%]
Piedmont	505,090	45,430	9.0
Valle d'Aosta	34,390	130	0.4
Liguria	58,920	58,340	99.0
Lombardy	498,980	72,530	14.5
Trentino Alto Adige	541,410	4,540	0.8
Veneto	551,920	169,530	30.7
Friuli-Venezia Giulia	94,430	5,890	6.2
Emilia-Romagna	783,910	49,700	6.3
Tuscany	846,500	69,650	8.2
Umbria	354,320	5,560	1.6
Marche	366,110	13,490	3.7
Lazio	666,610	312,410	46.9
Abruzzo	481,040	22,590	4.7
Molise	148,730	1,670	1.1
Campania	479,300	355,100	74.1
Apulia	855,850	125,090	14.6
Basilicata	471,100	45,790	9.7

Calabria	507,200	55,740	11.0			
Sicily	902,430	686,760	76.1			
Sardinia	994,110	64,780	6.5			
 Total	10,142,330	2,164,700	21.3			
 The percentage was calculate as [(GHS/TCS)*100]						

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Table 2 - Greenhouses cultivation areas in the provinces of Sicily (ISTAT 2010).

Province	[ha]
Agrigento	25,410
Caltanissetta	63,868
Catania	11,674
Enna	1,373
Messina	8,241
Palermo	6,867
Ragusa	469,057
Syracuse	81,724
Trapani	18,544
Sicily	686,760

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142 Along the coastal areas of the province of Ragusa, there is a great concentration 143 of tomato cultivation which requires specific features. In detail, tomato, is a warm-144 season vegetable crop, sensitive to frost and killed by freezing temperatures. To 145 properly growth tomato requires a temperature range between 10°-30°C. Plants do not 146 set fruit when night temperatures are consistently below 10°C and are damaged if 147 temperature exceeds 35 °C. Moreover, this cultivation requires high amounts of 148 potassium and calcium. Tomato crops are rather resistant to salinity and cherry-149 tomatoes develop a sweeter taste when grown under moderate salinity. In the selected 150 study area, the most widespread typologies of protected crops are tunnel-greenhouses 151 and A-shaped greenhouses. Tunnel-greenhouses are built with a steel bearing structure 152 and are composed of one semi-circular arch or of more joined modules. Its shaped 153 allows accommodating a larger volume of air inside and provides resistance to rain. As 154 regards A-shaped greenhouses, they traditionally are built with wood bearing structure 155 and their basic structural form is the span-type greenhouses, which has a double-156 sloped roof. Both typologies are covered by plastic films (Figure 2).

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176 In relation to the different types of both building structures and covering films 177 which characterize the protected crops located in the study area, the index was 178 modified by changing *Scr*, ρ , *TK*, *life*. The surface correction factor *Scr* is used in the equation (1) in order to consider more covering materials than that measured on the plan by aerial top views. It was estimated to be 1.12 (*Scr_G*) for A-shaped greenhouses and 1.5 (*Scr_T*) for tunnelgreenhouses. The plastic film density ρ was set to 920 kg m⁻³ or 930 kg m⁻³ in relation to film thickness, i.e., 180 µm or 200 µm. The useful lifetime of plastics film considered was 12 month or 24 months. Finally, the *Ucvc* factor which converts the result in kg ha⁻¹ yr⁻¹ unit was equal to 0.12.

To obtain the yearly APW estimation, two indices one for A-shaped greenhouses
type (PWI_G) and one for tunnel-greenhouses (PWI_T) were multiplied for their covered
areas, respectively.

189 2.3 The GIS-based model for APW computation

190 In this paragraph, a methodology for investigating the location and 191 quantification of APW film is described. To accomplish this goal, a GIS software tool 192 and statistical tools were used. Literature reports several case studies where APW was 193 mapped and estimated by GIS tools (Blanco et al., 2018; Vox et al., 2016). In some 194 research activities carried out in Spain and in Italy, remote sensing technologies have 195 been used both for greenhouse mapping and for APW evaluation (Aguilar et al., 2016; 196 Arcidiacono and Porto, 2010; Lanorte et al., 2017). Other studies compared the results 197 obtained by using GIS-based tool and digital image processing techniques for 198 landscape analysis and for detection of protected cultivation (Arcidiacono and Porto, 199 2012, 2010, 2008; D. Briassoulis et al., 2013; Demetres Briassoulis et al., 2013b; 200 Picuno et al., 2011).

In order to explore the spatial distribution of crop shelters in the study area and identify the major contributors to the generation of plastics waste, the GIS-based model was developed by using Quantum GIS (QGIS), a GIS software tool for collecting, organizing, analysing, and visualizing geographical data.

The GIS-based model was implemented by using data collected from base and thematic maps as well as from digital colour orthophotos and farmer interviews. To be more specific, the following data set was used:

The Regional Technical Map at a scale of 1:10,000, obtained from an aerial flight
 performed in 2008; it is placed in the zone EPGS:3004, Monte Mario/Italy zone 2
 reference system;

- Digital colour orthophotos at a scale of 1:10,000, obtained from an aerial flight
 performed in 2008; they were placed in the EPGS:3004, Monte Mario/Italy zone 2
 reference system and have a pixel ground resolution of 50 cm;
- Satellite color images from Google Earth Pro database, which allow the
- recognition of protected crops in an imagery dated 2017, which is the last

216 available coverage. This image dataset was used in order to analyse the

217 development of the greenhouse coverage in the last 10-year time range.

To compute APW deriving from the plastic covering films the steps reported belowwere performed:

Random selection within the Province of Ragusa of thirty area samples suitable
 for computing the different level of plastic waste production in the whole province
 of Ragusa. Each sample had an average surface of 150 ha, ranging from 143.81
 and 177.3 ha. The number of samples for each municipality was chosen in order
 to cover about 30% of the whole area covered by protected crops, i.e., A-shaped
 greenhouses and tunnel-greenhouses.

- Detection and further polygon extraction of protected crops located in each sample, subdivided into two typologies: A-shaped greenhouses or tunnel-greenhouses. This difference was considered because cultivation surfaces covered by tunnel-greenhouses require a greater amount of plastic films due to the geometry of their bearing structure (Figure 3).
- 231 Implementation of a GIS database with detailed information on covering plastic 232 materials used in the protected crops located in the previous step. The most 233 common covering films used in the study area for protected crops are low density 234 polyethylene films, called LDPE, and ethylene-vinyl acetate copolymer, called 235 EVA. These materials can present different thickness (from 14 μ m to 200 μ m), 236 different average life (seasonal, when they remain in operation 5-6 months; 237 annual, if they stay outdoors for at least 12-14 months; a long duration, if they 238 remain in place for 24 months or more). In this study, given the wide 239 heterogeneity found for the covering films detected in each sample, two different 240 thickness (i.e., 180 µm or 200 µm) and two different life durations (i.e., 12 241 months or 24 months) were considered after having carried out interview to 242 farmers which confirmed their relevant occurrence. Therefore, significant extreme 243 values of 6 months and of 36 months were excluded from the further analyses.

Computation of the plastic film waste index (PWI) with the equation (1) with the aim of quantifying the yearly production of APW deriving from the two types of protected crops, i.e., A-shaped greenhouses and tunnel-greenhouses. Different values of PWI were estimated and spatially analysed in GIS. Different results were obtained by considering the two analysed typologies of protected crops.

- Basic statistic evaluations to compute the yearly amount of plastic film waste
 (APW) production for each sample and for each municipality located in the study
 area.
- Production of thematic maps showing quantity and density of APW, at municipal
 level.

254 **3 Results**

Almost all samples were located close to the coast because of the highest
 concentration of greenhouses in this geographical area (Figure 2)



258 Figure 3 –. A-shaped greenhouses and tunnel-greenhouses located in the study area.

259 Within each sample, the classification of protected crops in two different types,

260 i.e., A-shaped greenhouse and tunnel-greenhouses, was carried out by visual analyses

of digital colour orthophotos (2012) (Table 3). Among the thirty selected samples, 17

showed a higher number of tunnel-greenhouses type than A-shaped greenhouses one.

263
264Table 3 - Cultivation surfaces covered by tunnel-greenhouses and A-shaped greenhouses within the samples
analysed.

Sample ID	Surface sample	T-G area [ha]	G area	T-G [%]	G [%]
1	148.82	6.16	88.4	4.14	59.4
2	146.79	20.15	76.88	13.73	52.37
3	144.06	45.64	38.81	31.68	26.94
4	143.81	18.14	73.44	12.61	51.07
5	146.44	11.51	38.97	7.86	26.61
6	160.53	23.73	40.73	14.78	25.37
7	154.7	17.42	42.46	11.26	27.45
8	159.12	39.84	31.14	25.04	19.57
9	145.12	36.17	17.27	24.92	11.9
10	158.26	47.39	17.58	29.94	11.11
11	145.62	17.07	5.08	11.72	3.49
12	167.45	29.73	45.03	17.75	26.89
13	177.29	38.18	57.19	21.54	32.26
14	148.54	11.51	59.91	7.75	40.33
15	151.4	13.09	32.88	8.65	21.72
16	157.05	21.15	20.04	13.47	12.76
17	155.16	20.7	16.1	13.34	10.38
18	156.76	14.85	16.48	9.47	10.51
19	143.89	12.59	21.67	8.75	15.06
20	143.38	32.75	47.41	22.84	33.07
21	171.57	24.4	7.9	14.22	4.6
22	149.98	23.84	0	15.9	0
23	149.35	10.33	5.94	6.92	3.98
24	149.33	10.08	5.25	6.75	3.52
25	152.87	33.65	0	22.01	0
26	156.22	8.24	10.03	5.27	6.42
27	146.98	46.32	0.09	31.51	0.06
28	160.05	48.72	2.57	30.44	1.61
29	157.29	12.92	0	8.21	0
30	150.84	19.07	2.08	12.64	1.38

T-G: tunnel – greenhouses; G: A-shaped greenhouses

A preliminary result obtained from the application of the GIS-based model is the heat-map reported in Figure 4, which shows the major concentration of A-shaped greenhouses and tunnel-greenhouses in the study area.

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Figure 4-protected crops heat map

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For each type of greenhouses, i.e., tunnel-greenhouses and A-shaped greenhouses,

274	four values of PWI were computed by changing thickness and life duration of the
275	covering material (Table 4).

	<i>PWI</i> [kg ha yr]						
Туре	Tunnel-gre	enhouses	A-shaped G	Greenhouses			
ΤΚ [μ <i>m</i>]	180	200	180	200			
12 [month]	2484.00	2790.00	1854.70	2083.20			
24 [month]	1242.00	1395.00	976.40	1041.60			
Mean	1863.00	2092.00	1415.55	1562.40			
SD	878.23	986.41	621.05	736.52			

277

278 The minimum value of PWI was 976.40 (kg ha⁻¹ yr⁻¹) for A-shaped greenhouses 279 type, for a film of 180 μ m thickness having a life duration of 24 months. The maximum value of PWI was 2484.00 (kg ha⁻¹ yr⁻¹) by considering tunnel-greenhouses type, 200 μ m thickness film and a material life duration of 12 months. Mean values and standard deviation were also evaluated as appear in Table 4.

For each territorial sample, the values of PWI_G and PWI_T were computed in order to obtain the yearly amount of plastic waste production (APW kg yr⁻¹) (Table 5).

285By comparing the APW values, based on same life duration, a variation of about28611% was observed between 180 μm and 200 μm for both tunnel-greenhouses and A-

shaped greenhouses.

288 Table 5- APW evaluation, results obtained by multiplying the four different values of PWI for the corresponding area of protected crops.

		Thickness/life duration							
		[μm/month]							
id	Area	180/12	180/24	200/12	200/24	180/12	180/24	200/12	200/24
	[na]	A	PW Tunnel	-greenhouse	S	AP	W A-shape	ed Greenhou	se
1	148.82	15301.44	7650.72	17186.40	8593.20	163955.50	86313.76	<u>184154.90</u>	92077.44
2	146.79	50052.60	25026.30	56218.50	28109.25	142589.30	75065.63	160156.40	80078.21
3	144.06	113369.80	56684.88	127335.60	63667.80	71980.91	37894.08	80848.99	40424.5
4	143.81	45059.76	22529.88	50610.60	25305.30	136209.20	71706.82	152990.20	76495.1
5	146.44	28590.84	14295.42	32112.90	16056.45	72277.66	38050.31	81182.30	40591.15
6	160.53	58945.32	29472.66	66206.70	33103.35	75541.93	39768.77	84848.74	42424.37
7	154.7	43271.28	21635.64	48601.80	24300.90	78750.56	41457.94	88452.67	44226.34
8	159.12	98962.56	49481.28	111153.60	55576.80	57755.36	30405.10	64870.85	32435.42
9	145.12	89846.28	44923.14	100914.30	50457.15	32030.67	16862.43	35976.86	17988.43
10	158.26	117716.8	58858.38	132218.10	66109.05	32605.63	17165.11	36622.66	18311.33
11	145.62	42401.88	21200.94	47625.30	23812.65	9421.87	4960.112	10582.66	5291.32
12	167.45	73849.32	36924.66	82946.70	41473.35	83517.14	43967.29	93806.50	46903.25
13	177.29	94839.12	47419.56	106522.20	53261.10	106070.30	55840.32	119138.20	59569.10
14	148.54	28590.84	14295.42	32112.90	16056.45	111115.10	58496.12	124804.50	62402.26
15	151.4	32515.56	16257.78	36521.10	18260.55	60982.54	32104.03	68495.62	34247.81
16	157.05	52536.6	26268.30	59008.50	29504.25	37168.19	19567.06	41747.33	20873.66
17	155.16	51418.80	25709.40	57753.00	28876.5	29860.67	15720.04	33539.52	16769.76
18	156.76	36887.40	18443.70	41431.50	20715.75	30565.46	16091.07	34331.14	17165.57
19	143.89	31273.56	15636.78	35126.10	17563.05	40191.35	21158.59	45142.94	22571.47
20	143.38	81351.00	40675.50	91372.50	45686.25	87931.33	46291.12	98764.51	49382.26
21	171.57	60609.60	30304.80	68076.00	34038.00	14652.13	7713.56	16457.28	8228.64
22	149.98	59218.56	29609.28	66513.60	33256.80	0	0	0	0
23	149.35	25659.72	12829.86	28820.70	14410.35	11016.92	5799.81	12374.21	6187.10
24	149.33	25038.72	12519.36	28123.20	14061.60	9737.17	5126.10	10936.80	5468.40
25	152.87	83586.60	41793.30	93883.50	46941.75	0	0	0	0
26	156.22	20468.16	10234.08	22989.60	11494.80	18602.64	9793.29	20894.50	10447.25
27	146.98	115058.90	57529.44	129232.80	64616.40	166.92	87.87	187.48	93.74
28	160.05	121020.50	60510.24	135928.80	67964.40	4766.57	2509.34	5353.82	2676.91
29	157.29	32093.28	16046.64	36046.80	18023.40	0	0	0	0
30	150.84	47369.88	23684.94	53205.30	26602.65	3857.77	2030.91	4333.05	2166.52

291 The computed average values of PWI_G and PWI_T were 1,477 kg ha⁻¹yr⁻¹ and 292 1,978 kg ha⁻¹yr⁻¹, respectively. These amounts were applied to obtain the yearly 293 production of agricultural plastic waste (APW kg yr⁻¹) per municipality (Table 6).

The results demonstrated that Acate was the municipality with the highest amount of APW_G, 467,375 kg yr⁻¹, corresponding to the 37.5 % of the total APW_G deriving from A-shaped greenhouse cultivation system. The highest value of APW_T was found in Vittoria municipality where the computed yearly production is 417,978 kg yr⁻¹, almost the 29.5 % of the APW_T whole amount.

Municipality	Density [kg ha ⁻¹]	APWI _G [kg yr ⁻¹]	APWI _T [kg yr ⁻¹]	Surface area [ha]
Acate	65.58	467,375	200,928	10,190
Chiaramonte Gulfi	0.01	100	100	12,659
Comiso	0.02	100	100	6,501
Giarratana	0.02	100	100	4,335
Ispica	21.32	3,928	236,943	11,297
Modica	4.35	22,564	103,708	29,048
Monterosso Almo	0.02	100	100	5,619
Pozzallo	11.55	3,072	14,279	1,502
Ragusa	10.90	274,838	206,944	44,181
Santa Croce Camerina	68.71	159,717	121,527	4,093
Scicli	9.84	20,437	114,902	13,757
Vittoria	39.28	294,287	417,978	18,135
Total	-	1,246,618	1,417,609	161,317

299 Table 6. Agricultural Plastic Waste (APW) yearly amount.

300

301 The entire amount of APW (APWI_G + APWI_T) was computed for the whole 302 province of Ragusa and reported on thematic GIS maps. Furthermore, two maps 303 describing the quantity and the density, respectively, of plastic waste film yearly 304 production (Figure 5 and 6) were elaborated.





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Figure 5-APW yearly amount in the municipalities of the province of Ragusa.

As clearly highlighted in Figure 5, Acate and Vittoria resulted the municipalities with the greatest amount of APW, i.e., 668,303 (kg yr⁻¹) and 712,265 (kg yr⁻¹), respectively. Whereas, Acate and Santa Croce Camerina municipalities reported the highest density, i.e., 65.58 (kg ha⁻¹) and 68.71 (kg ha⁻¹) (Figure 6).



Figure 6 - APW density in the municipalities of the province of Ragusa.

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The analysis of the achieved results shows that, considering the mean value of PWI, the total amount of plastic waste deriving from covering films of protected cultivation is about 1,7 tons per hectare per year. The computed yearly amounts of APW, APWI_G, and APWI_T per municipality are shown in Figure 7. By taking into account only the municipalities with the highest APW amount, i.e., Acate, Vittoria, Ragusa and Santa Croce di Camerina, APWI_G values resulted higher than APW_T values, except for Vittoria municipality.

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Figure 7- APW total, APW_G deriving from A-shaped greenhouses and APW_T deriving from tunnel-greenhouses computed for each municipality of the province of Ragusa.

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331 **4 Discussion**

332 Through the GIS-model proposed in this study it was possible to compute the 333 APW deriving from greenhouse cultivation system in the whole province of Ragusa, 334 which was chosen for its relevance with regard to the development of protected cultivations. The obtained results concerning the amount and location of APW are 335 336 essential for a better management of collection centres taking into account the existing 337 infrastructures in order to optimize the collection process and reduce CO_2 emissions 338 that is the major responsible for the global warming. During the research activities it 339 was possible to observe that only one collection and recycling centre was located in 340 the study area, in the municipality of Vittoria. Therefore, in view of obtaining new 341 materials from APW and in order to reduce the transport cost for transferring APW to 342 the recycling plants (De Montis, 2014; Osmani and Zhang, 2017), the optimization of 343 the location of new collection centres is required. In this context, the GIS-model 344 proposed in this study could be also used to plan the location of such collection centre 345 by using the heat maps. This could also limit the APW mechanical recycling costs 346 which often is higher than making plastics from virgin material because of the 347 collection, transportation and cleaning costs (Demetres Briassoulis et al., 2013a).

Furthermore, the application of the GIS-based model to the study area made it possible to monitor at a municipality scale the state of application of the territorial 350 policies aiming at the limitation of the environmental impact due to greenhouse 351 cultivation system. The results of the research study showed that despite the 352 indications of the Coastal Area Plan (CAP) contained in the Territorial Plan of 353 Coordination of the Ragusa province (Country Council of Territory and Environment, 354 2004), the major part of protected crops is localized along coastline (Figure 4). In the 355 study area considered for the GIS-based model application, the CAP had the aim of a 356 'reorganization of the coastal use' concerning agricultural activities, tourism, 357 infrastructures, urbanization, etc., in order to reduce the anthropic load of this zone and 358 allows the presence of ecological corridors in the coastal system. For a sustainable 359 growth of the territory and assuring landscape quality, the requalification actions 360 foreseen the displacement of greenhouses from coastal to rural areas. The CAP of the 361 province of Ragusa directives were disregarded because protected crops are still 362 concentrated in the coastal area. This result confirms the reluctance of farmers to move their agricultural activity far from the coast, probably because vegetable crops, 363 364 especially tomatoes, suffer from the cold climate. So, this study confirms again what 365 stated by Arcidiacono and Porto (2010) with regard the need of a policy action for the 366 identification of new areas of agricultural value where greenhouse cultivation system 367 could be moved as well as for providing incentives to farmers for the construction of 368 new greenhouses far from the coasts. Public financial aids to farmers should be 369 increased for both new land acquisition and installation of heating systems for 370 greenhouses. Currently, in Sicily the PSR 2014/2020 supports the investments in 371 agricultural sector ("Sottomisura 4.1") and aids farmers in order to introduce 372 technological innovations. However, the contribute for the renovation of greenhouse 373 system is too low and quite insufficient to delocalize protected cultivation far from the 374 coast. Currently, farmers are reluctant to move greenhouses from the coast to inner 375 areas characterized by less favourable climate conditions because of the higher cost 376 required to heat greenhouses. Therefore, technological innovations should be 377 financially supported in order to improve the development of new heating systems for 378 greenhouses.

As demonstrated by applying the GIS-model, most protected crops are tunnelgreenhouses which are structures built with modern construction systems, replacing traditional greenhouses. This means a major consumption of plastic materials for the same quantity of covered surface, due to the greater slope of tunnel-greenhouse typologies, as reported in Table 4. In future the use of newer generation of biopolymers (plastics made from biomass sources materials) as covering films, currently used for mulching (Kasirajan and Ngouajio, 2012), could represent an alternative solution to cope with concerns related to agricultural plastic use. Meanwhile, the method proposed in this study could be useful to compute density and spread of these tunnel – greenhouses in order to make policymakers able to evaluate the financial aid for farmer to replace conventional covering films with more sustainable ones.

391 Finally, the research study reported in this paper is in line with the Waste 392 Framework Directive (WFD) of European Union (Directive 2008/98/EC) that provides 393 correct procedures for collection, disposal and recycling of post-consumption plastics 394 in order to reduce the environmental effects of the use of plastics in agriculture. More 395 specifically, Waste Management Plans (WMP), that is an obligation of EU Member 396 States, must establishes the objectives to be achieved, to formulate strategies and to 397 identify the implementation means to improve protection of environment and human 398 health and to reduce impacts of the waste production and management. Since EU 399 Member States can ask the regional or local authorities to put forward WMP on 400 regional or local base, the GIS-based model proposed in this study could allow local 401 authorities to manage APW deriving from greenhouse cultivation system.

402 **5** Conclusions

In this study, a GIS- based model to locate and quantify the yearly amount of
APW coming from greenhouses cultivation system was developed and applied in the
province of Ragusa.

406 The index PWI to determine APW amount was chosen from literature and 407 applied to obtain heat maps related to covering plastic films. Then, by taking into 408 account different thickness, lifetime, and density of the covering films of the 409 greenhouses within the considered samples, the index was computed and ranged 410 between 976 kg ha⁻¹yr⁻¹ and, 2,484 kg ha⁻¹yr⁻¹.

The achieved results showed that the highest density of A-shaped greenhouses and tunnels-greenhouses is located nearby the coastline. Furthermore, the results obtained by the development the GIS-based model could be useful at a regional level since provide relevant information for the analysis of the environmental impact due to transportation of APW to collection centres, recycling industries or landfills located in the neighbouring of the study area. By using the GIS-model proposed in this research study local administrators could take advantage of a suitable tool for monitoring land consumption and putting forward adequate corrective actions to achieve the planned objectives and improve the sustainable disposal management of covering plastic films. In this context, the results of the study highlighted that the guidelines of the Territorial Plan of the Province of Ragusa were disregarded.

422 Moreover, from an economic point of view, if plastic materials are not recovered 423 after their use, the European Commission Directives purpose to transform Europe into 424 a more circular and resource efficient economy would be disregarded.

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