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NEW SECONDARY MATERIALS FROM RECYCLED AGRICULTURAL PLASTIC FILMS

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Abstract: *The extensive and expanding use of plastic material in the Italian agriculture for several diverse application results in increased accumulation of plastic waste in rural areas. The current practices adopted by Farmers consist, unfortunately, of a mismanagement of the plastic material that is abandoned or buried in open fields or burnt in a not controlled way, with heavy environmental consequences and a loss of material and energy.*

In the present paper, an analysis of the most technical efficient and economically feasible solutions for the management of agricultural plastic waste is given. These solutions represent main results of the European Project "Labelagriwaste" and they enable the analysis and planning of agricultural plastic waste fluxes, together with the possibility to investigate different development scenarios and to consider new planning strategies for the management of agricultural plastic waste.

Key words: *agricultural plastic materials, plastic material properties, plastic waste management, mechanical recycling*

1. INTRODUCTION

The territorial management and the issues related with the evolution of the study and planning experience cannot leave out to consider and investigate the environmental and landscape aspects related or induced by agricultural, forestry and agro-food activities [12, 23, 26]. Sludge and waste that come from agricultural and agro-food sectors could be also considered when strategic planning of the territory if adequate construction for their collection and disposal is foreseen.

Agricultural wastes are many and different, from livestock slurry to pruning residues, from parts of mechanical means to by-products from agro-industries, from agrochemical products to plastic materials. Regarding the last category, post-consumed plastic waste, it should be noted that the results obtained in agricultural productivity, thanks to the increasingly widespread use of plastic materials, especially in protected crops, are appreciable both from the economic and productive point of view. In fact, plastic films, characterized by low cost, ease of installation, low labor demand, lightness, ability to save energy and water, reduction of agrochemical consumption, etc., replaced other traditional materials, such as glass and paper to cover greenhouses or straw mulching for soil [8], significantly influencing the quality of the production and marketing (packaging, transport, storage and sale) of agro-food products with a positive impact on farmers' income.

The continuous innovation in polymer technology and plastic production helps to explain that, since 1950, plastic production has increased on an average of almost 10% every year on a global basis. In order to enable better production conditions and higher yields wide range of conventional polymers, such as PE, PVC and EVA, have been used in agriculture as greenhouse covering materials and as mulching materials.

The world consumption of agricultural plastics amounts yearly to 6.5 million tons; the official statistics suggest that they comprise less than 4% of the total plastics consumption in USA and 2% in Europe [15, 27]. Countries with the highest consumption of plastics are Mediterranean countries (Italy, Spain and France). Specifically, Italian agriculture absorbs about the 3% of the produced plastic materials, about 380.000 tons, the majority of which are films, nets, pipes and containers of various shapes and sizes (Table 1).

It is estimated that, currently, Italian agriculture generates 240,000 tons of plastic waste per year (Table 2) that causes severe environmental risk, considering that, at the end of their useful life, they are often poorly managed and disposed in different way from that contemplated by the Italian law in force.

Therefore, adequate and rational plans for the collection and disposal are needed. In the same way, there is a need for establishment of an appropriate traceability system for the agricultural plastic chain, especially for the regions characterized by intensive agriculture [3, 11, 12, 20, 22, 28].

Table 1: Main agricultural application of plastic materials (*Source*: CIPE, 2006).

AGRICULTURAL APPLICATION	Consumed (t/year)	PRODUCED EFFECT
FILMS (Greenhouse and tunnel, Low tunnel, Mulching, Nursery films, Direct covering, Covering vineyards and orchards)	133,000.00	• protection crops by meteorological phenomena, • control and climatization of the inside environment to obtain increased yields, production of early fruits and late harvest; • reduction of herbicide and pesticide; • frost protection and water conservation; • floating mulch; • soil solarization.
NETS	5,300.00	• protection from sun radiation, hail, wind, snow, or strong rainfall in fruit-farming and ornamentals; • shading nets also for greenhouse applications during the summer, cooling the inside microclimate;. • protection against virus-vector insects and birds; • harvesting of small fruits (olives, almonds) and post-harvesting operations (collecting of cut flowers and drying of fruits); • shading mushroom-beds; • shading of shelters for cattle breeding
PIPING, IRRIGATION /DRAINAGE	138,000.00	• water reservoir; • channel lining; • irrigation tapes and pipes; • drainage pipes; • micro-irrigation; • drippers.
PACKAGING	50,000.00	• fertilizer sacks; • agrochemical bottles; • containers; • tanks for liquid storage; • crates.
OTHER	55,000.00	• silage films; • fumigation films; • bale twines; • bale wraps; • nursery pots; • pots for ornamental plants and flowers; • soilless culture substrate; • strings and ropes.

Table 2 Estimated quantities of agricultural plastic waste per year in Italy

Agricultural Application	Covered surface	Consumed plastics	Lifetime	Produced waste
	ha	t	months	t/year
Greenhouses and large tunnels films	26,000.00	57,000.00	36	19,000.00
Low tunnel covering films	27,000.00	30,300.00	12	30,300.00
Mulching films	90,000.00	43,250.00	12	43,250.00
Direct Covering	12,000.00	2,500.00		
Nets		5,300.00	96.00	663.00
Silage film, bale wrap film		8,500.00	12	8,500.00
Micro irrigation systems	113,000.00	130,000.00	24	65,000.00
PP twine for hay and straw		10,000.00	12	10,000.00
Fertilizers sacks		12,000.00	12	12,000.00
Pesticide cans		2,500.00	12	2,500.00
Semi rigid sheet tanks, pots, crates, packaging fresh production other (pipes for drainage, application for mushrooms, tobacco, cattle, etc)		2,000.00 10,000.00 8,000.00 17,000.00 32,000.00 11,000.00 **80,000.00**	6 - 36	50,000.00
Total		**381,000.00**		**241,213.00**

2. Management of agricultural plastic waste

2.1. Environmental impact on rural territory

Agricultural plastic wastes represent an environmental and economic problem [23] since yearly they generate a flow that doesn't often follow a rational treatment process [21]. In fact in many cases, Italian farmers dispose plastic waste both forgetting the community and environmental interests and ignoring the national legislation in force.

The Table 3 shows some usual common practices for the agricultural plastic waste disposal and their negative consequences [12].

From the economic point of view, these practices determine a non-recovery of post-consumer plastics, which results in a considerable dissipation of energy and material.

Table 3: Common agricultural waste disposal schemes.

PRACTICES	CONSEQUENCES
Abandonment in the fields, along waterways or landfills	• severe and diffuse pollution and degradation to the landscape and environment, damaged (vulnerable) areas that are very often characterized by natural beauty and attractive tourist sites; • risk for domestic and wild animals; • obstruction to the natural water flow; • exhaustion of landfills causing environmental and economic impacts.
Burying in the files	• qualitative degradation of the soil; • irreversible contamination of the soil; • potential threat for the safety and quality of food produced on these areas.
Burning in the open field and in uncontrolled sites	• release of harmful substances, such as CO_2, CO, H_2S, SO_2, NH_3 and dioxin, in higher quantity per mass of material burned than the emissions from controlled incineration (e.g., 20 times as for dioxin; 40 times as for particulate matter, Travis and Nixon, 1991) due to inefficiencies of open combustion. In particular, plastic burning produces large CO_2 emissions (about 3,0 Kg of CO_2 per Kg of Polyethylene) therefore, if incineration is uncontrolled, this quantity is completely introduced in the atmosphere with the well-known negative consequences without any exploitation of energy or heat production; • release of combustion residues harmful to human and animal health through direct exposure - inhalation or dermal contact - or indirect - ingestion of plants or animals food contaminated, as well as polluting the soil and groundwater.

2.2. Post-consumption plastic waste

Generally, the European legislation on waste management is aimed at post-consumer waste from end-of-life products such as packaging, automotive, electric and electronic equipment, while a few countries, including Italy, have the legislation on agricultural waste management. Nevertheless, in Italy only a part of agricultural plastic waste is collected, transported and recovered in a controlled way by the “PolieCo” [11], the “Italian Consortium for the recycling of the PE materials”, except PE packaging, established by law in 1997. As part of their obligation to a sustainable agriculture, the plastic manufacturers, distributors and farmers are urged to ensure the safe disposal of agricultural plastic waste.

Agricultural plastic waste, such as silage films or greenhouse films, is a good input for mechanical recycling as it is made from a limited range of plastics, mostly polyolefins but the problem with these materials is that they are different in their properties. Recycling process of the silage film (as in UK) is cheaper because material is clean enough or is easily cleanable. Recycling of greenhouse films is more expensive because they are contaminated not only by plant material but mainly by particles of chemicals (pesticides and fertilizers) and particles of soil. Problem in recycling is when the plastic is mixed with recycle ferrous material (rings passes ties and metal spikes) as in the case of films and nets for covering vineyards and orchards. The situation worsens because the recycling process becomes more difficult and costly, since, in addition to the normal phases of cleaning and washing, the plastic waste must be previously separated from other foreign materials.

Unfortunately, in the year 2010 (as happened in the last 7 years), only 34% of the total post-consumption agricultural PE was recycled in Italy [16], according to the Italian Consortium “PolieCo”, a small amount if compared to Norway that manages, recovers and recycles virtually 100% of agricultural plastic waste. The low percentage of recycled material in Italy is due to the illegal trade of APW to other Countries, principally China. In 2012 year, the Italian financial police stopped a merchant-ship, containing 750,000 containers, that was leaving for China [16].

Solving the problem of waste agricultural plastic is possible applying some of the different strategies, such as:

a) increasing the lifetime duration of the materials by means of additives and proper applications and installation,
b) reducing the material thickness,
c) introducing and promoting the use of bio-based materials as alternative to the traditional plastic films produced with fossil raw resources,
d) transforming the plastic waste in resources

In reference to the biodegradable materials, biodegradable transparent films for covering the low tunnels and black or green films for mulching, based on maize starch as raw material (Mater-Bi) and biodegradable polyesters are nowadays available [2]. Unfortunately, a very small percent of the Italian agricultural land (4,000 hectares) is covered with biodegradable mulching films of Mater Bi used for crops with a cycle between 60 days and 6 months. Probably, the low diffusion of this material is due to the current price that is still higher than the LDPE films, with the same thickness and productive performances.

If the costs of plastic film collection, disposal and recycling process are taken into account by farmers, the price of the bio-based are comparable to the traditional ones [21].

2.3. Transforming the plastic waste in resources

2.3.1. Technological solutions for rational disposal

The main aim of the strategy to be pursued for optimal collection and disposal of waste is, in general, its transformation into resources that is in “secondary raw materials”. The strategy followed by the European Union (91/156/EC, 91/689/EC, 94/62/EC) was implemented in Italy by Legislative Decree No. 22 of 5 February 1997 (better known as "Ronchi" Decree), and subsequently repealed by Legislative Decree No. 152 of April 3, 2006 (and its upgraded), "environmental Regulations" in force on waste. According to them, waste management is an activity of public interest that must be carried out avoiding any damage to the environment and public health. At the same time, they preserve the hierarchical structure to follow in order to reduce the adverse impact of the agricultural plastic waste [8].

The management system must necessarily be rational and, above all, ensure an effective and lasting solution of the problem, contributing to the evolution in the waste management that, although slowly, is happening in Italy. This is "necessary but inevitable evil" that points to the enhancement of "secondary raw material" of the waste resource for a sustainable solution under the economic, social and environmental aspects [9, 11]. Aspects related to a rationalization of collection, transport, storage and final disposal of agricultural plastic waste have been the subject of the Scientific Research Project "Labelling agricultural plastic waste for valorizing the waste stream - Labelagriwaste", funded by the European Commission (Contract No. COLL-CT-2005-516256). Project results showed that the main options, able to ensure compliance with environmental and economic constraints, for the final disposal of post-consumed agricultural plastics, are mechanical recycling and energy recovery [4, 6, 7, 11, 18, 28].

2.3.2. Mechanical recycling

Mechanical recycling is the reprocessing of plastic waste, rigid or flexible, to produce raw materials to be used in the construction of new products. The waste is subjected to washing, grinding, milling and subsequently drying.

The different types of structures and use during the lifetime of the commercial PE strongly influence the recycling behavior of these materials. Indeed the presence of branching changes the degradation kinetic and then the final properties of the recycled material after repetitive processing steps. This behavior is particularly important for those plastic materials that are subjected not only to thermo-mechanical degradation during reprocessing operations, but also to some other types of degradation during their lifetime. Indeed, photo-oxidation or other types of degradation induce different structural and, as a consequence, morphological changes depending on the structure of the polyethylene [7]. The structure of the reclaimed LDPE coming from agricultural films, can be modified because the degradation is usually severe. For example, a dramatic reduction of the elongation at break is possible with the increasing of the exposure time; so, after about one year the ductile polymers become fragile. Of course these results cannot be generalized because they depend on the amount of solar energy, mostly UV radiation, absorbed by the polymer. The level of degradation, and then the level of structural and morphological modification (as remarkable amounts of oxygenated groups as result of photo-oxidative mechanisms) undergone by the polymer during its lifetime, determine the properties of the secondary material [17]. The main modifications are the increasing of the value of the melt index and a decreasing of the molecular weight; this latter and the presence of less deformable structures reduce the elongation at the break and this premature breaking can decrease the tensile stress [7]. The important feature to point out is that even if monopolymer blends are made up of two materials with the same chemical composition, but with some differences in molecular weight and chain structure (it is the case of the virgin/recycled homopolymer blends) because the eventual presence of the "alien" chemical group, present in recycled parts owing to photooxidative degradation, can alter properties, making the blend not suitable [18]. PE recovered from agricultural uses is a typical example. In fact this material contains an oxygenated group as a result of photooxidation, crosslinks, additives and stabilisers. Moreover, these films include in their formulation other polymers than ethylene such as vinyl acetate (in case of EVA films). Differences in the rheological properties of the virgin PE and of the recycled PE are also due to the presence of additives that are typically used in films for agriculture. In this case it is clear that even if the two starting materials are thought to be the same PE, they may be significantly different and give rise to incompatible blends [18]. It can be concluded that the final properties of the blend depend on the amount of degraded polymer but mainly on the extent of degradation. When degradation of the polymer is limited, good properties can be achieved, but if the degradation effects are more pronounced, there is a general worsening of all the properties [5, 14, 15, 19, 24, 25].

Depending on the characteristics of APW (homogeneity, cleaning and deterioration), the resulting material can be recycled, giving rise to two types of products: a granule of a higher category, such as to, subsequently, come in turn reused for the realization of new film [10, 13], albeit to a lesser level of technological applications; or when the APW does not have high quality properties, the extrusion process is performed in order to produce solid section profiles (rectangular, circular, etc.) which can be used as support structures, being characterized by properties and workability similar to wood.

Therefore, further investigation should be made on blends, paying particular attention to the formulation of the compounds to be recycled, both on the share of waste specimens in the mixture and on specific additives, in order to optimize and improve the mechanical and spectral properties of new recycled materials.

2.3.3. Energy recovery

For waste fractions that do not allow an economically optimal material recovery, such as recycling, energy recovery by combustion is probably the only alternative to landfill disposal, thank to its high calorific value, similar to oil, from which it originates. This is especially true when dealing with high calorific value waste fractions and low biodegradability, such as plastics (Table 4). Highly degraded or soil contaminated plastics, that cannot be mechanically recycled can be successfully used as an alternative fuel in power plants or in cement factories. In energy recovery the plastic behaves as a fuel: 1 ton of plastic gives off as much energy as 1 ton of oil [1].

Agricultural plastic waste could make an ideal replacement for regular fuels. By using plastic as fuel, other primary energy sources, such as gas, oil or coal, can be conserved. This therefore fulfills the basic idea of recycling, i.e., to conserve raw materials and reduce waste.

Of course, to be economically viable and technically valid, some conditions must be fulfilled, which respectively are low costs of storage, transportation and separation of materials, and material devoid of high levels of impurities (earth, moisture, chlorine, sulfur, heavy metals, etc.) or otherwise their values should be present within limits set by the plants.

Table 4: Caloric values of plastic materials, compounds, products and fuels [1].

Materials, compounds, fuels	Caloric value, MJ kg^{-1}
Polyethylene	46.0
Polystyrene	46.0
Polyvinyl chloride	18.9
Paper and wood	16.0-16.8
Methanol	22.7
Natural gas	53.4
Propane	50.0
Kerosene	46.5
Gasoline	45.9
Gas oil	45.6
Anthracite	29.7
Charcoal	33.7

Also in this case it is possible to distinguish between two classes, based on the characteristics of the waste. A category, consisting of waste agricultural plastic that does not need to be mixed with other alternative solid fuels and that can be used as fuel in cement plants, after being subjected to treatments to prevent impurities that could affect the performance of the clinker, as well as to prevent the release of harmful substances in the flue gas and in the atmosphere. Alternatively, in the absence of better solutions, the waste may be sent to cogeneration plant of electricity with waste heat recovery, in combination with other waste categories. Unfortunately, in Italy, for energy recovery only plastic materials from Urban Solid Waste are used while APW also is not considered.

2.3.4. Landfill

Agricultural plastic waste that cannot be subject to the above-mentioned disposal techniques (non-usable waste resulting from recycling processes, waste of energy recovery processes, mulching films with large amount of soil residues, etc.), will be destined for final disposal in landfills.

3. CONCLUSIONS

Agricultural plastics have been used worldwide in the last 50 years thanks to numerous properties such as versatility, lightness and low cost. In agriculture, the use of plastic materials results with many and different benefits such as increasing of the yield and the quality of production and a more efficient use of agricultural land. Consequently, a large amount of agricultural plastics waste is produced and, if not properly collected, treated and recycled, pollutes the rural areas and releases harmful substances in the environment. Even worse, when APW are illegally burned, many pollutants can enter the food system at the base of the food chain.

Therefore, the strategies to reduce the environmental effects of the plastics use in agriculture are: the increase of the lifetime duration of the materials by means of additives and proper applications and installation; the reduction of the material thickness; the introduction and promotion of bio-based materials and, a correct procedure for the collection, disposal and recycling of post-consumption plastics. For this last option, all stakeholders of the agricultural plastic chain should be more awarded and involved in the operations of production, use, collection and storage, according the Italian legislation in force. In particular, rewarding mechanisms should be, for producing companies, able to introduce traceability systems of materials in order to make more rational and efficient the collection-transport and disposal system.

Subsidies and facilities (e.g. logistic, equipment for collection, storage and recycling, economic and legal advices) should be programmed for farmers and/or associations of farmers in order to motivate them to adopt suitable and right collection practice.

Finally, the activity of the National PolieCo Consortium should be further propagated and spread to all Italian agricultural enterprises (commercial farms), the small and isolated ones too.

It can be concluded that there are several and significant aspects to improve and guarantee a suitable management system from collection and transport to a correct disposal, regardless the waste typology and consisting, above all, of mechanical recycling and energy recovery, that transforms agricultural plastic waste into a secondary raw material.

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