Report on use of plastics in agriculture

Wageningen, May 28th, 2019

Schuttelaar & partners

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This literature study on the use of plastics in agriculture was commissioned by Emese Brósz on behalf of the SAI working group.

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Introduction

The past decades have seen the rapid increase in the production and consumption of plastics and these numbers are still increasing. In 2017, 348 million tonnes of plastics were produced worldwide (PlasticsEurope 2018). To put this in perspective, all the people living on the planet in 2005 together weigh approximately 287 million tonnes (Walpole, Prieto-Merino et al. 2012). Asia is the largest producer of plastics (50.1%) followed by Europe (18.5%) and North American Free Trade Agreement-countries (NAFTA) (17.7%). Figure 1 shows the global annual plastic production in million tonnes from 1950 until 2015.

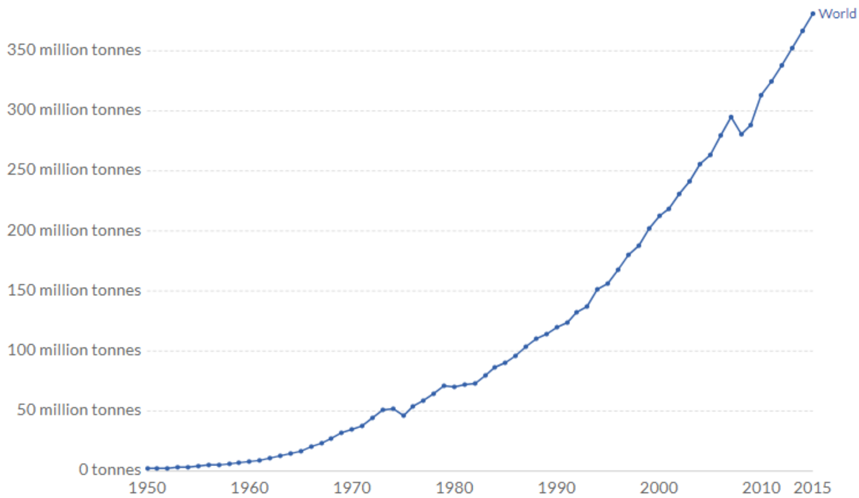

Figure 1 Global plastics production. Annual global polymer resin and fibre production (plastic production), measured in metric tonnes per year. Retrieved from: (Geyer, Jambeck et al. 2017)

The amount of plastics used in agriculture worldwide was 2% of the global production in 2010 (Vox, Loisi et al. 2016). If the plastic use in agriculture still accounts for 2% of the global production, which is indicated by Picuno (2014) as well, 6.96 million tonnes of plastic were used in 2017 in the agricultural sector.

Materials and usage

The most important applications of plastics in agriculture identified by PlasticsEurope (PlasticsEurope n.d.) are greenhouses, tunnels, mulching, plastic reservoirs and irrigation systems, silage and other plastic applications (crates for crop collecting, handling and transport; components for irrigation systems like fittings and spray cones; tapes that help hold the aerial parts of the plants in the greenhouses, or even nets to shade the interior of the greenhouses to reduce the effects of hail). Sarcasascia-Mugnoza et al. (2011) provided a more comprehensive overview of applications of plastic in agriculture. The applications are shown in figure 2.

Protected cultivation films:	**Nets:**	**Packaging:**
• Greenhouse and tunnel • Low tunnel • Mulching • Nursery films • Direct covering • Covering vineyards and orchards	• Anti-hail • Anti-bird • Wind breaking • Shading • Nets for olives and nut picking **Piping, irrigation /drainage**: • Water reservoir • Channel lining • Irrigation tapes and pipes • Drainage pipes • Microirrigation • Drippers	• Fertilizer sacks • Agrochemical cans • Containers • Tanks for liquid storage • Crates **Other:** • Silage films • Fumigation films • Bale twines • Bale wraps • Nursery pots • Strings and ropes

Figure 2 Applications of plastics in agriculture. Retrieved from (Scarascia-Mugnozza, Sica et al. 2011)

The identified applications by PlasticEurope (n.d.) and Sarcascia-Mugnozza et al. (2011) are used as starting point for the literature research and hence the applications focused on. The applications described are in order of magnitude, starting with the application(s) used in the largest quantity. Furthermore, the materials used are described briefly for every application. A detailed description of the most traditional polymers used in agriculture is provided in annex 2.

Protected cultivation films

The group of protected cultivation films,or agricultural films, is by far the largest group of plastics used in agriculture. In 2012, the global use of agricultural films[1] accounted for 4.4 million tonnes and is expected to grow to 7.4 million tonnes in 2019 (Sintim and Flury 2017). The use of protected films in agriculture is also referred to as plasticulture. The United States Department of Agriculture defined this as "*the use of plastics in crop production and*

[1] The group consists of films used for greenhouses, mulching, and silage.

cultivation protection, including plastic film mulches, row covers, tunnels and greenhouses". In general, the key benefits of plasticulture include an increase in crop yield, saving of other agricultural inputs such as agrochemicals and fertilisers and the saving of water.

According to Espi et al. (2006) the most important agricultural applications of plastic films are mulching, greenhouses and walk-in tunnels (high tunnels), and low tunnel covers. Each application is described below.

Mulching

Mulches are defined by Kader et al. (2017) as materials that are applied to soil surface, as opposed to materials that are incorporated into the soil profile. Mulch is a layer of material(s) that covers the soil surface, and mulching is a water conservation technique that increases water infiltration into the soil, retards soil erosion and reduces surface runoff. Mulching is an effective method of manipulating the crop growing environment to increase crop yield and improve the product quality by controlling soil temperature, retaining soil moisture and reducing soil evaporation. Plastic mulches are primarily used to protect seedlings and shoots through insulation and evaporation prevention, thus maintaining or slightly increasing soil temperature and humidity. Furthermore, the application of plastic covers is known to reduce weed and pest pressure. Often reported benefits are minimisation of the development time for seed and fruit, yield increase, the prevention of soil erosion and weed growth and consequently reduction of herbicide and fertiliser use (Espi, Salmeron et al. 2006, Scarascia-Mugnozza, Sica et al. 2011). Plastic mulch films consist mostly of low-density and linear low-density polyethylene, which do not readily biodegrade. As a result, these polyethylene-based mulches must be retrieved and disposed after usage. Agricultural plastic mulch films are often contaminated with soil, and therefore are not accepted by many recycling facilities. This limits disposal options for polyethylene mulches, which often must be landfilled.

It is reported that 1 million tonnes of mulch film are used worldwide every year in agriculture (Halley, Rutgers et al. 2001). However, Liu et al. (2014) estimated the amount used in China alone already at 1.25 million tons in 2011 (Liu, He et al. 2014). Moreover, Sintim and Flury (2017)estimated that plastic mulch accounted for over 40% of the total plastic films used in agriculture in 2012. If this still applies, roughly 2.75 million tonnes[2] of mulch film were used in 2017 in the agricultural sector.

Greenhouses and high tunnels

The terms greenhouses and high tunnels are used interchangeably in the context of plastics, but they are not the same.

[2] Based on 6.96 million tonnes of plastics used in the agricultural sector in 2017 as described in the introduction.

A greenhouse is generally defined as a large structure in which it is possible to stand and work. The main difference between a greenhouse and a high-tunnel is that in a greenhouse it is possible to control the environment, while this is not the case in a high-tunnel due to their open structure (Espi, Salmeron et al. 2006). The lifetime of greenhouse plastics varies between 6-45 months, depending on the photo stabilizers[3] used, the geographic location, the weather and the use of pesticides.

A high tunnel (hoop house) is defined as a non-permanent, non-taxable structure which is vented manually by rolling up the sides. A high tunnel is simply a particular form of construction and many varieties can be found all over the world. Lamont (2009) describes high tunnels '*in their purest form*': high tunnels have a pipe or other framework covered by a single layer of greenhouse-grade 4 to 6 mil plastic and they have no electrical service, automated heating or ventilation system. In the temperate parts of the world, high tunnels are used to extend the growing season by creating a warmer environment for crop growth, while in tropical regions of the world, high tunnels also extend the growing season by permitting crop production during the rainy or monsoon seasons. Most crops grown in high tunnels use plastic mulch on the ground and drip irrigation to help control disease pressure and warm up the soil. Tunnels are covered with a single layer of plastic, or in some instances, a double layer of plastic is sandwiched between roping material but is not inflated.

The estimated area of protected crops (plastic greenhouse and high tunnels) in different regions is shown in table 1. Plastic greenhouses and high tunnels are mainly located in two geographical areas: Asia (China, Japan and Korea) with almost 80% and the Mediterranean Basin with 15% of the worlds' greenhouse covered area. The area covered by greenhouses has been steadily increasing at a rate of 20% per year during the period 1992-2002 (Espi, Salmeron et al. 2006). Development in Europe is very weak, but Africa and the Middle East are growing at 15-20% annually. The amount of plastic films used in China has grown from 4200 ha in 1981 to 1,250,000 ha in 2002 (30% per year).The volume of plastic films used for this application would thus be about 1,000,000 tonnes/year (Espi, Salmeron et al. 2006). The huge differences in the numbers - 440,000 in table 1 and 1,250,000 described by Espi et al. (2006) – can be explained due to the unclarity of the definitions of agricultural films, greenhouses, tunnels and plasticulture[4].

[3] Photostability is the stability against photochemical change. Photostabilizers are organic compounds that help to prevent UV filters from losing their effectiveness in sunlight.
[4] For more information, please see the reading guide in annex 1.

Table 1 Estimated area (ha) of protected crops (plastic greenhouse and high tunnels) by region worldwide. Retrieved from: (Lamont 2009)

Region	Area (ha)
Asia	440,000
Mediterranean	97,000
Africa + Middle East	17,000
Europe[5]	16,700
Americas	15,600
Total	586,300

The main crops cultivated in greenhouses and high tunnels are tomatoes, cucumbers, melons, sweet peppers, lettuce and strawberry.

Low tunnels

A low tunnel is a structure built just high enough to cover the canopy of the plant. The films that are used, are usually thinner compared to high tunnels and the plastics have a shorter lifespan. The plastics are usually used for less than one agricultural campaign (6-8 months). The polymers most frequently used are EVA or EBA copolymers, due to their transparency, clarity and thermal insulating effects.

The area covered with low tunnels has been very stable during the last decade, except for China, which has had an annual growth rate of 15% during the last decade. In the rest of the world the stagnation of this application is surprising but can be explained by a splitting of the market. On the one hand, one part of the market is centred in modernized greenhouses to cover parts of the market demanding products of controlled quality. On the other hand, another part of the market is centred around a tendency to control costs using cheap techniques like mulching. The small tunnel, of intermediate cost, is losing ground to the other two alternatives. The market volume of small tunnels is estimated to be 170,000 tonnes of plastic per year (Espi, Salmeron et al. 2006).

Other

Silage

Storing silage in wrapped bales is a very popular technique in many countries, since it offers advantages over hay production, such as more flexible harvest dates, less weather dependency and a greater flexibility in ration formulation (Bisaglia, Tabacco et al. 2011). Currently, there

[5] excludes European countries on the Mediterranean Sea

are generally two types of bale-wrapping systems. (1) Individual, in which each bale is wrapped as a completely sealed, stand-alone unit or silo or (2) in-line where bales are positioned end to end with PE-film wrap applied around the circumferential surface of large-round bales. Next to bale-wrapping, silage of piles of grass and pulp from sugar beets is used in order to store and fermentate the product after harvest. After harvest, sugar beets can be temporarily stored in a silage pile covered by plastic to protect the beets against rain. The use of plastics for silage is higher in the north of Europe compared to the south, whereas in South Europe more plastics are used for greenhouses, tunnels, and irrigation pipes. The literature search did not result in data of this application on tonnes plastic used or volume of silage covered worldwide or for Europe. In Italy in 2005 silage was about 3% of the total agricultural plastic use (Scarascia-Mugnozza, Sica et al. 2011).

Nets

Castellano *et al.* (2008) propose the following definition of plastic nets: a plastic net is a product made of plastic threads connected with each other, in a woven or knitted way forming a regular porous geometric structure and allowing fluids to go through. Plastic nets are widely used in various agricultural applications such as protection from hail, wind, snow or strong rainfall in fruit-farming and ornamentals, shading nets for greenhouses and nets moderately modifying the microenvironment around a crop. Moreover, nets for the protection against virus-vector insects and birds, as well as for harvesting and post-harvesting practices (of small fruits, flowers) are often used. In addition, nets are used for shading (mushroom-beds, ginseng, cattle etc.) (Castellano, Mugnozza et al. 2008). The most widely used raw material for agricultural nets is high density polyethylene (HDPE). Polypropylene (PP) is also used as raw material for nets, mostly to produce non-woven layers.

According to Castellano et al. (2008) it is not possible to determine the European consumption of agricultural nets because there is no data available from agricultural and manufacturers associations at a European level. Moreover, the net producers are not able to define the consumption of agricultural nets, because a part of their production is sold for non-agricultural purposes such as shading nets for car parking, permeable coverings of scaffoldings, construction of provisional fences and anti-insects nets for windows. However, in Italy, the estimated consumption of HDPE for agriculture net production is 5.300 ton per year, while the total consumption in agriculture of HDPE is 30.000 ton per year. The total agricultural net production is thus approximately 17% for Italy (Scarascia-Mugnozza, Sica et al. 2011).

Piping, irrigation and drainage, and packaging

According to literature, piping, irrigation and drainage, and packaging are used in agriculture. However, the literature research did not result in data quantifying the amount of plastics used in these applications globally or in specific regions. A possible explanation could be like the explanation of why there is no data available quantifying the use of nets in agriculture: the products can be sold for non-agricultural purposes as well. When zooming in on the global use of plastics, packaging is a separate category and accounts for 35-45% of the total plastic production worldwide (Beckman 2018). The applications of plastic packaging for agriculture are however not disaggregated.

Trends

Based on this literature review, the following trends can be discerned:

Use of plastics (in agriculture) is increasing

The numbers published by PlasticEurope (2018) about the global plastics production demonstrate an increase from 335 million tonnes plastics in 2016 to 348 million tonnes in 2017. Sintim and Flury (2017) describe the rapid growth of the market for agricultural films: the global use of agricultural films accounted for 4.4 million tonnes in 2012 and is expected to grow to 7.4 million tonnes in 2019 (Sintim and Flury 2017).

Plastic mulch films are an upcoming technology in Europe. In 2011, mulching films were responsible for the largest proportion of covered agricultural surface in Europe (4270 km^2), an area four times larger than that covered by greenhouses and six times that of tunnels (Steinmetz, Wollmann et al. 2016).

China is a fast growing market

The use of plastic films in agriculture is rapidly growing in China. A high increase is demonstrated in the use of plastics for greenhouses and walk-in high tunnels, and low tunnels. In figure 3 and figure 4 the surface coverage of different regions is shown.

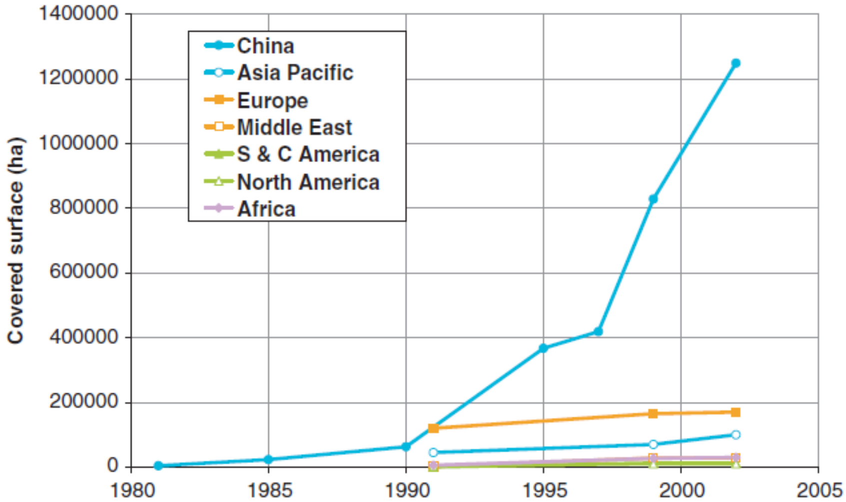

Figure 3 Agricultural surface covered with plastic film for greenhouses and walk-in high tunnels. Retrieved from: (Espi, Salmeron et al. 2006)

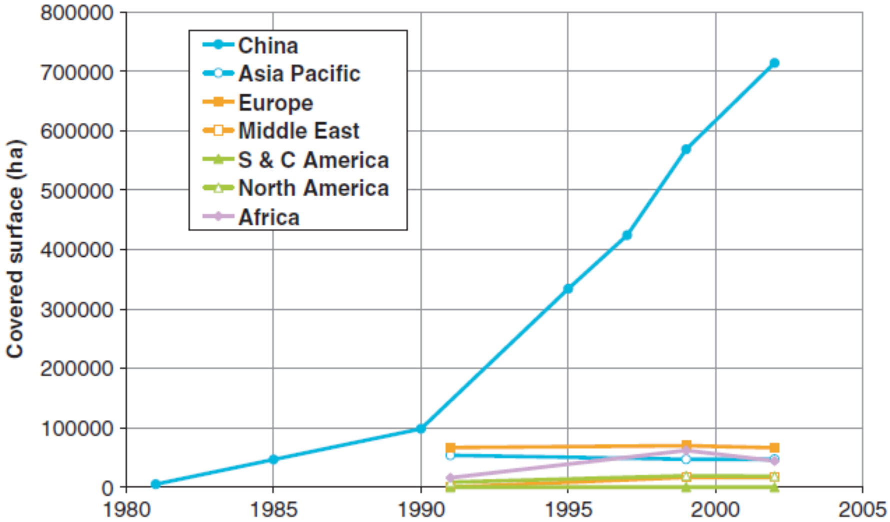

Figure 4 Agricultural surface covered with plastic films used for low tunnels. Retrieved from: (Espi, Salmeron et al. 2006)

Plastic waste is an issue

Although plastic waste or the environmental impact of the use of plastics in agriculture was not the focus of this research, it became apparent that this is a problem. More recent articles about plastic use in agriculture that were found in the scientific databases were mainly focused on biodegradable alternatives or identifying the environmental issues.

Vox et al. (2016) indicate that plastic materials in agricultural practices are characterized by short usage durations; the plastic films in particular are affected by a progressive deterioration of their mechanical and spectro-radiometric properties mainly due to their thickness, their exposure to the solar radiation and pesticides, the variations in temperature and relative humidity, the wind and rainfall actions and the installation mode. Therefore, the frequent replacement of films and the use of other plastics generate large amounts material that need to be properly managed. At the end of their useful life plastic wastes are often burned in the open field, abandoned in the fields or along watercourses, buried in the soil or disposed in the landfills. Inappropriate disposal of agricultural plastic waste causes soil and water contamination, releasing harmful substances and air pollutants, food contamination, soil quality degradation as well as aesthetic pollution and landscape and agro-ecosystem degradation.

Conclusion

The estimated amounts of plastic used for different applications are shown in table 2. Plastic cultivation films are by far the largest group of plastics used in agriculture, accounting to more than 90% of the total plastics used. Relatively little plastics are used in agriculture for silage, irrigation and nets. Polyethylene (PE) is mainly used for plastic cultivation films and therefore the type of plastic that is used most in agriculture.

Table 2 Amounts of plastics used

Use	Estimated amounts worldwide /year
Total plastic	348 million tonnes
Total plastic for agricultural purposes (2017)	6.96 million tonnes[6]
Application	
Plastic cultivation films (2017)	6.5 million tonnes[7]
- Mulching (2017)	2.75 million tonnes[8]
- Greenhouses and high tunnels (2002)	1 million tonnes
- Low tunnels (2006)	170,000 tonnes

[6] Based on the data from PlasticsEurope (2018): 348 million tonnes of plastic used of which 2% is used for agricultural.
[7] Based on the estimation of Sintim and Flury (2017) that the market for plastic agricultural films will grow from 4.4 million tonnes in 2012 to 7.4 million tonnes in 2019. Assuming the growth is stable, the volume is estimated at 6.5 million tonnes in 2017.
[8] Based on the statement from Sintim and Flury (2017) that plastic mulch films accounted for 40% of the total plastic use in agriculture.

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Annex 1: Research strategy and reading guide

Schuttelaar & Partners was asked by Emese Brósz on behalf of the SAI working group to perform a literature research on plastic use on agricultural farms. The literature review was carried out as follows:

- **Step 1**: First scan of available data on the use of plastics in agriculture, using several scientific databases (Scopus, PubMed and Google Scholar) and websites of related organizations and institutions.
- **Step 2**: Prioritizing information and determination of the structure of the report
- **Step 3**: Writing report

The following should be considered when reading the report:

Interpretation of data
Based on the current information, the numbers quantifying the specific plastic applications in agriculture should be considered estimations. The scientific publications are not completely up to date, particularly with respect to the rapid growth of the market. For example, it is estimated that the market for plastic agricultural films will grow from 4.4 million tonnes in 2012 to 7.4 million tonnes in 2019. Considered that the growth of the use of plastic agricultural films is almost 70% in 5 years, data before 2012 is outdated. The -more up-to-date- data from other institutions or market organizations are focused on the total plastics market or the total use of plastics in agriculture, not specifying for the different applications. Furthermore, the definitions used to describe the different applications -and the associated numbers- differ in scientific literature. For instance, the terms greenhouses and high tunnels are used interchangeably, and it is not always clear from literature which films are covered by the definition ‘agricultural films’. The different applications can also be used simultaneously: the ground of high tunnels/ greenhouses can be covered with mulching films as well.

In conclusion, the numbers quantifying the global use of plastics can be considered appropriate approximations and the data quantifying the different applications rough estimations.

Annex 2: Description types of plastic used in agriculture

The most traditional ‘agricultural’ polymers are described by Sarcascia-Mugnozza et al. (2011) and shown in table 3.

Table 3 Overview of main traditional polymers used in agriculture. Derived from: (Scarascia-Mugnozza, Sica et al. 2011)

POLYMER	DESCRIPTION
Polyethylene (PE)	A thermoplastic polymer belonging to the polyolefin family. PE exists in two main forms, namely high density polyethylene (HDPE = 0.94-0.96 g/cm3) and low density polyethylene (LDPE = 0.92-0.93 g/cm3). Also linear low density polyethylene (LLDPE) is used in order to produce film characterized by minimum thickness and high mechanical properties. PE has a wide range of agricultural uses because of its low cost, good workability, high impact resistance, excellent chemical resistance and electrical insulation properties. In particular LDPE is used to produce films (for greenhouses, low tunnels, mulching, silage) and irrigation tapes, while HDPE is generally used to produce pesticide cans, nets and irrigation pipes.
Polypropylene (PP)	The second most common linear thermoplastic polymer of the polyolefin family. In comparison to low and high density PE, PP has a lower impact strength, but superior working temperature and tensile strength. PP is most widely used as fibres and filaments produced by extrusion and is used in agriculture for piping, sheeting, nets and twines.
Polyvinylchloride (PVC)	A thermoplastic polymer; it is a vinyl polymer and it is the third most widely produced plastic, after PE and PP. PVC is mainly used in agriculture for irrigation pipes or tubes and semi-rigid sheets for greenhouses cladding. Only a few tons of flexible PVC (films) are still used as covering material for greenhouses.
Ethylenvinylacetate (EVA)	A copolymer of ethylene and vinyl acetate. The weight percent of vinyl acetate usually varies from 10 to 40 %; usually, it is equal 14 % for agricultural films used to cover greenhouses. EVA is a polymer that approaches elastomeric materials in softness and flexibility, yet can be processed

	like other thermoplastics. The main characteristics of the greenhouse covering film are: elasticity and good resistance to tensile stress, tear and perforation; high transmissivity to the sunlight in the visible light range, especially in the photosynthetic activity range (PAR), 400-700 nm; high capacity to absorb the radiant heat in the LWIR range and to retain them inside the greenhouse during the night time, known as "greenhouse effect"; long lasting of the mechanical properties and transparency.
Polymethylmethacrylate (PMMA)	An atactic thermoplastic polymer and is the most widely used in the class of polymers known as acrylics. Some characteristic of PMMA are that it has crystal clear transparency in the solar range (≈90 %) and an outstanding resistance to ageing, but it is susceptible to a large number of solvents. PMMA is the most important polymer for the preparation of sheets, corrugated or alveolar, and rods.
Polycarbonate (PC)	Characterized by high transparency in the solar range (90 %) and lack of colour. Instead, the UV are absorbed, causing the yellowing of the material during ageing; therefore additives are used as stabilizers (e.g. benzotriazole) or protections are applied to the external surface of the PC sheet. There are different PC sheets, single (simple/compact or corrugated) and double layer (alveolar); the last are used as covering of greenhouse when a good thermal insulation is required.
Glass reinforced polyester (GRP)	Used to be largely used in agriculture for greenhouse covering or for containers, but recently its consumption is limited due to ageing problems.

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