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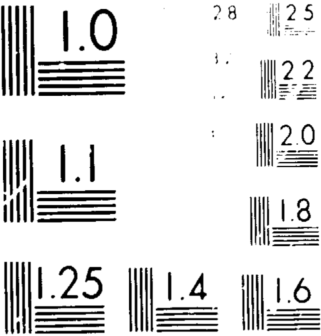

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Distr.
LIMITED

ID/WG.327/2
3 September 1980

ENGLISH
ORIGINAL: FRENCH

United Nations Industrial Development Organization

Eighth International Congress on the
Applications of Plastics in Agriculture

Lisbon, Portugal, 6 - 11 October 1980

POLYVINYL CHLORIDE FILM STRUCTURES FOR CROP PROTECTION *

by

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* The views expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO. This document has been translated from an unedited original.

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As long ago as 1965, Professor Favilli in his excellent paper to the Second National Congress on the Use of Plastics in Agriculture at Latina remarked that "whereas there has been considerable progress in the area of plastics for use in greenhouses, progress has been negligible in the area of the supporting structures. Very often these structures are not appropriate to the physical and agricultural requirements of the greenhouse, and likewise do not permit the optimal use of the covering material, whose serviceability and durability are consequently limited."

In his work at the Montedison Agricultural Technology Centre, Servizi Agricoltura S.p.A., the author of the present paper has always been particularly interested in research into structures, specifically with respect to the use of plastic films, including polyvinyl chloride (PVC) film, which is the most difficult to work with.

All experimenters in this field (whose most important works are listed in the bibliography) have consistently recognized the superiority of PVC over other plastic film material with respect to thermal efficiency and the greenhouse effect due to PVC's high radiation-retention capacity (i.e., the ability to hold back the sun's medium- and long-wave infra-red emission) and its potentially greater durability.

The following advantages flow from PVC's positive characteristics:

1. More effective crop protection against the cold;
2. The promotion of earlier crop maturity;
3. Higher yields;
4. Improved product quality;
5. The possibility of sterilizing the soil through heat treatment, with the greenhouse kept hermetically sealed during the summer.

All of these advantages can perhaps be summed up under the single notion of increased yields. Despite this, however, the use of PVC film as a greenhouse covering is generally very limited, save in Japan where some 50 per cent of all film used for covering tunnels and greenhouses is PVC. By way of comparison, in Italy PVC does not yet account for even 10 per cent of the consumption of all the plastic film materials used for these purposes.

The reasons for this limited use are to be found in certain negative properties of PVC film, which can, nevertheless, be partially corrected during the formulation of the compound:

1. The film's greater elasticity makes it more difficult to achieve uniform and constant tension, the result being lower wind resistance. This defect, in combination with the lower tear resistance which is typical of PVC film, often leads to the total destruction of the covering, causing serious economic loss not limited to merely the replacement of the covering. This is because, since it is not always possible to replace the film immediately, the crops themselves may be severely damaged. This shortcoming cancels out the film's potentially greater durability. Added to this is the fact that, when it is not taut enough, the film's great elasticity tends to give rise to large pockets of rain water, which, in the presence of even the slightest obstacle, impede the run-off of the water along the slope line of the cover.

2. Being highly electrostatic, the film attracts and traps smog and atmospheric dust, which causes a substantial reduction in its transparency and clearness. In areas with particularly high pollution levels, this shortcoming may make it necessary to replace the film after one or two years at the most, even when it is still intact.

3. The film's cost per kilogram, on the basis of one year's use, is currently about 18 per cent higher in Italy than the cost of "four seasons" polyethylene (PE). In addition, the specific weight of PVC film is about 30 per cent greater than the specific weight of PE film. All this is reflected in an approximately 65-per-cent higher cost per square metre. This is the situation on the basis of current prices; a few months ago the difference was even more marked and the cost per square metre of PVC was nearly twice that of polyethylene.

4. The greater difficulty in the extrusion-production of PVC film in widths sufficient to permit the covering of large shelters. At the present time, Italian producers, using special formulations, are manufacturing films 0.12 mm thick and exceeding even 6 m in width, which are in most cases large enough for use as structural covers. Although it is possible to produce still larger widths, the 6.4-metre size is commercially the most common, so that where larger coverings are required, individual films must be welded together.

5. Greater difficulties in greenhouse management because of PVC's higher thermal efficiency. The fact is that because excessively high temperatures can check growth and cause production losses, in greenhouses with PVC film covering there must be greater provision for ventilation in order that the higher temperatures may be kept within reasonable limits.

Until now, horticulturists using plastic films have preferred to side-step these difficulties by employing PE film, which in fact offers greater mechanical resistance, is lower priced, and is easier to use, although in so doing they have sacrificed the advantages to be had from PVC's higher thermal efficiency and greater greenhouse effect. For these reasons, over a period of about ten years we of the Montedison Agricultural Technology Centre, Servizi Agricoltura S.p.A., have studied and gradually perfected a type of structure which makes it possible to reduce the risks associated with the shortcomings of PVC film, while at the same time exploiting to the fullest extent possible this material's positive characteristics.

The structure in question is a multiple-arch tunnel manufactured from galvanized steel to the following dimensions:

- Width at the base:	6.00 m
- Height to the gutter:	about 1.50 m
- Height to the ridge:	about 3.20 m
- Door:	2.00 m
- Evolution of the arch:	about 7.00 m
- Volume, cubic metre/running metre:	about 2.40 m

The arches, which are slightly ogival in form and fashioned of square galvanized Sendzimir tubing, are of varying dimensions and thickness (side - 25-35 mm; thickness - 1.5-2.5 mm), depending on whether the locality in which the tunnel is to be built is or is not particularly windy. In areas where considerable snowfall can be expected, the base width is shortened to 5 m and the curvature of the arch is made more pronounced.

These arches are seated in the outer arms of each pair of Y-shaped uprights, which have their own anchoring system and are sunk to a depth of about 50 cm in the ground. Naturally, the section and thickness of these uprights, which have been galvanized in a melted zinc bath at 500° C, are greater than those of the arches so as to permit easy insertion and adequate resistance to weight and pressure.

The air within the tunnel is renewed through openings in the vault that are protected by paired louvres, which can be opened or closed in series on either side, depending on the direction of the wind, simultaneously along the entire length of the tunnel. Through the action of these openings, known as "butterfly-wings" because of their structure, a kind of flue effect can be created, providing optimum ventilation and even eliminating the pockets of highly humid air which tend to form beneath the gutters of the tunnel.

In late spring or summer, the coverings can be raised up along the edges of the gutter, thereby increasing aeration to produce a more tolerable climate.

The edge of the film is attached at this point, by means of shaped sections of light sheet metal or rigid PVC, to a square tube measuring 20 mm per side and having a thickness of 1.5 mm and length equal to that of the tunnel (the maximum advisable length is about 60 mm). This tube runs through a series of open rings, one per arch, so fashioned as to allow the film to pass through and the tube itself to rotate when the film is rolled up on it.

Once the film has been drawn taut, the tube is locked into place at the desired height by means of a branch consisting of a small steel cable. This cable is connected to another, thicker, cable, equal in length to the tunnel, running through a series of rings attached to the Y-shaped uprights at the point at which they are joined together.

In this way, the tunnel can be hermetically sealed by securing the cover to the gutter, or else the cover can be left more or less loosely detached from the gutter to permit a degree of ventilation beyond that provided by opening the louvres in the tunnel ceiling.

In one version of this system, the gutter is fashioned from the film itself, which, before it is rolled on to the square tube, is wrapped around another, round, tube located lower down.

By rolling the film on to the square tube as described above, with the aid of a few reducing gears at either end of the tunnel, the film can be drawn taut in such a way as to eliminate any flapping and, thus, the possibility that it may tear or that water pockets may form. Within a few days, some slack in the film may be observed, particularly if it was installed during a cold period followed by warming temperatures. In this case, it will be necessary to draw the film taut again, repeating this operation several times, if need be, until the film is stabilized and retains its essential tension.

When using PVC film one must make certain that it is free of even the smallest hole or snag, since such defects may give rise to far more extensive tearing, which needless to say diminishes the effectiveness of the over-all structure.

With this in mind, the cover is fitted to measure to the tunnel. After imparting an initial and fairly moderate tension to the film, it is laid out over the arches, or else it is secured to PVC sections reinforced with iron shapes and a thin wire tightened by means of a lever.

Over the butterfly-wing louvres, the film is secured, before cutting, to the same sections that will later keep it stable. In turn, these sections are held firmly in place by means of pressure screws. If holes or tears occur, they are to be repaired as soon as possible using patches obtained from the film itself.

The doors at either end of the tunnel are shield-like in form. Matched to the contour of the tunnel, they turn on hinges attached to a transverse bar some 60 cm from the vault. The crescent-shaped section thus formed at the top of the vault can be opened and may be used both to aerate the tunnel vault so as to prevent condensation droplets from forming, and to permit the entry and exit of bees, even when the door is closed. The very contour of the door itself has been designed to permit the unimpeded circulation of bees.

When installed in this way, PVC film can be exploited to the maximum of its potential durability, particularly if directly above the points on which it rests on the arches it is painted white to reflect heat radiation.

Unfortunately, because the material is so highly electrostatic, it attracts and traps smog and atmospheric dust to the degree that its transparency falls off sharply from about the second year. As a result, it may happen that in certain regions - the Po Valley is one - where the intensity of the light is naturally somewhat low, even film that still appears intact must be replaced.

In order to deal with this problem, we have devised a precautionary measure which has been found to be very useful: instead of installing film with a thickness of 0.20 mm (0.15 mm in less windy regions), we have used PVC film with a thickness of 0.15 mm, or even 0.12 mm, accompanied by an external second film, this one of polyethylene, measuring 0.08-0.10 mm thick, which remains stable for at least one year. After one year's service, this outer PE film (and with it all the accumulated dust) is removed, usually in the autumn, and replaced. In this way, the structure always remains highly transparent and there is an improvement in resistance to wind and hail, all that is necessary being the yearly replacement of the very thin and less expensive PE film.

This two-ply design results in a space, however small, between the two films, which makes for better heat insulation and shields the PVC film from that part of the ultraviolet radiation which is absorbed by the polyethylene.

The result is a considerable extension of its useful life, which may be as much as 5-6 years. Accordingly, the costs for the covering, over a six-year period, are lower than they would be using PE of the same thickness.

For example, assuming a battery of ten tunnels, each measuring 60 m long and 6 m wide for a surface of 3,600 m^2, the costs - in current (June 1980) prices - would be as follows:

Covering using "four seasons" PE (duration one year, cost 1,650 lire/kg):	
Two covers, 60 x 9 m each (for the external tunnels); thickness 0.20 mm; 210 kg	346,500 lire
Eight covers, each 60 x 7 m (for the internal tunnels); thickness 0.20 mm; 650 kg	1,072,500 lire
Labour for installation: 126 hours at 5,000 lire/h	630,000 lire
Labour for dismantling the remnants: 50 hours at 5,000 lire	250,000 lire
	2,299,000 lire

These costs are repeated every year, so that in six years they total 13,794,000 lire.

Covering using "long-life" PE (duration two years, cost 2,050 lire/kg):	
Two covers, 60 x 9 m each, thickness 0.20 mm, 210 kg	430,000 lire
Eight covers, 60 x 7 m each, thickness 0.20 mm, 650 kg	1,332,500 lire
Labour for installation: 126 hours at 5,000 lire/h	630,000 lire
Labour for dismantling the remnants: 50 hours at 5,000 lire	250,000 lire
	2,643,000 lire

These costs are repeated every two years, so that over six years they will amount to 7,929,000 lire, representing a saving of 5,865,000 lire over the previous option.

Covering using PVC (duration six years) plus PE "four seasons" (duration one year):	
1st year: (PVC "Plypac", 1,950 lire/kg; PE "four seasons", 1,650 lire/kg)	
Two covers, 60 x 9 m each (for the external tunnels), PVC "Plypac", thickness 0.12 mm 170 kg at 1,950 lire/kg	331,500 lire
Two covers, 60 x 9 m each, PE "four seasons" thickness 0.10 mm 110 kg at 1,650 lire/kg	181,500 lire
Eight covers (for internal tunnels), 60 x 7 m each, PVC "Plypac", thickness 0.12 mm 510 kg at 1,950 lire/kg	994,500 lire
Eight covers, 60 x 7 m each, PE "four seasons", thickness 0.08 mm 260 kg at 1,650 lire/kg	429,000 lire
Labour for the installation (both films are installed at the same time), 126 hours at 5,000 lire/h	630,000 lire
Total for the first year	2,566,500 lire

Over the following years it will be necessary to replace the polyethylene film five times, so that the cost will increase each time by 810,500 lire (for the purchase of the material), making a total of 3,052,500 lire. To these costs must be added, again five times, the cost of labour (250,000 for the dismantling of the remnants plus 630,000 lire for the installation of the new film) plus the cost for the final dismantling of the film, making a total of 4,650,000 lire. All told, the costs of the covering over six years will amount to 10,269,000 lire, representing a saving of 3,525,000 lire (or 25.6 per cent) over the covering using "four season" polyethylene alone.

Covering using PVC plus long-life PE (PVC "Plypac" at 1,950 lire/kg and "long-life" PE at 2,050 lire/kg):	
Two covers (for the external tunnels), 60 x 9 m each, PVC "Plypac", thickness 0.12 mm, 170 kg at 1,950 lire/kg	331,500 lire
Two covers (for the external tunnels), 60 x 9 m each, "long-life" PE, thickness 0.10 mm, 110 kg at 2,050 lire/kg	225,500 lire
Eight covers (for the internal tunnels, 60 x 7 m each, PVC "Plypac", thickness 0.12 mm, 510 kg at 1,950 lire/kg	994,500 lire

Eight covers (for the internal tunnels), 60 x 7 m each, "long-life" PE, thickness 0.08 mm, 260 kg at 2,050 lire/kg	533,000 lire
Labour for the installation, 126 hours at 5,000 lire/h . .	630,000 lire
Total for the first year	2,714,500 lire

In subsequent years it will be necessary to replace the polyethylene twice at an additional cost of 758,000 lire each time for a total of 1,517,000 lire plus 780,000 each time for labour and 250,000 lire for the dismantling of the film at the end of the six-year period at a total cost of 3,327,000 lire. Thus, the total cost of the covering over six years will be 6,041,500 lire, representing a saving of 23.8 per cent over the [previous] covering option.

These examples show that it is possible to gain the economic advantages flowing from the earlier maturity and better quality of crops together with a lower risk of frost damage by exploiting the higher thermal efficiency and better greenhouse effect of polyvinyl chloride film.