

DESIGN AND USE CRITERIA OF NETTING SYSTEMS FOR AGRICULTURAL PRODUCTION IN ITALY

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1. Introduction

Plastic nets are widely used in various agricultural applications: protection from hail, wind, snow, or strong rainfall in fruit-farming and ornamentals, shading nets for greenhouses, or nets for moderately modifying the microenvironment are the most common cases. Moreover, nets for the protection against virus-vector insects and birds, as well as for harvesting and post-harvesting practices are often used.

In the market, both woven and non woven products are defined as nets. In order to avoid misunderstanding, the following definition of plastic nets is proposed: *a plastic net is a product made of plastic fibres connected together with each other, in a woven or knitted way forming a regular porous geometric structure and allowing fluids (gases and liquids) to go through.*

The most widely used raw material for agricultural nets is the high density polyethylene (HDPE). Polypropylene (PP) is also used as raw material for nets, mostly for the production of non woven layers.

It is not possible to determine the European consumption of agricultural nets because no data are available from agricultural and manufacturers associations at a European level. Moreover, the net producers are not able to define the agricultural nets consumption, because an amount of their production is actually sold for non-agricultural purposes, such as shading nets for car parking, permeable coverings of scaffoldings, construction of provisional fences, anti-insect nets for windows, fishing nets, etc. In Italy, the estimated consumption of HDPE for agriculture net production is 5.300 tons/yr, whilst the total consumption in agriculture of HDPE is 30.000 tons/yr and of PP is 46.500 tons/yr [22].

A systematic review of the current state-of-the-art of most common agricultural applications of nets has been developed by means of a literature study, technical investigations, interviews with permeable covering producers and specialised greenhouse builders as well as insurance organisations and¹ growers, who are familiar with permeable cladding (net) applications.

2. Net types

Net types are characterised by different structural features like kind of threads, fabrics, shape and dimensions of fibres and meshing, by physical properties like weight, colours, shading factor, durability, porosity, air permeability and mechanical characteristics such as stress, strength at break and elongation. Normally the available dimensions of nets vary a lot for both the width and the length. The width usually varies from 1 m to 6 m or from 12 to 20 m (depending on the type of net) and the length from 25 m to 300 m. Wider nets are constructed by joining the required number of widths. A first classification of nets can be based on the material, the kind of fabric, the colour and additives used.

2.1 Material

The most used raw material for agricultural nets is high density polyethylene ($\gamma_{\text{HDPE}}=0.94-0.96 \text{ g/cm}^3$) (Fig. 1): it is a non-toxic material, which can be used in direct contact with plants; it is completely recyclable; easily convertible; waterproof; durable, if stabilised to ultra violet (UV) radiation agents are added in the correct quantity and has good mechanical characteristics (tensile stress $\sigma=20\div37\text{MPa}$, elongation at break $\epsilon=200\div600\%$).

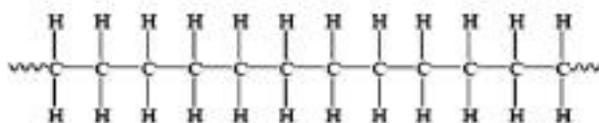


Fig. 1 - Polymeric chain of high density polyethylene.

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Polypropylene ($\gamma_{pp} = 0.90-0.91 \text{ g/cm}^3$) is used as raw material in the production of non woven layers (Fig. 2). This kind of membrane, which envelops the plant, is employed, in horticulture and for orchards, as direct cover to preserve cultivations from the rain, the frost or the wind.

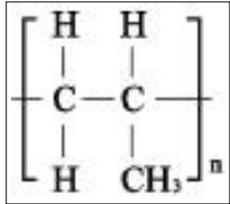


Fig. 2 - Polymeric chain of polypropylene; 'n' is the number of copolymers.

Starch based biodegradable materials are also used in some innovative agricultural nets productions. At the end of their life, biodegradable materials can be disposed directly in the soil or can be incorporated in a composting plant with organic materials, such as food and vegetable residues and manure, in order to generate carbon-rich compost [15]. Actually biodegradable materials are not very common in the market due to their high costs, compared with other plastic materials, and to the reduction of their physical and mechanical properties due to the prolonged exposition of the material to the climatic agents, mainly to solar radiation [21].

2.2 Types of agricultural nets

Yarns of HDPE are produced in two main typologies: monowires, round or flat, and tapes. Depending on the kind of loom, the weave defines three main typologies of nets in most common agricultural applications: flat or Italian; English or Leno; knitted or Raschel (Fig. 3).

Flat woven is characterised by a simple orthogonal weave between weft and warp. Flat woven nets are light and stable in their shape, but they are relatively stiff and do not allow strong deformations.

English woven is a modified flat woven net and it is produced with the same type of looms. It is based, like the flat one, on the orthogonal weave between weft and warp directions but with a double fibre in the weft direction, enclosing the warp fibre in between (Fig. 3). The produced net is used when a more rigid protective covering is required such as for vineyards during strong hail falls.

Raschel looms produce nets with longitudinal 'chains' and transversal knitted elements (Fig. 3). In Raschel membranes all threads are linked with each other in order to prevent the unravelling of threads, for example under the action of strong wind or hail falls.

Selvages on the borders usually stabilise and secure the fabric weave and reinforced buttonholes enable nets to be installed more easily and quickly to the supporting structure.

2.3 Colours

The colour of the net is obtained by mixing chromatic additives to HDPE grains before the production of the compound.

The most common net colours are: black, green or transparent. Transparent nets are used for those applications in which the shading effect of the net is considered as a negative consequence of net performances. Black nets are generally used for shading installations in which the reduction of incoming solar radiation is desirable. The black colour is obtained by using 'carbon black' additive, which also acts as a UV-stabiliser and consequently the durability of nets with black threads is higher than transparent one. Carbon black is usually added in a quantity of less than 1%, since higher quantities could decrease the mechanical stability of the yarn. The other colours are obtained by means of pigments: for example, ftalocianine based additives are used to obtain blue and green nets.

Coloured nets are developed to modify the spectral transmittance of the sun radiation in order to obtain

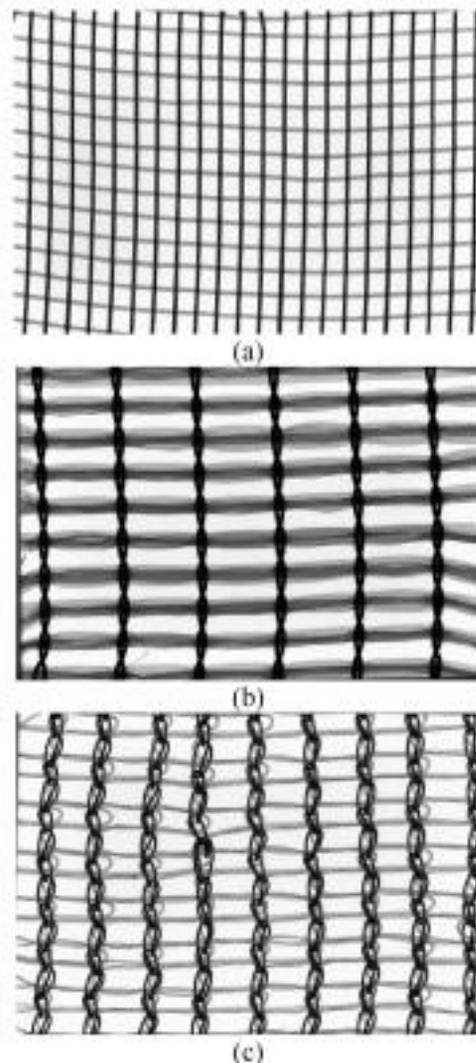


Fig. 3 - (a) Scheme of monowire flat woven; (b) monowire and tape English woven or Leno; (c) monowire Raschel. In the figure warps are vertical, weft are horizontal.

different effects on the plants which are light-regulated, such as the increasing of the fruit size and control the duration of the cultural cycle [23]. Red and yellow nets stimulate the growth, blue nets cause dwarfism in ornamental plants, whilst grey nets stimulate branching and produce 'bushy' plants with short branches and small leaves. Modifications of the flowering period and of the quality of the production were observed in cut flowers species covered with coloured nets [16], [17], [23].

Concerning the application of coloured nets on vegetable crops [4], [5], [12], [13], only few data are available. However, a higher air temperature (1.5-3.0°C) was observed, when a red net was used, compared to a transparent net. Coloured nets are also used for insect proof applications because they may attract some insects [6].

Green nets are widely used in agriculture. Their sun radiation screening factor is a compromise between transparent and black net, the transmittance curve of the sun radiation passing through the net has a pick in the green range of the spectrum ($\lambda=500-550\text{nm}$) and from an aesthetic point of view they better fit in the landscape (Fig. 4).

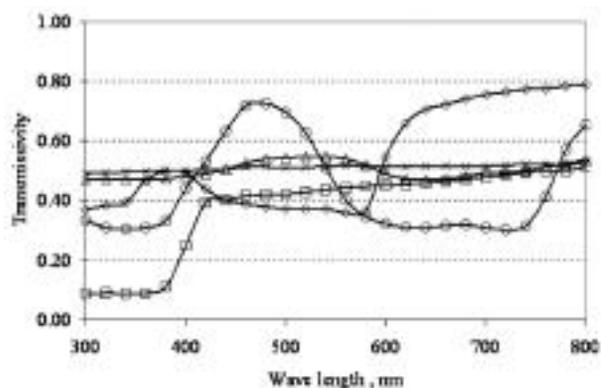


Fig. 4 - Diagram of transmissivity measured in 300-800 nm wavelength range on different coloured nets tested in laboratory: X, black; O, blue; Δ , green; \diamond , red; \square , white.

Silver nets are produced by extruding an HDPE tape fibre together with an aluminium layer and provide high reflectance. Silver nets are used both inside the greenhouses as thermal screen and outside, as a shading membrane.

2.4 Additives

Additives are used in order to improve or change the mechanical and physical characteristics of the plastic yarn and its ageing behaviour. The most common ones are chromatic and UV stabilisers. Additives are also used in order to increase the permeability to the water, to retard fire effects on the polymer, to reduce the accumulation of dust (antistatic additives). They are produced in grains and mixed with HDPE, with appropriate proportions in order to form the compound.

3. Characteristics of existing plastic nets

3.1 Dimensions of fibres and meshes

The thickness of a net is given by the thickness of single threads in mm. Generally it varies from 0.25 mm up to 0.32 mm. The mesh size is given in mm for both the warp and weft and varies from 0.2 mm to 3.1 mm for insect nets, from 1.7 mm to 7.0 mm for shade nets, from 2.5 mm to 4.0 mm for anti-hail nets, from 1.8 mm to 7.0 mm for windbreak nets, while higher values, 3-4 cm, characterise the anti-birds nets.

3.2 Weight

The weight of plastic nets depends on the thickness of threads, the kind of fabric and on the mesh size: generally, it varies from 15 g/m² up to 325 g/m². The only Standard related to the definition of the weight of the nets is provided by Italian Bureau of Normalisation: UNI 9401/89- *Reti in plastica per l'agricoltura- Determinazione della massa per unità di superficie* [Agricultural plastic nets- definition of mass per square unit] (Tab. 1).

3.3 Shading factor

The shading factor describes the ability of a net to absorb or reflect a certain part of sun radiation (Fig. 4). It is defined by Italian Standard UNI 10335/94- *Reti in plastica per l'agricoltura- Determinazione del potere ombreggiante delle reti in fibra polietilenica* [Agricultural plastic nets- evaluation of shading factor in polyethylene fibre made nets] (Tab. 1).

3.4 Durability

The stability of the mechanical properties of HDPE mainly depends on its resistance to UV radiation, which is the main agent of HDPE degradation. The UV degradation resistance of the net is expressed as the amount of kilolanglely (kly) necessary to reduce the tensile strength of the net to the 50% of the original value (note: the unit of kilolanglely expresses the global incident solar irradiation: 1 kly=1 k cal/cm² = 41.84 MJ/m²).

Commercial nets have a solar radiation resistance equal to 400-800 kly which corresponds to a durability of the polymer of 5-6 years in mild climates, such as those of Mediterranean area (100-120 kly/yr), or 3-4 years in tropical areas with more than 140-160 kly/yr. The evaluation of the stability of the polymer against UV radiation is described in the following standards: ASTM D4329/99- *Standard practice for fluorescent UV exposure of plastics*; ASTM G154/00- *Standard practice for operating fluorescent light apparatus for UV exposure of non metallic materials*; ASTM G151/00- *Practice for exposing non metallic materials in accelerated test devices that use laboratory light sources*; UNI ISO 4892-1/2/3 2002- *Materie*

<i>UNI Standard</i>	<i>Remarks</i>
UNI 9401:1989 'Nets for agricultural uses. Determination of the mass per unit area.'	The standard prescribes to take samples of 2-3m of each side, to remove enforcements and selvages, to measure the membrane with instrumentations of millimeter precision and to weight the sample with a balance of 0.1g precision. Finally it is defined the surface mass (unit mass) as the ratio between the mass of the sample (g) and its measured area (m ²).
UNI 9402:1989 'Nets for agricultural uses. Determination of the linear density of the constituent threads.'	Samples, of minimum length of 25m, are taken from the net with approximation of ±0.5mm. Samples are weighted and the linear density is the ratio between the mass and the length of the sample, expressed in tex (10 ⁻⁶ kg/m).
UNI 9403:1989 'Nets for agricultural uses. Determination of the number of threads per unit length.'	Thread for unit of length (5cm or 20cm depending on the kind of net) are counted by means of a wire counter containing at least 25 wires. Wires are counted on the sample or unthread from the sample.
UNI 9404:1989 'Nets for agricultural uses. Determination of length and width of rolls.'	The length and the width of rolls is measured on the net without external stress. The net is spread on a surface and marks are made at the distance of 2-3m. Every 24h the distance between marks is measured. When it is constant it is possible to measure length and width of the rolls, expressed in meters with approximation of one centimetre.
UNI 9405:1989 'Nets for agricultural uses. Determination of breaking strength and elongation.'	For each measure, 5 weft samples and 5 warp samples 100x300mm, have to be taken. The elongation at break (%) and the breaking load (daN) of net samples are measured, separately for warp and weft directions, by means of a dynamometer with constant speed of load increasing.
UNI 9735:1991 'Nets for agricultural uses. Determination of the mass per unit length. Skein method.'	Threads are rolled around a skein with a tension of 0.5cN/tex and a counter of turns and is measured a length of the thread of 100m. The sample is weighted and the mass per unit length expressed in tex (10 ⁻⁶ kg/m) is defined.
UNI 10334:1995 'Nets for agricultural applications. Nets of polyethylene fibre for the shading of cultures.'	Parameters of nets (mass per unit area, stress strength, elongation) and values to indicate in identification label are defined depending on their shading factor.
UNI 10335:1994 'Nets for agricultural applications. Determination of the shading power of nets of polyethylene fibre.'	Samples, 600x600mm size, are put in a black box between the lighting source, a 150W incandescent lamp powered with stabilized voltage, and the luxmeter cell. The shading factor will be defined as the ratio between luxmeter measurements with and without the net sample.
UNI 10336:1994 'Tests for agricultural applications. Nets polyethylene fibre. Determination of elongation at constant load'	The length of thread is measured before and after the elongation of wires with a mass of 10g/tex for ten days, the ratio between the elongation and starting length defines the elongation at constant load.
UNI 10337:1994 'Nets for agricultural applications. Nets of polyolefin fibre. Determination of the shrinkage in boiling'	The length of thread is measured before and after the immersion of the sample in hot water for 60s, the ratio between two measurements defines the shrinkage.
UNI 10406:1995 'Nets for agricultural applications. Tests of polyethylene fibre for agricultural protection from hail. Definition, classification and requirements.'	Minimum values of parameters of anti-hail nets (mass per unit area, stress strength, elongation, shrinkage, etc.) are defined. Only Leno nets are defined as anti-hail and are classified in three classes -A, B, C- depending on their construction parameters.

TABLE 1 - Set of Italian standard regarding agricultural nets.

plastiche - Metodi di esposizione a sorgenti di luce di laboratorio [Plastic materials- exposing to laboratory light sources methods].

The durability of the net also depends on the kind of contact with structural elements, such as columns and cables, on the environmental temperatures (HDPE is a thermoplastic material), on the use of chemical pesticides containing sulphur and/or chlorine and even on the chemical composition of the objects placed in contact with the material (for example metal posts) which can generate a premature chemical deterioration of the product (hot spots) [9]. A premature degradation can also be caused by mechanical stress due to unusual climatic environmental conditions in the area such as wind and hail storms.

3.5 Structural characteristics of nets

The most important mechanical characteristics of nets are the elongation at break and the tensile strength. They are defined by Italian Standard UNI 9405/89- *Reti in plastica per l'agricoltura- Determinazione della forza e dell'allungamento a rottura [Agricultural plastic nets- evaluation of strength and elongation at break]* (Tab.1).

Until the introduction of the metric system, the unit of the mechanical quality of silk and man-made fibres (still used in the USA and in many other countries) was the *denier* (*den*). It represents the weight of a 900m length thread, where the weight of a standard den is 1N: $1den=1.1 \cdot 10^{-2}N/m$. The denier can be considered as an indication of the area of the cross sec-

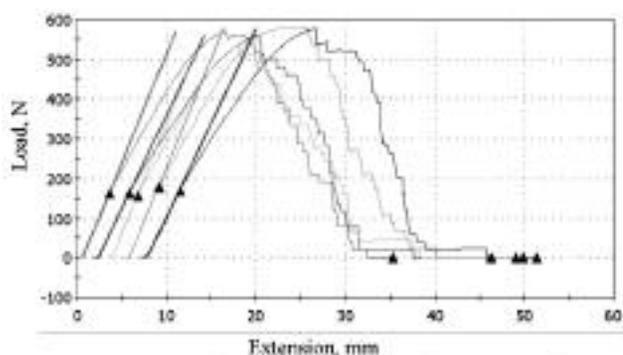


Fig. 5 - Typical stress-strain diagram of an agricultural net (five specimens of net Fructus 2.6 tested in the warp direction at the Agricultural University of Athens according to a modified EN ISO 10319:1993 method).

tion of a fibre and consequently can be associated to its mechanical resistance. Other units used in the market are: $g_{\text{rex}}=10^{-6}$ N/m and $\text{tex}=10^{-5}$ N/m.

Some producers indicate the tensile strength as the ratio between the breaking load and the area of the cross section of the sample in N/mm^2 , or the breaking load and the length of the net sample in N/m or in function of the deniers in N/den. The stress-strain test highlights that the tensile strength of the yarn and of the fabric (Fig. 5) are completely different.

3.6 Porosity and solidity

The porosity represents the percentage of void space in a porous material and can be expressed as the ratio of the open area divided by the total area of the net sample. It can be evaluated by means of three methods: radiation balance, interception of solar radiation, analysis of images of materials [8]. The solidity ratio is a parameter used in the evaluation of the wind force on porous structures in accordance to structural Eurocodes (ENV1991-2-4). It can be expressed as the ratio of the fabric area divided by the total area of the net sample and so it is complementary to the porosity.

3.7 Air permeability

The air permeability represents the ability of the net to transmit the air through it. It depends on many parameters such as air viscosity and speed, dimension and shape of fibres, spaces between fibres, texture of fabric [14]. The permeability and the porosity are basic parameters which influence both the pressure coefficients on the net and the climate under the nets, in terms of air speed, humidity and temperature.

4. Agricultural applications of nets

Main agricultural applications are: protection against meteorological hazards, insects, little animals; reduction of solar radiation; soil cloth. Moreover, they are used also for the harvesting of fruits- such as

olives, chestnuts, almonds, walnuts and other little fruits- for packaging and for post-harvesting operations such as collecting of cut flowers and drying of fruits.

It is not always possible to associate a net to a specific application, as in many cases they accomplish more functions at the same time, for example shading nets protect also cultivation from hail.

4.1 Protection against meteorological hazards

One of the most important agricultural uses of plastic permeable coverings is to protect cultivations from wind, hail, snow, frost and rain.

Windbreak nets are used in order to: avoid mechanical damages (e.g. breaking of branches, flowers) and biological consequences (high evapo-transpiration, difficulties in pollination) due to the action of the wind on the cultivations; increase the quality of products by protecting them from dust, salt and sand; reduce the wind load on agricultural structures; minimize the heat loss of animals due to ventilation in open livestock farms.

Anti-hail nets prevent damages on cultivations due to hail. They are largely used in field applications, especially in fruit tree cultivations such as grape, peaches, apricots and cherries, where they are installed with a specific supporting structure or directly applied on the cultivations. Anti hail nets are considered, in some cases, a necessary protection of greenhouses covered with glass panels, where damages caused by hail could have onerous economical consequences on materials and crops and could be a danger for the safety of personnel working inside the greenhouse. In these applications anti-hail nets also induce a reduction of incoming solar radiation during the summer time, which could be considered a positive effect, especially in regions such as Southern Italy, where the more dangerous period for hail falls is during the periods of May-June and August-September. During these periods a reduction of solar radiation is required in order to reduce the temperature increase inside the greenhouse.

Anti frost effect is usually reached by means of non woven sheets spread on the cultivation, whilst in other cases it is considered a secondary effect of the net.

Anti rain nets avoid damages caused by heavy rain falls in orchards such as cherries; its effect is usually combined with anti-hail one.

4.2 Reduction of the solar radiation

Shading nets aim at screening the solar radiation in order to reduce the air temperature increase inside the greenhouses or the incoming radiation on cultivations, such as ornamental plants, requiring low levels of light. They are used also to prolong or delay the harvesting period in sunny areas: for example shading nets are used in southern Italy for 'cherry' tomato harvesting in August while, normally, they are harvested in June. Shading nets are also used in screenhouses

for virus free productions. The increasing of the air humidity and the reduction of air flow could be a limiting factor in their use.

Thermal screens are used inside the greenhouses in order to limit both convection and thermal radiation heating loss, especially during the winter nights. Usually this kind of application requires aluminium colour nets to increase the reflection of the far infrared radiation emitted by the inside area of the greenhouse.

4.3 Protection against insects

Insect-proof nets are considered as an environmental and human health friendly alternative to pesticides and are usually employed in organic farming. Insect proof nets are used in screenhouse coverings, with simple or double layer, for virus free productions. Screening to exclude insects, can enhance integrated control programmes, reducing dependence on chemical pesticides [10], [24]. Moreover, they may avoid inoculative feeding of the disease vectors, such as Aleyrodidae, thrips and Aphids [7]. Insect proof nets are also used to avoid the escape of pollination insects, like bubble bees, from the greenhouse. For this kind of net it is very important the size of the mesh of the net and the colour which may attract insects. Consequently, insect-proof nets are characterized by an high shading effect and a very low porosity and permeability. In order to limit the reduction of solar radiation transmittance, white or transparent fibres are used whilst, the reduction of air flow and the increasing of air relative humidity can be a negative effect for cultivations.

4.4 Protection against birds and little animals

Nets installed on the vents of greenhouses or directly on the trees are used to protect the cultivations from the attack of birds and little animals such as rabbits, hares and mice.

4.5 Soil cloth

Permeable coverings are used as soil cloth in a wide range of application: for protected cultivation and garden centre in order to create walking areas, for soil mulching; against weeds and barrier against roots, underneath wood plank bridges, terraces and ramps and in fruit tree cultivations against weeds.

5. Nets supporting structures

5.1 Protection against meteorological hazards

Windbreak nets are usually fixed to a supporting structure consisting of columns or trusses, made of steel, concrete or wood, fixed at a foundation plinth (Fig. 6). Sometimes they are installed by the growers

directly on trees planted at the field borders. The wind reduction depends on the height of the structure, the porosity of the net and the distance of the fence from the cultivation [18], [20]. Aim of the design of the



Fig. 6 - Windbreak net supported by a concrete structure in southern Italy.



Fig. 7 - Orchard anti hail netting on concrete structure in northern Italy.



Fig. 8 - Vineyard anti hail netting on wooden supports in southern Italy.



Fig. 9 - Shading and anti hail system running over the roof of a glass greenhouse in southern Italy.

windbreak structure is to find a balance between the wind reduction effect and the structural costs, both depending on the net porosity. Moreover, low values of porosity have been found to induce wind vortex on the leeward side which are potentially dangerous for the cultivation [19]. Windbreak supporting structures require a certain distance from the cultivation or from the agricultural building protected from the wind in case it is not installed on the northern side because the shading effect of the windbreak net could cause a decrease of the crop production.

Anti-hail nets are used both in field cultivations and over greenhouse structures. In field cultivations, like grapes with a pergola cultivation system, a supporting tensile structure is required with longitudinal and transversal steel cables tensioned to a supporting structure or at the soil with columns made of steel, concrete or wood. In pergola with traditional (*hut*) system (Figs 7 and 8) there are upper longitudinal wires on the top of the columns placed at 4.0-5.0 m from the ground and lower transversal wires at 2.5-3.0 m from the ground. The net is tensioned and fixed on both wires and has a slope of 50-60%, from the ridge on longitudinal wires, in order to allow the hail to fall down. The traditional system is used in Europe for almost 20-30 years and it is appropriate for high trees with the same distance in longitudinal and transversal direction. In a flat net system, suitable for trees of 3.0-3.5 m height, both longitudinal and transversal wires are fixed on the top of the columns. The net is spread on and fixed to longitudinal wires. In this case it is not allowed the hail stone to fall down, consequently the cables and the structure shall be designed to resist to hail load. Sometimes the net is fixed to the cables by means of 'break control' plaques which breaks when the hail load exceeds a defined threshold, consequently the net falls down preserving the structure. The flat net system is less expensive and easier to install than the pergola one. Sometimes, in flat net systems, the net is fixed to the top of columns by means of rubber bands, so that the net comes back in its position after the deformation due to the hail fall. This system is also known as the French system. It is

very important to avoid the load due to hail accumulation on the structure which could induce, if not properly designed, the collapse of the system. These kinds of structures are empirically designed due to the lack of data regarding climatic loads on nets and to the difficulties in calculation of tensile structures. Anti-hail nets over greenhouses require specific supporting steel system connected to the structure of the greenhouse. The net can be moved along the supporting structure in order to control its shading effect in function of the season and of meteorological conditions (Fig. 9).

5.2 Reduction of the solar radiation

Shading nets are usually supported by structures made of steel elements specially designed for greenhouses. These structures are generally designed with an arched or a vaulted (Fig. 10) or a flat roof (Fig. 11). Such supporting frames are empirically calculated due to the lack of data regarding climatic loads on permeable coverings. When the net is used to shade greenhouses it can be deployed on steel frame, supported by



Fig. 10- Steel made vaulted roof with eaves shading structure in central Italy.



Fig. 11 - Steel made flat roof shading structure in central Italy.



Fig. 12- Thermal and shading screens inside a greenhouse in northern Europe.

the main structure, with a distance from the covering of the greenhouse of almost 50 cm (Fig. 9). Thermal screens are installed inside the greenhouses, running on rails, generally at the gutter level (Fig. 12). Thermal screens systems have a slight shading effect also when they are not used. Therefore they have a negative effect during winter days.



Fig. 13- Impollination net system in Wageningen (NL).



Fig. 14- Screenhouses for certified crop production with a double layer of anti insect nets on the arches and with a stand-alone structure for the shading system at the University of Bari (It).

5.3 Protection against insects

Insect-proof nets are used as covering of specific supporting structure in case of screenhouses (Figs 13 and 14) or at greenhouses vents. The structures of screenhouses are made of steel elements usually designed for greenhouses, with arched, vaulted or flat roof. This kind of frame is empirically designed due to the lack of data regarding climatic loads on permeable coverings. When the insect proof nets are used for greenhouse cultivations they are installed at the vents in order to avoid the incoming of virus vector insects that can affect the crops. For some cultivations, such as to protect apple trees from bugs, it is laid on the soil and vertically on the border of the cultivation.

6. Current regulations and standards

No European standard exists regarding agricultural nets. There are currently only a few national standards regarding specifically agricultural nets and films. Concerning nets, there is a set of Italian Standards (Tab. 1) that cover a wide range of properties for agricultural nets. Other national standards deal with agricultural films like the French standard NFT 54 190 and the Italian standards UNI 9738 and UNI 9298.

7. A case of study in Italy: existing plastic nets in agricultural applications

In order to develop an inventory of existing plastic nets for agriculture and their applications, two questionnaires were developed, one for Italian growers, familiar with structures with permeable nets, and one for Italian net producers. The questionnaires were distributed by means of direct contact, phone, e-mail, or ordinary mail, with the co-operation of some national associations of growers. The research was integrated together with literature study and technical visits.

The questionnaire for growers consisted of sixteen questions (Tabs 2 and 3), with a very simple language, and multiple answers. The grower, anonymously, had the chance to fill in one among of the multiple answers or to add other items. The aim of the investigation was to achieve qualitative information regarding the current agricultural practice of plastic nets. The questionnaire for plastic net producers (Tabs 4 and 5) had a more technical target with the aim to define the main mechanical and physical characteristics of most common plastic nets. The questionnaire regarded only the following net applications: shading; anti-hail, windbreak, anti-insect and anti-birds.

7.1 Interviews with growers

Based on the results of the questionnaires the main characteristics of nets in Italian agricultural applications were defined. Almost 400 farmers were contact-

Questions	Answers	(%)
In which Region your farm is located?	Northern Italy	53.4
	Southern Italy	46.6
Are nets used for organic farming or for certified cultivations?	Yes	19.7
	No	80.3
Which is the total area covered by nets in your farm?	<10.000m ²	45.0
	>10.000m ²	55.0
Which is the colour of the net?	Black	36.4
	Green	24.2
	White	21.7
	Transparent	10.0
	Others	7.7
Which is the shading factor?	<30%	51.7
	30%-50%	24.9
	50%-75%	9.3
	>75%	14.1
Which is the expected duration of the net ?	< 5 years	20.0
	> 5 years	80.0
In which period are you going to install the net?	January-March	15.1
	April-June	40.6
	July-Sept	35.1
	October-Dec.	9.2

TABLE 2 - Results of questionnaires for Italian growers: farming information, characteristics of nets.

Questions	Answers	(%)
Which kind of cultivation do you cover with nets?	Vegetables	37.6
	Orchard	29.1
	Apple trees	12.4
	Ornamental	11.2
	Fruit harvesting	9.7
Why are you going to use nets? (Multiple answers were possibles)	Anti-hail	40.2
	Shading	35.5
	Anti-insect	29.7
	Windbreak	12.2
	Anti-birds	8.8
	Rain protection	5.9
Which kind of structure does support the net?	Steel	34.4
	Steel-concrete	21.3
	Wood	11.8
	Concrete	5.6
	None	26.9

TABLE 3 - Results of questionnaires for growers: agricultural applications of nets, supporting structures.

ed and invited to fill in the questionnaire, 154 farmers (39% of contacts) answered the questionnaires: net covered area was greater than 1 ha in 55% of cases, the 24% of growers covered with nets an area of 0.5-1.0 ha, in 21% of farms net covered area was less than 0.5 ha (Table 2). Nets are associated to organic farming in 20% of the cases.

Most common colours are black 36%, green 23%, white 21%, transparent 11% and orange 9%. Black nets are used as shading screens and to protect from insects in the cultivation of apple tree for which are

also laid on the soil. Green nets are used as shading screen, as anti-hail and for birds protection. White and transparent nets are diffused as anti-hail and insect proof membranes (Tab. 2).

Fifty two percent of nets have a shading factor lower than 30%, shading values between 30% and 50% characterised the 25% of nets, 23% have a shading factor higher than 50% (Tab. 2).

The expected duration of the net is higher than 5 years for the 80% of growers, 19% of growers assume that the durability is of 3-5 years, only 1% expects that the net will be replaced in less than 3 years (Tab. 2).

The nets are installed preferably during spring and summer periods. Almost 72% of growers remove periodically the net (Tab. 2).

The net is combined with film plastic coverings by 28% of growers, because this agricultural practice is very common in greenhouse cultivations and in vineyard, in Southern Italy, where the plastic film is used to anticipate or to delay the harvesting.

The main agricultural nets applications are vegetable 38% and orchards, 29%. Moreover, they are used in flowers and ornamental plants cultivations, 11%, to collect harvested fruit from tree cultivations, 7%, and for little fruit, 3%. Apple tree cultivations have been distinguished from orchards because nets are often employed to protect the fruit from beetles and permeable membrane is also spread on the soil and on the sides of the field (Tab. 3).

The supporting structure is made of steel in 34% of the cases, of concrete and steel in 21%, of wood in 12% and concrete in 6%. Wood and concrete piles are very common supporting elements of pergola structures (Tab. 3). Almost 27% do not use specific supporting structure of permeable membranes, setting them directly over the soil or over the cultivation.

Main agricultural nets applications are: hail protection, 40%; shading, 35%; insect protection 30%; wind break 12%; birds protection 9%; frost protection, 8%; rain protection, 6%. The sum of percentages is higher than 100% because, in the questionnaires, it was possible to give multiple answers (Tab. 3) due to the fact that, for instance, a grower can use the same net for shading and for anti hailing and it demonstrates the multi purpose use of nets.

Concerning nets disposal, 25% of growers dispose nets in landfill sites; 46% of growers transport nets to a collecting centre to recycle them; 29% of growers do not know exactly what to do.

7.2 Interviews with nets producers

The net factories which participated to the research were the main manufacturers in Italy. They produced, during 2003, almost 4500 ha of agricultural nets, corresponding to almost 2700tons of HDPE.

The best selling nets are: shading screen and anti-hail, 73%; insect proof, 16%; wind break, 8%; bird protection, 3% (Tab. 4). The most common shading

<i>Agricultural application</i>	<i>Yarn</i> ⁽¹⁾	<i>Shading (%)</i>	<i>UV res. (kly)</i>	<i>Areic mass (g/m²)</i>	<i>Tract. long. (kN/m)</i>	<i>Tract. transv. (kN/m)</i>	<i>Elong. at break (%)</i>	<i>den</i>
Shading	Tr, Ta	25-90	400-800	50-250	4-10	2-15	20-30	450-800
Anti-hail	Tr, Ta	10-25	400-800	30-70	4-7	2-4	20-40	500-700
Anti-insects	Tr	10-20	400-600	70-130	4-5	2-4	20-30	300-450
Windbreak	Tr, Ta	30-70	400-800	60-180	5-15	4-18	20-35	300-450
Anti-birds	Tr	5-15	300-600	10-30	0.5-2.5	0.5-2.5	20-30	300-450

TABLE 4 - Results of questionnaires for net producers: physical and mechanical characteristics of most sold permeable membranes for agricultural purposes: ⁽¹⁾ Thread (Tr); Tape (Ta).

factors are 30-50% with an average unit mass of 50 g/m². Shading nets are, principally, black, green or white coloured. Anti-hail nets are white, transparent or green. White and transparent nets are mostly used in insect protection in order to limit as much as possible the solar radiation shading. White, green and orange colours characterised anti-birds nets, while most sold windbreak nets are black, green, white and orange (Tab. 5). These data confirm that no scientific criteria are shared between researchers, producers and growers, about parameters, which influence the performance of nets used for agricultural productions. Moreover, it was not possible to define a relationship between the kind of fabric and its agricultural applications: flat woven, English woven and Raschel knitted are all used for different purposes (Tab. 5).

<i>Applications</i>	<i>%</i>	<i>Colours</i>	<i>%</i>	<i>Weaving</i>	<i>%</i>
Shading	40.9	Black	50.2	Raschel	54.6
		Green	40.1	Flat	34.3
		White	9.7	Leno	10.1
Anti-hail	32.3	Transp.	40.4	Leno	55.0
		Green	34.6	Raschel	45.0
		Black	25.0		
Anti-insect	15.7	White	50.3	Flat	70.0
		Transp.	49.7	Leno	30.0
Windbreak	8.0	Black	49.0	Raschel	50.4
		Green	36.3	Flat	34.8
		Others	15.7	Leno	14.8
Anti-birds	3.1	Green	57.9	Raschel	80.0
		White	32.8	Extruded	20.0
		Orange	9.3		

TABLE 5 - Results of questionnaires for net producers: colours of nets and kind of weaving depending on their agricultural application.

The net durability varies between 5 and 8 years for shading and anti-hail nets. Lower duration, 3-5 years, is expected for insect-proof nets and anti-birds nets.

Nets are certificated with UNI9405 only by the greater producers. No one performs radiometric or permeability test, but only one producer performs an ageing test based the ASTM G151/ standard.

8. Conclusions

The use of plastic nets is rapidly increasing in vari-

ous agricultural applications all over Europe. Protection from hail, wind, snow, or strong rainfall in fruit-farming and ornamentals, shading nets for greenhouses, or nets for moderately modifying the microenvironment are the most common cases. At the moment, a large number of net typologies are characterised by different kind of construction and performance properties such as: fibres, fabrics, dimensions of fibres and meshing, weight, colours, shading factor, durability, porosity, air permeability, breaking strength and elongation. A systematic review of the current state-of-the-art of most common agricultural applications of nets has been developed by means of literature study, technical investigations, interviews with permeable covering producers and specialised greenhouse builders and growers, who are familiar with structures with permeable nets. It appears that scientifically justified technical requirements for nets used in specific agricultural applications have not been established yet. During technical inspections it was noticed that in many cases different, not even similar, net typologies were adopted for the same application and the same cultivations by various growers. It is evident that neither growers nor producers have clear ideas about the relationship between the net typology optimisation for a specific function and the choice of the net, but this depends often on empirical or economic criteria and not on scientific considerations.

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SUMMARY

At the moment, there is a large number of agricultural net typologies on the market characterised by different texture features such as threads, texture, dimensions of fibres and meshing, physical properties such as weight, colours, shading factor, durability, porosity, air permeability and mechanical characteristics such as stress, strength at break and elongation. Protection from hail, wind, snow, or strong rainfall in fruit-farming and ornamentals, shading nets for greenhouses, or nets for moderately modifying the microenvironment are the most common applications. A systematic review of the current state-of-the-art of structural param-

eters, standard and regulations, most common agricultural applications of nets and their supporting structures has been developed by means of a literature study, technical investigations, interviews with permeable covering producers, specialised greenhouse builders and growers, who are familiar with permeable cladding applications. The interviews were based on questionnaires concerning characteristics, use and disposal of nets. As a result, the survey highlighted that in many cases different, not even similar, net typologies were adopted for the same application and the same cultivations by various growers. Results show that neither growers nor net producers have clear ideas about the relationship between the net typology optimisation for a specific function and the construction parameters of the net. The choice still depends often on empirical or economic criteria and not on scientific considerations. Moreover, it appears that scientifically justified technical requirements for nets used in specific agricultural applications have not been established yet.

Key words:

Membrane, plastic nets.