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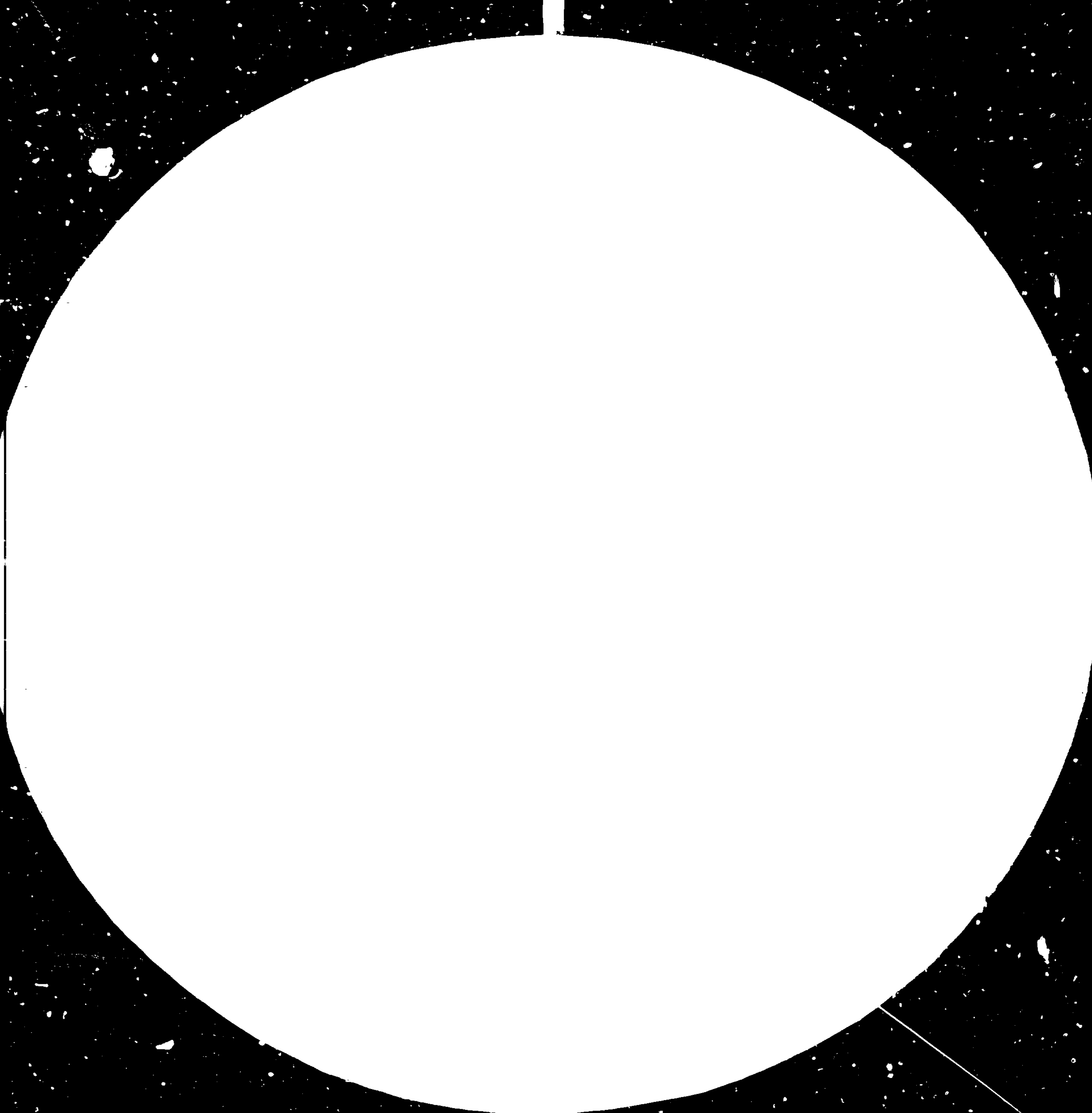

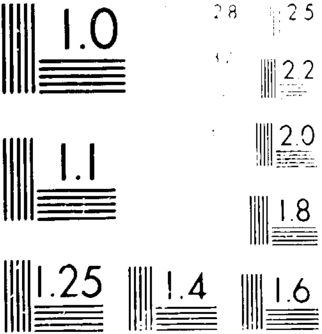
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PLASTICS IN AGRICULTURAL APPLICATIONS IN DEVELOPING COUNTRIES*

by

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1.0 Summary

The use of plastics in agricultural applications represents a positive growth market for the plastics industry, particularly in developing countries. A mechanism for achieving the necessary transfer of technology to the ultimate user, the farmer and grower, is outlined and this is considered as an essential key to effective market penetration.

A number of selected uses of plastics in agricultural applications in developing countries are described, including their use in growing, water conservation and produce storage. The use and development of plastics film as a 'mulch' (a covering of the soil) are described indicating how this very simple but performance effective material product can be altered to meet the varying environmental and economic conditions unique to each country.

It is suggested that a Plastics Technology Centre could support and assist the plastics industry to adapt and develop the necessary technologies, and quality standards, so that it could successfully expand this and other market areas. This would also benefit the country both economically and socially as well as providing additional opportunities of employment.

2.0 Introduction

The large scale use of plastics in agriculture is relatively new having started to build up in volume only during the last decade. It is now estimated that on a world basis more than 1.2 million tons of plastics are currently being used each year in agricultural applications. During the period, 1952-72, when the original developments were being undertaken in the United States of America (USA), in Europe and in Japan the growth rate for plastics in agricultural applications was about 20%. Once the volume market applications had become established it was natural that this very high growth rate would decline and it settled to a level of 8-10% during the period of 1973-80. It has subsequently dropped to 6% due to the current economic recession (1981/2).

It is only in more recent years that a number of developing countries have now started to show an active interest in this subject. The reason for this awakening interest is due to the realisation that plastics, of the correct quality, can offer both technical and economic solutions to many agricultural problems. In this sense plastics are currently being regarded as a tool to serve the needs of agriculture both by way of increasing efficiency as well as outputs. Being man-made materials they can be formed and shaped to meet specific criteria of performance in agricultural applications. With new petrochemical complexes coming on stream in several developing countries the polymer producers are turning their attention to find suitable market outlets. Based on current information it can be expected that, given the necessary technical and technological support, the growth rate for plastics in agricultural applications in developing countries will be about 12-15% and will be one of the fastest growth sectors for plastics applications.

It should be stressed that the successful development of these applications has been based on finding solutions to particular agricultural problems in a specific country taking account of its various constraints such as climate, soil conditions, economic conditions as well as man-power criteria etc. In consequence, each solution is unique to a given set of circumstances and it does not follow that the same solution will necessarily give the same results in another country. Thus, if any lesson has been learnt from past experience it is that each country must carry out its own development and experimental trials, under its specific conditions of usage, if plastics are to provide both the technical and economic solutions to the agricultural problem. Obviously a knowledge of existing applications in current commercial use as well as of applications under current development can assist the technical personnel concerned with these developments. Also, it may offer the possibility of reducing the actual development time necessary to effect both a technical and economic cost benefit assessment. Discussions with researchers, active in this field, will often bring to light past failures in development trials which are seldom published. This negative information is often useful in a development programme since it offers the possibility of leap-frogging certain steps of the development thus effecting a faster solution to the problems.

This is of particular relevance to the Plastics Industry since they normally undertake their development work under laboratory conditions, and are generally unaware of the nature of agricultural development operations. Development programmes for plastics in agricultural applications involve a knowledge of two technologies - plastics and agriculture - and the development work also involves outdoor trials and demonstrations at suitable agricultural experimental sites before effective solutions are obtained. In practice this means, for most of the trials, that they are seasonally and crop dependant. If for any reason the season is missed it is necessary to wait a year for the next appropriate season before the trials can be started. Experience indicates that it generally takes three seasons, sometimes five, to arrive at satisfactory solutions and it becomes vitally important therefore that the development programmes are carefully and well-planned before the work is started. Any information which could assist in shortening this development period is therefore well worth the effort to obtain.

3.0 Technology Transfer

After the expenditure of much effort and other development resources it can be expected that the plastics industry technologists will have succeeded in developing a specific quality of plastics product that provides both a technical and economic solution to a particular agricultural problem. It is generally at this point that the industry learns that selling this product becomes extremely difficult and market resistance is felt. This is due to the fact that the technology involved in using the plastics product has to be suitably transferred to the ultimate user, the farmer and the grower. Even with very highly profitable applications there have been problems in securing the necessary technology transfer to the ultimate user, and this also includes Government Departments where they hold responsibility for infra-structure operations such as the development of irrigation schemes. Consequently there is a need to establish a mechanism which will transfer the technology to the ultimate user and this is the key to effective market penetration.

It has been found that technology transfer can be best achieved by three inter-related activities:

1. National Committee for Plastics in Agriculture
2. Demonstration trials
3. Extension services.

Utilising, wherever possible, existing organisational structures and institutional services to avoid duplication of effort and costs.

3.1 National Committee for Plastics in Agriculture

Since the use of plastics in agriculture is a relatively new technology in agriculture, it became clear that there was a need to provide a suitable platform to bring together, for the first time, the many different parties, organisations and institutions with a common interest in agriculture. This has included the plastics industry, Government Departments, financial institutions, research workers, farmers and growers associations etc. This has been achieved in several developed and developing countries by the formation of a National Committee for Plastics in Agriculture acting as an apex body. It has provided the necessary centralised institutional facilities whereby knowledge and experience could be pooled and exchanged, and also permitted a wider promotion of the use of plastics in agriculture to be achieved by means of field demonstrations, conferences, meetings, visits, public relations, etc.

National Committees have been formed in Argentina, Bulgaria, France, German Federal Republic, Hungary, India, Italy, Japan, Mexico, Portugal, Spain, United Kingdom and United States of America.

It is open to National Committees to become members of the International Committee for Plastics in Agriculture (CIPA) operating from Paris, France. Through membership of this organisation, a wider range of contacts with international experts and institutions becomes possible, as well as participation at the International Congress which is organised every three years. National Committees are invited to host such international events and this presents opportunities, at a later stage, to show to international personnel the development in the use of plastics achieved nationally and the areas where future assistance might be required. Additionally, there are opportunities for a full and free interchange of information through on-the-spot discussions with international experts. The 9th International Congress is scheduled to be held in Mexico 6-11 November 1983.

Experience has shown that where National Committees have been formed, this is followed by a positive up-surge in the use of these materials in agriculture bringing with it an improvement in agricultural output and quality.

Through the activities of national committees the areas of priority and development needs can be identified, and suitable work programmes determined for execution by appropriate agricultural research institutions and experimental stations.

3.2 Demonstration trials

In many developed countries the use of plastics in agricultural applications was and still is being determined by experimental field-scale trials. Such trials are conducted at both Governmental and private-enterprise supported "Agricultural Experimental Stations" as part of a continuing programme in the general development and improvement of agricultural technology.

Plastics demonstration trials are used to establish the most effective technology of the application of plastics in agriculture in relation to local environmental conditions and agricultural practices. These trials enable various factors to be evaluated, such as the effect of type and quality of the plastics product, the method of the application of the plastics to meet specific agricultural requirements, the adaption of agricultural techniques, if required, etc.

By giving access to these demonstration trials of all interested parties including farmers and growers and members of the plastics industry, an opportunity is also presented for on-the-spot technical discussions with the station experts. By this means, and supported by the use of audio-visual aids, a wider knowledge of the use of plastics in agriculture and applications becomes known to farmers and growers, plastics industry personnel, and also to national agricultural extension experts and to administrators.

Through the use of these techniques, a practical knowledge of the technology is disseminated. This technology is now called "PLASTICULTURE", the application of plastics to agriculture.

3.3 Agricultural Extension Service

In many countries there already exists an agricultural extension service which is able to provide on-the-spot general and specific agricultural advice, assistance and service at regional, district and village levels. This service has been fully utilised in developed countries to carry the technology of plasticulture to all levels of the agricultural community. It was achieved by arranging suitable training sessions for the agricultural extension experts at demonstration trials, at meetings and by the provision of adequate follow-up literature and illustrations; and subsequently by regular up-dating visits to demonstration trials where a two-way technical dialogue soon became established.

By the utilisation and co-ordination of these services it has been possible to achieve a satisfactory technology transfer.

4.0 Selected Applications of Plastics in Agriculture

From many developing countries visited a range of applications have been noted that may be of interest to other countries that have yet to fully exploit this market area. The countries concerned included Argentina, Chile, Cyprus, Guatemala, India, Jordan, Lebanon, Malaysia, Nicaragua, People's Republic of China, Singapore and Upper Volta. Some applications from developed countries are also included where these were felt to be appropriate.

It should be noted that the applications mentioned in this paper are only a selection of a very wide range of applications which have been developed, and the development process is a continuing one.

4.1 Planting Bags

The replacement of the traditional clay pot for young plants at the nursery stage is perhaps one of the first applications that is adapted by a developing country. This is due to the fact that a simple LD PE bag is generally considerably more economic, as a direct cost, than a clay pot. Moreover, growing trials to prove the effectiveness of the bag are simple to make and involve little cost to the grower.

The following nursery plants have been observed growing, in commercial production, in PE planting bags:

Tea; Rubber; Palm oil; Tamarin; Citrus; Tomatoes; Chrysthanthemums; Lilies; etc.

The normal bag is gusetted so that it stands firm when filled with soil. Black bags are the usual colour since they prevent weed growth developing from the sides. They absorb sufficient heat during the day to retain warmth in the soil during the night and thus greatly assist the establishment of root growth. In some countries transparent PE bags have been used and the plastics industry has not persued the matter of establishing black bags as a standard.

For the plastics industry this can be of importance since much overun printed film, short lengths and off-colour runs can all be recycled into black film if the melt flow index of the materials are not too dissimilar. Providing that suitable master batches are utilised the film produced can be of first class quality. It must be stressed that this is not a question of merely adding 'black' colour. When PE is processed it is slowly oxidised and if the oxidation is progressively continued the material will gradually become physically weak, until in the end it embrittles. It is necessary therefore to ensure that the master-batch contains effective and sufficient anti-oxidants to prevent this deterioration of properties in the re-cycling process. Most reputable PE producers will give specific technical advice on this matter if requested and a number of them provide suitable master batches for this purpose.

Normally up to 30% of PE film rework can be processed this way, and depending on the particular type of plant being operated considerably higher quantities have been successfully reworked.

In tea plantations a bottomless bag is used, since the film is not sealed. A special type of sandy sterile soil is used for filling the bags, and being slightly moist, it consolidates when it is tamped into the PE 'bag'. Thus, it remains intact when the filled bag is lifted.

4.2 Plastic covered tunnels and greenhouses

There are many forms of plastics covered tunnels in use in many countries. Ranging from low tunnels, as referred to above, up to "walk-in" tunnels or greenhouses. Whilst the original and traditional concept of a greenhouse was to provide a warm atmosphere, in which plants could be grown "indoors" in countries where the winter climate was too cold for outdoor growing, this concept has taken new meaning. By providing low cost transparent tunnels in which the plant can be grown it is now possible to control the total environment in which the plant grows, thus enabling optimum yields to be obtained.

In Mediterranean countries low tunnels are used to both advance the harvest date and to increase yields and quality of produce. In countries with hot climates like Jordan. Israel, Iraq, Kuwait, the Emirate States and Southern Iran, plastics covered tunnels are currently in use to produce a variety of horticultural crops. In these locations the covering prevents wind and sand storm damage as well as providing warmer night temperatures during the winter period. Thus there are wide ranging climate conditions in which utilisation of plastics tunnels has found economic solutions.

Various types and sizes of low tunnels, covered with PE film, have been observed in several developing countries. The largest size low tunnel was one 3 metre wide but only approximately one metre high. A narrow wooden beam supported on wooden stakes provided the central ridge support of the tunnel. Steel wire hoops were set along the ridge at intervals of about 2 metres. One edge of the PE film was battened to the ridge and additional wire hoops placed over the outside provided sufficient tension to keep the film in place. This film covered only half of the tunnel, and a second length of film was similarly attached to cover the other half. This technique enables a wider tunnel to be achieved where only relatively narrow widths (2 metres) of PE film are available. The tunnels were to be planted with tomatoes, and as the plants grew it was intended to raise the polythene sides, in progressive stages, until such time as the tunnel height restricted growth. At this point the PE film would be rolled up and tied to the ridge bar. The crop at this point not requiring further protection in the particular climate concerned.

There are many methods of making tunnels, but essentially they should be constructed with the cheapest available materials capable of withstanding the mechanical stresses involved. For low tunnels, galvanised wire, bamboo, palm leaf stems have all been used as mechanical supports. For walk in tunnels and greenhouses wood, both as rough and sawn timber, galvanised steel tubes etc. have been successfully utilised. In this latter application much will depend on the width of plastics film available. Because LD PE film is a low cost material this is more widely used despite certain technical advantages to be obtained by PVC or EVA films. Wide-width LD PE film, that is film of 8-12 metres wide, is normally required to effect the most economic greenhouse or walk-in type of tunnel construction. Narrow widths mean more structural members are required to support the film and thus increase costs.

It should be noted that wide-width LD PE film also has other applications for use in agriculture such as in reservoirs and canal construction, grain storage systems and animal shelters. It can also be used in concrete-road construction and in building applications.

The quality of the film used for greenhouses and tunnels is very important both in its mechanical strength and environmental resistance. This requires the use of special additives and the selection of a suitable grade of LD PE. Normal packaging grade of PE film is not suitable generally for this application. However, the special grades required can be produced easily and satisfactorily on conventional blown film processing units.

In UNIDO supported projects in Cyprus and in Jordan work is currently in progress to evaluate the actual life of new formulations, developed by the projects, for long-life greenhouse films in LD PE.

4.3 Flat tunnels

A more recent development is that of the 'flat tunnel', also known as 'floating mulch'. It is a mechanism which utilises the actual crop as it grows to be the mechanical support for the plastics film cover, and it thereby eliminates the need of mechanical arch supports. The young plants or seed-bed is covered, by hand, with a clear perforated LDPE film generally of 6 metres width and 50 micron thickness. The edges of the film are covered with soil to secure the film. The perforations prevent the film being sucked up and blown away by the action of the wind. The perforations of 10mm diameter are punched into the film at the factory, and various densities of perforations are available, 250, 500, 750 and 1000 per square metre, with 500 being more commonly used. The perforations permit the wind to enter below the cover and it travels along its length in a wave-like action dispersing its energy at the same time. By this mechanism the tunnel is self-ventilating and resolves the labour problem required for ventilation of more traditional small tunnels.

The solar radiation entering the flat tunnel warms the soil and the air layer. The degree of temperature lift depends on the degree of automatic ventilation, which in turn, is pre-determined by the density of the ventilation holes. The system has been used very successfully in Germany for production of spring vegetables such as cabbage, carrots, potatoes, etc. With potatoes it permits earlier planting since the cover affords protection against 2-3^{o}C of frost which can occur occasionally in the spring period and which would otherwise kill an unprotected crop. Once the plants have become well established and the daytime temperature increases with the advancing spring weather the protective film cover can be removed by hand, rolled up, and put away for use in the following years.

Watering of the crop under the ventilated cover can be achieved by natural rainfall or by spray irrigation which passes easily through the ventilation holes, or by trickle irrigation.

An alternative type of self-ventilating film has become available for this application from Switzerland. Known as 'Ziro' film it has some 3,000 small cuts in the film per square metre and this permits the film to both self-ventilate and expand with the crop as it grows.

4.4 Fruit protection

An established use for PE transparent film has been as a protective sleeve over the banana fruit from the time it is formed to the time of cutting. Perforated lay-flat PE film of 50-100 microns thickness is cut into length of about 2-3 metres, sufficiently long to cover the fruit and allow the ends to be bunched and tied. The inside of these cut lengths of lay-flat film is dusted by the grower with insecticide before the fruit is covered. Not only does the film protect the fruit from bird and insect attack, it also promotes higher yields in the fruit and shortens maturity time.

The PE lay-flat is printed with different coloured stripes so that the sequence in which the fruit is to be cut can be more readily identified, and is related to the time when the fruit was first covered.

Work carried out in Australia on the use of coloured translucent PE film for the covering of bananas indicated that blue, green, yellow and red PE films significantly increased the fruit yield and time to maturity compared to a control which was uncovered. More recent work indicated that a reflective cover performed better than the conventional cover, and also offered a bonus of additional protection from fruit burning during the summer heat.

It would appear that there remains much work to be done by the plastics industry to exploit the results of this development work to the particular conditions of each individual country.

4.5 Shading and windbreaks.

4.5a Shading systems

In many countries with arid or semi-arid climates the solar radiation can reach 90,000 to 100,000 lux in summer and half these values in winter (100,000 lux is approximately 1 kw per square metre). Under the summer conditions of intense light and heat plants stop growing and can burn.

If the growing season in such countries, normally October - March in the northern hemisphere, is to be effectively extended then there is a need to reduce the solar energy input and this has been achieved by shading the crop under a plastic netting. The netting can be of either woven or extruded type based on special weather resistant grades of HDPE. The choice of type of net will be dependant on local cost. An opacity of 50 or 55% has been found generally to be suitable.

In Abu Dhabi the use of such nets has enabled two crops to be grown under shade each year. For a tomato crop it was reported that the two cropping periods were August to December, and February to June. Thus, by shading, the normal cropping season was extended by three months..

In Jordan nursery plants are grown in greenhouses covered with a plastics net replacing the normal plastics film. This reduces the temperature effectively for the production of young seedlings and permits adequate ventilation.

Plastics netting is a relatively high capital investment in horticultural terms and alternative low-cost systems have been developed.

In the Cameron Highlands in Malaysia black strips one metre wide, of plastics film were fixed to the roof area to produce a 50% opacity of shade for a nursery green house. An effective system has been developed by Spice. It consists of weaving 10cm wide strips of black LDPE film through a suspended plastics netting of approx. 12 x 12 cm spacing so that any desired density of shade can be made. The netting is generally available as it is standard type used for fitting to the goal posts for football matches. The method is labour intensive and the plastics strips generally require renewal each year.

A different type of shading is used on tobacco plants, in the nusery stage, where a diffused light is required. For this purpose a white LD PE film is used in several countries, including Argentina. The white film is semi-opaque and transmits between 40 to 60% of the light. The film is securec to a wooden frame over young tobacco plant to prevent too much heat build during the critical period of growing. Large sheets of 150 microns thickness are often required for this purpose, approximately 5 x 4 metres.

4.5b Wind-breaks

Plastics nets and the Spice net system can both be used also as wind-breaks, when erected in a vertical position and supported by posts and tensioned wire.

They give excellent crop protection by reducing the wind velocity and thus reduce the evapo-transpiration of the plant. A 50% opaque net will give protection for a distance of 10 to [illegible] times its height.

4.6 Mulching

One of the more simple applications of plastics film in agriculture is its use as a 'mulch'. This technical term means 'a covering of the soil'. Straw, hay, dead leaves, etc. have all be used for many centuries as a natural mulch to keep the soil moist. With plastics film however there is one important difference. It is completely impermeable to water. It therefore prevents the direct evaporation of moisture from the soil and thus limits the water losses. In this manner it plays a positive role in water conservation. The suppression of evaporation also has a supplementary effect, it prevents the rise of water containing salts, which is important in countries with high salt content water rescurces.

The plastics film is normally laid on the soil, in strips, with the edges buried in the soil, or otherwise secured from the effects of wind, and the plants are then planted through holes which are made at appropriate intervals as required by the cultivation technique being utilised. The holes vary in size, according to need, but are generally between 3 to 8 cms for the majority of crops. The holes can be made in the factory producing the film by simple mechanical punching devices, or in the field by burning through the film with a gas-heated metal disc, and are made after the mulch film has been laid in position.

4.6a Types of mulch film.

A wide range of plastics films, based on different types of polymers, have all been evaluated for mulching at various periods in the 1960's. LDPE, HDPE and flexible PVC have all been used and although there were some technical performance differences between them they were of a minor nature. Today the vast majority of plastics mulch is based on LDPE because it is more cost effective in use.

4.6b Thickness of mulch film

The early mulch films used commercially were of 50-75 micron thickness and utilised on high value row-crops such as strawberries. Subsequently, as economic pressures increased the film extrusion technology and its associated machinery control, were progressively improved This led to production of mulch films in LDPE of 35 microns, and with improved LDPE polymer it was later possible to produce films of 25 and 20 micron thickness. More recently films in LDPE of 15 microns have been produced commercially, but at this thickness the films are difficult to handle. The films are mechanically weak, as shown by their easy tearing when pulled under tension. This is more easily seen when used in the higher ambient temperatures of arid or semi-arid areas. To overcome this limitation R & D work is currently proposed in a UNIDO supported project in the People's Republic of China to develop stronger films by the use of mixed polymer combinations including the use of LLD.PE, and by other techniques.

Cultivation trial with mulch on open field crops such as cotton, maize, sugar cane, ground nuts (peanuts), potatoes, pineapples etc. have shown that significant increases of yield can be obtained in the range of 22-100% depending on types of crop. The development of plastics mulching techniques to field crops offers a very large market potential for plastics film mulch. However, the economics of the system do not really become attractive until a film of 10-12 microns can be offered for this type of mulching. It is for this reason that development work needs to be undertaken to further advance the film production technology so that mechanically-strong films in the range of 8-12 microns or even thinner can be produced on a commercially viable basis.

4.6c Coloured mulching films

Plastics mulch has an additional advantage. It makes effective use of solar energy to warm the covered soil. Soil temperatures may be raised 2 - 10^{o}C, according to season and type of soil, and dependant on sunshine and degree of humidity. Clear film mulch gives rise to higher soil temperatures during the day than those recorded using opaque black film. Despite this difference both films maintain a soil temperature higher than the uncovered soil during the night. This warm soil enables seeds to germinate quickly, and for young plants to rapidly establish a strong root growth system.

The use of an optically opaque black mulch also carries an additional benefit. Since it eliminates the penetration of daylight below the mulch weeds are unable to grow, so it suppresses weed growth. Thus it eliminates the need to use expensive herbicides, and in the absence of weeds the nutrients in the soil are totally available to the young plants.

The black film acts as a heat absorber of solar energy and also as a radiator. It has been reported that in arid areas surface temperatures on the black mulch may reach 40-60^{o}C, and this is detrimental to young plants since it will burn leaves and fruit on contact with the film.

On the other hand, in a semi-arid zone in Upper Volta, trials undertaken in a UNIDO supported project have shown excellent results with black film mulch. The plots were irrigated in the traditional manner by surface (flood) irrigation. After the water subsided it left a thin layer of light-coloured mud which adhered to the mulch when dried. This layer acted as an effective heat reflector. Tomatoes and aubergines gave increases of yield of 250 and 300% respectively. In these trials attention was paid to the size of the hole made in the mulch so that the leaves of the young plants did not make direct contact with the mulch film.

To reduce the high surface temperature experienced with black film mulch, other coloured mulch films have been tried. White and aluminium coloured films have been tested and found to effectively reduce the film surface temperature. In more Northern temperate climates where light levels are extremely low in the winter period white and aluminium film mulches have been used for another purpose. It has been found that the light relected from the mulch on to a lettuce crop gave a yield increase of some 5-10% more than when mulched with a black film.

While both white and aluminium colour plastics film mulches produce successful plant growth in semi arid and arid areas they suffer the disadvantage that some light passes through the films and weed growth occurs below the mulch. In many developing countries the cost and use of herbicides is relatively high. It is therefore important that if a mulch is to be used for specific crops then, if possible, it should also serve to suppress weed growth. Over the past few years a two coloured laminated mulch has been produced using an aluminium (or white if required) coloured top film on an opaque black base film. When used with the aluminium colour surface facing upwards the heat is reflected and lower soil temperatures are obtained, at least 20^{o}C lower, and successful cropping has been achieved in areas where a black mulch would normally burn the plants.

In addition to black, white and aluminium coloured films other colours which have been used for mulching are grey and brown. The grey film represented a compromise solution to reduce the film surface temperature but still to retain some soil warmth. In the brown films the actual colour results from the nature of the additives used in the compound to produce a 'thermic effect'. These mulches are designed for use in applications where improved soil temperatures are required. The films are designed to let the solar energy pass through the film to heat up the soil, but at the same time are opaque to the heat radiated from the soil thus permitting higher soil temperatures to be achieved.

In the general development towards thinner plastics film mulches (10-12 micron) it must be anticipated that there will be technological problems to be resolved in relation to the colouration of such thin films, particularly black films. As the thickness of the film is decreased it becomes technically necessary to increase the percentage of black pigment to produce an optically opaque film. Apart from the difficult dispersion problems that this entails there will be economic factors to consider. One may begin to approach the area where the cost of the pigment starts to represent a substantial part of the cost of the film, and the economic advantages of using a thinner film then rapidly begin to disappear. Much plastics processing and development work is needed to be undertaken in this area, but little appears to be in progress

4.6d Microbiological effect.

In using plastics mulches it has been observed that there is a further effect which has a positive influence on growing. At the inter-space between the soil and the underside of the mulch it has ben observed that there is evolved a micro-climate which is higher in carbon dioxide than the outside surrounding air. This appears to be due to a higher level of microbiological activity in the warm and moist soil below the mulch. The additional carbon dioxide assists in accelerating plant growth and has an ultimate effect in increasing the crop yields. There is little doubt that the influence of solar energy in providing a warm soil condition stimulates this biological activity thus making a contribution to increased agricultural production.

4.6e Soil structure

It has been noted that provided the soil was well prepared before the plastics mulch is laid then the soil structure is maintained during the period of cropping. This is important in two aspects. First, it allows a lateral infiltration of water under the film and this is important since any rain water which accumulates on the bare uncovered area could easily be lost by evaporation. Secondly, it permits an easier exchange of gases, such as carbon dioxide generated within the soil by micro-organisms, and reduces the possible danger of build-up to a toxic level.

In addition, a well prepared soil assists in the establishment of a good root system.

4.6f Removal of mulch

After the mulch has been laid and the crop grown there finally remains the problem of how to deal with the mulch after harvesting has been completed. Much will depend on the individual circumstances in each country as to how this may be tackled. The following two examples illustrate how both the plastics and the agricultural technologists, by co-operating and working together, can adapt their individual technologies to provide acceptable solutions to this problem.

In the climatic conditions of Northern France and Germany the mulching of maize enables earlier planting to be achieved as well as increasing the crop yield. However, because these countries are highly dependant on mechanised farming it was not possible to develop this system commercially until appropriate farm equipment was developed which automatically laid the plastics mulch and planted the seeds through it at the same time. To overcome the problem of the mulch becoming entrapped in the harvesting machinery recourse was made to the use of a plastics mulch which is photo-degradable.

By compounding appropriate additives into the plastics compound it is possible to produce a film which, after exposure to light (solar radiation), will start to break up at a predetermined time and eventually disintegrate into very small friable fragments. The time period can be 60, 90, 120 or 150 days and for maize a 60 day photodegradable mulch is used. However, there are still some further problems to resolve. It has been observed that the edges of the mulch, which are buried to secure the mulch to the soil, remain intact and became a litter problem when brought to the surface during the post-harvest ploughing. Currently much development effort is being made to find a satisfactory solution to this problem.

In direct contrast, in developing countries which have agricultural-labour available a different approach can be made. For example in the Peoples Republic of China trials have been made using a plastics mulch of 15 micron thickness on a sugar cane crop. After the rattans have been planted through the mulch they are left to grow for a period of one month. At the end of this period the mulch is removed, by hand, and wound-up so that it can be utilised for a second season. A yield increase of 26% was obtained representing an increase of 30 tons per hectacre.

These two examples not only demonstrate the diversity of mechanisms available for resolving the problem of mulch removal, but also illustrate the different techniques which have been developed, in different countries, to utilise the advantages of plastics mulch to increase agricultural yields. It also indicates the necessity for each country to adapt and develop mulching technology to meet its own specific requirements of climate, resources and economics. To undertake such technology development there is a specific requirement that both plastics and agricultural development facilities are available.

4.6g Effects of mulching

In summarising the effects of mulching it will have been observed that this simple agricultural system can exhibit five positive influences on the development of plant growth.

a. Retention of soil moisture by prevention of evaporation.

b. Increase of soil temperature, dependant on mulch colour.

c. Suppression of weed growth, with black mulch.

d. Development of microclimate rich in carbon dioxide.

e. Maintenance of soil structure.

4.7 Soil sterilization.

The intensive cultivation of crops under environmentally controlled conditions in greenhouse is generally accompanied by an increase in plant disease problems. The conditions necessary for optimum plant production also enable microbiological pathogens to flourish. At the end of each cropping period it has become a routine system of horticultural management to sterilize the soil to eliminate soil-borne pathogens and other harmful pests. This has been achieved either by application of steam, which heats the soil to a depth of 20 cms, or by application of chemicals. Both are relatively expensive operations.

A promising new development from Israel is the solar pasteurisation of soils by plastics mulching without any chemical agent. A clear plastics film covers the soil area, which is kept moist by suitable trickle irrigation, and the soil temperature can rise to 44 -50^{0}C or higher during the hottest months of the year in semi-arid and arid zones. This temperature has been found to be maintained at depths of 5 to 20 cms. After one month of such treatment it was found that thermal killing of the pathogens was effective. In addition it was also observerd that there were other favourable results of such treatment. The micro-organisms which prevent re-infestation of the pathogens were enhanced and kept the soil free of infestation for up to a year. The soil fertility was improved and increases in yields ranging 35-200% were noted for crops such as tomatoes, cotton, peanuts and eggplant.

This solar pasteurisation system of disease control is of low cost, safe to use with no toxic residues produced, and requires no chemicals. However, it is limited in its use to areas which have suitable climates and the soil is free of cropping for at least one month. It is an application which warrants additional development effort.

4.8 Crop drying by Solar Energy

4.8a Drying of Tobacco

Solar energy as a heat source for the drying (curing) of tobacco has been used for a number of years in France, Germany and Italy. The driers are generally plastics film covered structures within which the tobacco leaves are suitably suspended.

Various types of structures have been used which are essentially dual-purpose, functioning as a greenhouse for market garden crops when not in use for drying of tobacco.

Some units are fabricated on the farm from local timber fitted with curved metal tubes which act as the arch support for the roof area. Other units are conventional plastics greenhouses. When used for drying tobacco the clear LDPE film is subsequently covered with an opaque film during the yellowing stage. If the structure is covered only with opaque film (black) it cannot be easily used for greenhouse growing without being recovered with a transparent film.

A development of this type of unit in France which is restricted to tobacco drying as its sole function has black metal plates for the roof structure, to act as solar collectors and radiators, and only the sides and ends of the structure are covered with clear film.

A more simple arrangement has been observed in Jordan where temporary structures are erected in the tobacco drying season, September - December period. The structures are made of wood, about 1.5 metres high, to form a rectangular shaped tunnel with a flat roof. These are covered with clear LDPE film and the tobacco is allowed to dry in these tunnels. At night the tunnels are covered over with hessian (cloth woven from jute) to prevent condensation problems that can occur with the rapid fall of night temperature which is normal in that region.

After five days the film is progressively removed from the tunnels and replaced by hessian so that the degree of drying is controlled to a technology which has been developed by the local personnel. It was interesting to note that the film used was clear LDPE film discarded from the greenbouses in the Jordan Valley. In addition it was observed that a roll of new LDPE film was also available for use, presumably in case the old greenhouse film failed in use through embrittlement.

4.8b Drying of forage crops

In Europe and in the USA much R and D work has been carried out to develop solar heating systems. Most of the systems that have been developed were concerned with producing hot water and associated heat storage facilities. These systems could have application in the heating of greenhouses, but with the low levels of insolation in Europe they are unlikely to be cost effective unless the cost of other energy sources becomes extremely high. On the other hand the higher levels of insolation in semi-arid and arid areas offers wider possibilities to exploit the use of solar systems and work is currently active in pumping water, low temperature storage and crop drying each of which has some plastics application.

A novel and low cost system for drying of forage crops has been developed in Germany by Schulz. Air is blown, by fans, through a black LDPE tube of 70 cm diameter and of 25 to 50m length. This black absorber-tube is located within another but larger tube 80cm diameter of transparent (clear) LDPE. Through a hole situated at the start of the inner-tube sufficient air is allowed to enter the space between the two tubes, and this forms an insulation air layer between the tubes. It also stabilizes and acts as a support carrier for the outer tube.

Through the greenhouse effect of the transparent outer tube and the heat absorbsion characteristics of the black inner-tube the air passing though the inner-tube is raised in termperature. On a sunny day, with an outside temeperature of 20^{o}C, under cloudy sky conditions a temperature lift of 4 to 5^{o}C was recorded. The continuous flow of heated air has been used to dry crops of cereals, hay and straw.

This solar-heated crop drier offers potential opportunities for use in many other countries. Solar heated driers for coffee are being evaluated in Kenya which are also of low cost construction.

4.9 Crop storage

There are a number of systems which have been developed for crop storage which involve plastics of which the following are some examples.

Galvanised wire mesh silos have been constructed for the storage of grain and are lined with LDPE film. Some include facilities for removal of the grain by use of a mechanical auger. This is a low cost and effective means of rapidly providing additional crop storage facility. Like all applications for plastics in agriculture, further development is necessary in each country to ensure the most economic solution to a particular problem.

In India their agricultural scientists developed the PUSA bin, which is an excellent example of intermediate technology. The traditional mud-brick built grain storage unit of about 2-3 tons capacity suffers from penetration of moisture and air. Thus the stored grain can deterioriate during a period of six months or so. Losses of up to 14% have been recorded. By sandwiching a LD PE film between the two mud-bricks layers forming the wall of the bin, suitably sealed at the joints by heat-sealing, an air tight and moisture-proof bin has been achieved. The whole operation was designed so that local farmers could carry out the construction by themselves.

In Hungary, a filament wound FRP silo has been constructed for grain storage. It has a capacity of several hundred tons. This example merely indicates the great strength that can be achieved with FRP composites when correctly designed.

Emergency storage of grain, in India, has been in jute bags built into stacks of about 40 tons, on wooden pallets, and covered with large LD PE sheets. These sheets were secured against wind damage, due to flapping of the film, by plastics nets and cords. The stacks were periodically vented and fumigated to prevent losses. Several million tons have been stored in open weather conditions by this technique with losses reported to be smaller than under conventional storage.

A small flexible container of about 2 ton capacity has also been developed in India which is fabricated from HD PE film. This is relatively cheap and indicates that there are a wide range of possibilities of using plastics for storage of grain and other agricultural produce. It all requires development to meet local environmental and social needs however.

4.10 Water Conservation:

4.10a Reservoirs:

Today, the use of LD PE film as a waterproof membrane for lining large agricultural reservoirs has become a standard practice.

The basic technique consists of excavating the ground to a predetermined depth, with low sloping sides. This "hole-in-the-ground" is then lined with large sheets of black PE film 250 microns thick, 7.5 metres wide and normally 30 metres long. Jointing between sheets is done by means of a specially formulated mastic, and a PE self-adhesive tape acts as a second line of security. The outer peripheral edges of the film are securely anchored by burial in a trench around the reservoir. The whole LD PE membrane is then covered to a minimum depth of 10 cms and the sides 20 cms. The nature of the back-fill used for this covering operation is unimportant and the excavated material can normally be used. However, if the material is coarse or contains sharp stones, then a layer of sand or soil should first be spread to act as a cushion. The reservoir is then ready for filling.

A PE film lined reservoir is known to have been constructed in Sudan a few years ago by a UK company using new techniques to protect against termite attack. The main advantage of the technique lies in its low cost compared to more traditional methods of reservoir construction.

Australian-style, circular ponds for water storage for cattle use are constructed of concrete. They inevitably tend to leak and can lead to large water losses. By utilising large sheets of PE film, development work has shown how, when building these ponds, they can now be made water-proof at relatively low cost. This is a good example of a development to a specific local problem.

4.10b Canal Linings

The use of LD PE film as a waterproof membrane for the lining of canals, so as to make irrigation systems practicable at low cost, has been undertaken in many parts of the world, including Iraq, Pakistan, India, South America, Australia, Canada and Romania. The purpose of the lining is to prevent seepage and control weed growth. In Canada more than 160 km of canals have been lined with LD PE film.

In the Rio Negro province of Argentina a large irrigation canal, more than 30 metres wide, has been successsfully lined with plastic film to eliminate water losses. The cost was more economic compared to traditional methods of lining.

In India much detailed work on canal lining has been undertaken since 1960. They have evolved a very economic lining system in which LD PE film is lined on the bottom of the canal, instead of the more usual bottom and sides. The sides are then lined with a double layer of bricks or concrete slabs, in their traditional manner, and the bottom is backed-filled with earth on top of the plastics film. There are several variations of this system depending on local conditions etc.

LD PE film which has been in use in India for 22 years has been examined and found to be still water tight and mechanically unchanged. More recently the matter of plastics film lined canals has been re-activated and papers indicating significant cost benefit have now been published in relation to various types of canal lining systems. More recently it has been decided to use LD PE film lining in canal restoration works.

4.10c Fluming

The use of a large diameter plastics layflat tube for transporting low pressure water is called "fluming". This type hose is also known as "Khrisi Hose" (farmer's hose) in India. Both PVC and LD PE layflat tubing can be used, of about 40 cm layflat width and 100-200 microns thick. (400-800 gauge). In the Argentine one kilometre length was seen in use to transfer irrigation water from one area of a farm to another.

4.10d Channel irrigation

The traditional channels used for leading water into the field for furrow irrigation also suffers from severe seepage losses. Lining of such earth constructed channels with LD PE film has been successfully demonstrated in India.

In Malaysia, FRP composites have been utilised to form prefabricated irrigation channels. This has been established to shorten the time required to construct new channels required in the expansion of their rice production programme. They also take up less land space than the traditional concrete channels which are extremely time consuming to prepare and install.

4.10e Trickle (Drip) Irrigation

There is an increasing trend to move to piped water supply for irrigation. This is particularly so where trickle irrigation is used. The principle of trickle irrigation (also known as drip irrigation) is to deliver to the plant roots only sufficient water for the plant's needs, thus achieving a more efficient management of limited water resources. The advantages of trickle irrigation are:

1. Water economy (30-50%) compared to furrow irrigation, thus larger areas can be watered for any given water resources;

2. Improved quality and size of agricultural product;

3. Increased yields of 20-40% compared with furrow irrigation and of 10-20% over spray irrigation;

4. The possibility of using water with a higher mineral content (saline) since the salt leads to the periphery of the wetted root zone, permitting root formation within the zone but away from the salt concentration itself.

5. Space between the beds is dry and this assists harvesting operations whilst undesirable weed growth is greatly reduced.

A wide variety of trickle irrigation systems have been developed which are of two basic types; low pressure and high pressure systems. Low pressure systems are those which operate at pressures below 2.5 Bar (25 psi) and high pressure systems which generally operate at 3.0 Bar and upwards. Each have their own area of application.

Low pressure systems can be utilised with the emitters (drippers) having a relatively wide orifice for the drip. They therefore tend to be free from clogging problems which are more apparent in the high pressure systems where the water orifice is generally of very small diameter. Good filtering systems for the water should be used with both types for trouble free irrigation.

All the systems involve design mechanisms to reduce the water pressure at the emitter (dripper) so that water is applied on a 'drop by drop' basis to the plant. The initial capital investment cost varies greatly depending on the choice of system and degree of sophistication required. The nature of the systems vary from that designed for use in Indian Village farming to completely automated systems used in some developed countries. Sophistication of the process involves the introduction of metered nutrient solutions into the irrigation system for more economical utilisation of resources.

Initial development and usage of these systems was in high intensity cropping in greenhouses where the system could be automated and thus lead to a reduction of labour. However, from 1960 onwards various trials have been conducted on open crops, and the system modified to produce satisfactory results under these conditions. The work received an impetus from countries like Israel and Australia where there are water resource limitations which hastened this development. From 1970 serious exploitation of this system of irrigation has been undertaken not only in Israel and Australia but also in Argentina, Germany, India, Italy, Mexico and the USA.

It has been reported that at least 15,000 hectares were now irrigated in the USA by this technique. An indicative cost (1980) of the tube system fitted with drip nozzles was 500-700 US$ per hectare and this particular system was used for more widely-spaced crops such as fruit trees in orchards.

Flat sheathed and other systems are principally used for close-grown crops such as vegetables in open fields, and food crops and flower crops in greenhouses, and here the cots were 600-1200 US $ per hectare of which 50% or more was made up by the mains and secondary pipes which are used for distribution of the water to the sheaths.

There appears to have been little, if any, development work undertaken to attempt to reduce this initial investment cost by reduction of the cost of the pipes used etc., and this is certainly an area which warrants attention.

Some controlled comparison trials of drip and furrow irrigation of tomatoes has been carried out in the USA. It was concluded that drip irrigation used less water and the tomato yields were higher than with furrow irrigation.

Various methods of trickle irrigation in the Arizona desert for growing pecans and lettuce has been evaluated. The water saved by the use of trickle irrigation was significant. Lettuce was produced with only 25% of the water normally required; and three years old pecans grew with only 20% of the water used in furrow-irrigated plantings. Salt accumulation was less in trickle irrigated plots, and further studies are to be undertaken to find an optimum situation for crop growth.

Of the trickle systems on the market, most have been developed to suit the requirements of developed countries. There are many possibilities to reduce the systems cost; but even at the present investment level the cost benefits are significant.

Trickle irrigation is undoubtedly a technology which developing countries will find produces many benefits for water conservation as well as increased crop yields. The major area of interest traditionally has been in horticultural crops where high returns have been possible, but it is also spreading to citrus and other orchard crops as well as coconut plantations.

4.10f Drainage

Water storage, transport and distribution, as dealt with in the foregoing text, are all aspects relating to water conservation and usage. Another agricultural technique relating to water conservation is that of drainage. Drainage deals with systems for effecting a reduction of high water tables whether natural or man-made.

The use of plastics pipes and corrugated tubing for land draining is now well established. It competes with traditional tile drains, and has specific advantages of longer useful life since blockage due to silting is slower. Unplasticised PVC is used for this type of application, and it offers complete resistance to all types of soil conditions, being highly chemical resistant. The corrugated tubing is flexible, due to the corrugated nature of its construction, and can be coiled. It can be laid by an adaption of the standard mole plough technique thus avoiding the need to dig open trenches to lay it as required for clay tile drains.

By the design and installation of suitable drainage systems water-logged ground can be effectively drained to permit such ground to be brought into effective agricultural use.

The economics of drainage have to be carefully balanced. Even the drainage of different areas in the same country can show considerable differences in the system costs involved. This is a specific area where specialised expertise is required to design drainage systems to suit the particular local area conditions. It does not always follow that plastics will be the lowest cost system, but the installation period may be shorter in time and thus enable an additional crop to be grown than might otherwise have been possible. Thus special attention has to be given to the total overall benefits that can be obtained as distinct from just examining a systems costs for drainage.

5.0 Plastics Industry Development

The need, in developing countries, to undertake both the plastics and the agricultural development work should be of concern both to the Plastics Industry as a whole and also to the Government. For the plastics industry the use of plastics in agriculture generally represents a new market area both of large potential size and with the prospects of repeat orders. This represents a solid base for the development and expansion of a plastics processing industry.

For the Government the advantages to be derived for the national economy through the use of plastics in agriculture are great. There are also desirable social improvements arising through increased incomes which derive from increased and/or more efficient agricultural outputs. In addition the expansion of the market will also lead to additional employment opportunities.

However, in many countries much of the plastics processing outputs are directed to the easier household consumer market where product quality is not critical; and, in many cases, is a sellers market. Thus everything processed, whether good, bad or average is sold without question and quality control is often unknown. In such a situation the majority of processors are in business to make a quick profit and thus they only take a short term view. They are seldom interested in the medium term, yet alone the longer term development of future potential markets. Experience in many developing countries indicates however that there are normally a few companies who see plastics processing as a long term business and are prepared to back medium and long term development operations in principle, but generally are unable to undertake such work themselves for financial reasons. Against this background it is highly unlikely that the economic and social advantages that could be derived in the development of a country through the applied application of plastics in both agricultural and industrial uses will ever materialise unless there is some Government intervention or the plastics industry is able to organise itself in a financial and corporate manner to tackle such problems. It should be understood that there will always be a place in plastics processing for household consumer items like toys, combs, handbags etc. but it should not be to the exclusion of the development of wider market areas serving the national interest, of which plastics in agricultural applications is only one. Other areas of application cover packaging, transport, building and construction, electricals/electronics, medical, textiles, engineering, etc.

6.0 Plastics Technology Centre

In order to successfully develop these wider market areas against such an industrial background it would appear necessary to establish a suitable institution that would be equipped and staffed with specialists capable of providing the necessary technological development and subsequent technical services to support and strengthen the plastics industry, as well as providing suitable training facilities.

Such institutions have been promoted by UNIDO as 'Plastics Technology Centres' (PTC) or 'Plastics Development Centres' (PDC) in other developing countries, and represent one area in which UNIDO is able to assist in the industrial development of a country.

A PTC also performs other functions, for example by having a wide range of testing equipment available to service its own development programmes the PTC would also be able to determine the performance parameters of the plastics products relative to their economic application. Thus they would be able to assist the plastics industry establish meaningful draft standards, an essential step in the extension and development of markets for plastics products where performance characteristics are the main criterion for the product, for example, in agricultural, packaging and other industrial applications. In addition, the PTC would be able to undertake training operations at various levels as may be required by the industry.

The need to produce and supply plastics products to specific performance characteristics leads to the development and introduction of quality control and quality assurance systems. Marking the product with a specified standard mark is one way in which quality assurance can be introduced and thus build up the customer confide[illegible] required in these new areas of application. Nothing can be worse for the future of the industry than to have sub-standard products fail in use. In agricultural applications this can put a complete crop at risk. To help and assist the plastics processors understand the need for and to introduce quality control are areas again where a PTC could be of service to the industry. Its staff would be able to guide processors not only to have a better understanding of the processes they operate but of the technology involved and its influences on product quality. These examples are only a few of the areas in which the establishment of a PTC can help to strengthen and support the development of the plastics industry.

This brief explanation of the functions which such an institution could undertake emphasises the need for this to be an autonomous body. In many ways it would supplement the work of a technical service laboratory normally established by polymer producers to support their market development programmes. The establishment of such a PTC would also assist in bridging the communication gap that normally exists between Government, raw material suppliers, importers, machinery and equipment suppliers, plastics processors and above all, the ultimate users.

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8.0 Abbreviations

LD.PE	low density polyethylene
LLD.PE	linear low density polyethylene
PVC	polyvinylchloride
EVA	ethylene vinyl acetate co-polymer
PP	polypropylene
FRP	fibre reinforced plastics
R & D	research and development
MICRON	0.001 mm (thickness of a cigarette paper is 25 microns)
CIPA	International Committee for Plastics in Agriculture, 65 Rue de Prony, 75854 Paris, Cedex 17.