I. Introduction

What is Plastic Film Technology?

For a long time, agricultural production has been constrained by low temperatures, drought, short frost-free periods, over-abundant precipitation, waterlogging, saline-alkali effects, and other adverse impacts.

From ancient times, farmers have used traditional mulch technology to overcome these adverse conditions, for example, by spreading straw or fallen leaves on the ground to protect the roots of crops and by putting stones near the plants to increase the temperature of the soil and reduce evaporation. These methods are useful, but they have many limitations which result in them not being very effective in overcoming the problems mentioned above; they also cannot be used throughout all regions and on all crops.

In the 1950s, plastic film was introduced into agriculture as a new film material which brought about great changes. Plastic film technology is considered to be an important breakthrough, transforming traditional agriculture into modern agriculture.

Plastic Film Technology (or Technology for the Promotion of Root Cultivation) uses plastic film (usually polythene film) for plant cultivation.

In Plastic Film Technology (PFT), the surface of the earth is covered with polythene film (0.014 ± 0.003mm) in order to increase temperature, retain moisture, promote seed germination and emergence, accelerate the growth and development of roots and of the whole plant, and achieve high yields and good crop qualities.

Following the introduction of this technology in China in 1979, it has been used over large areas, has proved suitable for many crops, has increased yields by considerable margins, has been highly lucrative, and has become so popular with farmers that it has compared favourably with other agricultural technologies. At present, this technology is used throughout China in 29 municipalities, provinces, and autonomous regions. According to Chinese farmers, "it is a white revolution".

Global Use of Plastic Film Technology

Plastic Film Technology developed along with the petrochemical and high polymer chemical industries. Many countries have successfully applied PFT in agriculture. Japan, which started to use PFT in the 1950s, is one of the earliest countries to take a lead in the use of PFT and is still the leading country in developing new covering materials, manufacturing varieties of polythene film, and introducing technological innovations. The United States, France, Germany, Italy, and Spain have also made significant achievements in studying, applying, and developing covering materials.

At present, PFT is very popular in Japan and it has become an indispensable, agricultural cultivation method. PFT was first used in greenhouses, in plastic canopy cultivation, and then on open land. Many crops, such as seasonal vegetables, peanuts, sweet corn, tobacco, rice, potatoes, sweet potatoes, soyabeans, sesame, tea, mulberries, citrus fruits, apples, pears, peaches, and grapes, have been cultivated using PFT. Out of these tobacco, sweet corn, strawberries, garlic, and lettuce are exclusively cultivated by using PFT. PFT helps prevent damage from insects and diseases, improves the quality and maturation of products, promotes earlier maturation, and increases yields by 30 to 50 per cent and sometimes by 100 per cent or more. By using PFT, many thermophilic crops can be successfully cultivated in the northern areas where such crops have never been cultivated. It has been proven that PFT can be used in arid areas (because it retains moisture and increases soil temperature), in cold areas with short frost-free periods (because it increases soil temperature and effectively prolongs the growth period), and in wet areas with high temperatures (because it protects crops from waterlogging and controls the loss of nutrients from the soil).

In Japan in 1975, PFT was applied in the cultivation of vegetables, peanuts, tobacco, and rice, over an area of 158,00 hectares. In 1977, this increased to more than 200,000 hectares, accounting for 16.7 per cent of the total area (except for orchards and pasturelands). During this period, plastic film application machines were popularised in Japan. Large or medium-sized machines could be drawn by tractors and small-sized machines were suitable for manual operation.

In order to promote the development of PFT, an Association of Rice Cultivation with PFT was formed in 1965 and the name was changed to the Japanese Association of Plastic Film Technologies in 1969. The association is responsible for research, demonstration, and extension through the organisation and mobilisation of agricultural institutions, universities, factories for manufacturing PFT products, and households specialising in PFT. These institutions have carried out a series of experiments and demonstrations on environmental changes caused by the application of PFT, studied the effects on the growth and development of various crops, and devised operating technologies for different crops. They have also studied the spectrum of various polythene films and their effect on the enzymatic activities and photosynthesis of roots. They have studied the effect of capturing and avoiding reflex light from different types of polythene films and the effect on the colour and quality of fruit. Through these efforts, Japan has been making improvements in the application of PFT.

The United States, which is not comparable to Japan in crop species and area, has considerable achievements to its credit also. It has carried out research on PFT and developed new covering materials. For example, the U.S.A. has studied and applied seedling-protective film in the field, disinfectant film to prevent diseases, biodegradable polythene film (which can be absorbed by the plant after use), and porous film sheet made of decomposable cellulose which can be used to protect seeds and soil from erosion.

R.L. Carolus of Michigan University carried out extensive experiments on vegetables by using black PF. The results of eight years' research (1954-1962) have proven that PF can promote the growth of vegetables in the early stages, increase the early stage yield, and increase total yields which vary according to species and varieties. For example, musk melon and cucumber are sensitive and respond better than tomatoes and sweet pepper; the early stage yield of pumpkins is higher than contrast crops by 18 per cent, and the yield of "Baby Hybrid" muskmelon, grown during cool seasons, increased by 76 per cent in comparison with contrast crops. The early stage yield of "Fireball" tomatoes covered with PF (with irrigation) increased by 109 per cent in comparison with contrast crops. R.L. Carolus considered that the advantages of black PF were that it is inexpensive, is durable, protects crops from weeds, saves labour, increases yields, improves the quality of crops, and has great potential.

California is the foremost State for strawberry cultivation in the United States. When the strawberry fields were covered with PF (black PF or black-white PF), strawberry yields reached 104 tonnes per hectare. In Hawaii, for pineapple cultivation, the land is first covered with black PF, holes are punched in the PF, and finally the seedlings are planted through the holes. It is believed that black PF can kill weeds and increase yields and that results are even better in arid areas.

G.J. Hoenmuth (1983) studied the effects of black PF and ridge farming on sweet potato cultivation in northern America. The production of American sweet potatoes is concentrated in the south mostly, but a well-known area for sweet potato cultivation stretches along the Atlantic coast from New Jersey to Georgia. In the north, e.g., New England, natural conditions are unfavourable for sweet potato cultivation. In this experiment, the "Gem" variety of sweet potato was cultivated by ridge farming and covered with black PF. The results showed the leaf area, the leaf number, and the total dried weight of viticulae of the experimental plants to be higher than contrast crops. The yield of tubers reached 18.6 tonnes per hectare. The number of first-grade tubers apparently increased. The experiment proved that it was possible to increase the yield of sweet potatoes in the northern areas.

PFT is not only used in semi-arid areas, but also in countries where sufficient water resources exist, e.g., the Mediterranean countries. In 1961, PF was used to cover only several hundred square metres of cucumber fields in France, but, after 10 years, the PF-covered areas had reached 2,500 hectares and cucumbers, muskmelons, tomatoes, strawberries, lettuce, grapes, and asparagus were cultivated by the application of PFT. In 1965, Italy began to use PF to cultivate cash crops such as vegetables, strawberries, pineapples, tobacco, and coffee. From 1978 to 1980, a trial was carried out in Britain on cultivating potatoes by using PF and the yield of potatoes increased to six to seven tonnes per hectare and matured seven to 14 days earlier than before. At present, three kinds of polythene film (Coverall, Sanfilm, and Blanker) are popular in Britain.

In the CRS (the former USSR), in early spring when temperatures and humidity levels are lower, PF is used to increase the soil temperature and retain moisture. According to experiments using PF during 1974 to 1977, the maturation of strawberries was four to six days earlier than on open land. The leaf area, the number of stolons, the percentage of fertile fruit, and the yield were also higher. On the other hand, as the fruit did not touch the soil, the incidence of mould rot was lower than without PF, and the economic benefit was evident. The results of other experiments with PF showed that when the strawberry fields were covered by a small canopy above the ridge, the temperature in the canopy increased by 309.3°C, the relative humidity increased by 20 to 30 per cent, the percentage of fertile fruit increased by 26.5 to 78.4 per cent, and the total yield increased by 67.5 to 78.9 per cent.

In recent years, PFT has been applied and popularised rapidly in different countries. In Bulgaria, milk-white PF is used for tank agriculture (nutrient solution cultivation) and black PF is used for strawberry cultivation. The PF is replaced every three years. In Morocco and Algeria, the area of commercial vegetable gardens using PF has been increasing year by year. In the Netherlands, a comparative experiment on apple trees, which were grafted on to one-year old dwarf stocks covered by black PF and cultivated through sod culture, was carried out in News Station. After several years, the results showed that the yield of apple trees covered by black PF increased 1.5 times more than the yield of those cultivated using sod culture. In addition, the apple trees covered by black PF had advantages in terms of a strong root system and more lateral and small roots; less weed growth and protection from frost; and therefore savings in labour and cost. In Portugal, it was found that young pear trees covered by PF increased their trunk girth by 48 per cent. In Spain, newly-planted young citrus trees covered by PF compared favourably with other trees in terms of the damage caused by tilling and weeding. The PF also retained moisture and controlled weeds around the young citrus trees. In Tunisia, when a citrus orchard was covered by black PF, the yield increased by 50 per cent, the water for irrigation was saved by 30 per cent, and weeds were also controlled. In Cape Verde, it was found that less irrigation water was needed when PF was used in banana orchards.

According to the statistics of the Council of International Plastics for Agriculture (CIPA), every year the member countries of CIPA consume more than one million tonnes of plastic resin (excluding packing materials), 70 to 80 per cent of which is used to manufacture products to develop modern agriculture. Table 1-1 shows the areas using PF in different countries (1980-1983).

Table 1-1: The Areas Using PF in Different Countries

Unit: hectare

Country	1980	1983	Country	1980	1983
China	1,667	6,286,700	Hungary	1,000	-
Japan	175,000	207,441	German	1,775	-
American	80,000	-	Belgium	1,000	-
France	35,000	48,000	U.K.	300	1,000
Spain	26,000	32,600	Portugal	1,800	2,000
Italy	9,000	-	Czechoslovakia	320	500
Israel	2,000	-	Mexico	400*	-
Bulgaria	1,000	-	Argentina	400*	-

Source: Chinese Association of Plastic Film Technology : A Complete Value of Plastic Film Technology, 1988

Use of Plastic Film Technology in China

The petrochemical industry developed later in China than in the western countries. From the end of the 1950s to the beginning of the 1960s, PF was used to manufacture small canopies for vegetables to promote earlier cultivation in the suburbs of Beijing, Shanghai, and Tianjin. It was also used for rice seedling cultivation in some southern areas of China. In 1966, the first big PF canopy was used in Changchun, Jilin Province. In 1978, the area covered by big PF canopies reached about 5,400 hectares and parts of used PF canopies were used as ground covers, bringing evident economic benefits. But this technology did not become popular on a large scale because the PF used was very thick (about 0.1mm) and could not nestle close enough to the earth, therefore it was unable to increase temperature and retain moisture. In addition, every hectare needed about 1,500kg of PF, making it very expensive for and unaffordable by farmers.

In 1978, several PF technologies (including agronomic methods, special PF, and complete covering machines) were introduced from Japan into China. By means of comprehensive studies and demonstrations, PFT was gradually popularised throughout the whole country. In order to disseminate this technology over a wider area, and to promote the exchange of existing knowledge, some organisations were established to study and domonstrate PFT. In 1980, the Liaoning Association of PFT was formed. Under the association, several study groups conducted research on the following topics: vegetables, cotton, peanuts, tobacco, rice, and PF. As a result of the activities of the association, by the end of 1981 the area using PF reached 4,700 hectares, accounting for one-third of the total area using PF in the country. Since then, many study groups, associations, a united experimental group, and cooperative agencies have been set up in 17 provinces, greatly accelerating the development of PFT. In 1984, the Chinese Association of PF Research was founded in Beijing. Nine special study groups were formed for various crops and inputs: cotton, peanuts, vegetables, melons, tobacco, rice, sugar crops, PF, and PF machines, and, through experiments and demonstrations, PFT was further developed. At the same time, information on PFT and its applications was disseminated. These efforts were successful in popularising PFT over a wider area and in imparting training to personnel.

Over the years, the application of PFT in diverse areas and on a variety of crops increased rapidly and breakthroughs were also achieved in research. In 1979, the total demonstration area reached 1,600 hectares and, in 1982, it totalled 118,000 hectares. Again in 1984 and 1985, it reached 1.33 million hectares and 1.47 million hectares respectively. In 1986, it reached 1.80 million hectares, making China the world leader in terms of the extent of PF usage (see Table 1-2). In 1991, the total PF application area reached four million hectares.

In other countries, PF is mainly used to cultivate horticultural crops such as vegetables, strawberries, and melons, but, in China, it has been used successfully to cultivate more than 80 species, e.g., vegetables, cotton, peanuts, tobacco, and melons as well as for rice seedling culture, dried rice cultivation, sugarcane, beets, mustard, fibre crops, mulberries, tea, sunflowers, fruits, herbs, and medicinal plants. It is used extensively in nurseries, and more than 40 species have performed very well and yielded good profits.

Concomitantly, basic research on the effects of PF has been carried out by Chinese scientists. They have carried out comprehensive research on the effects of PF on the growth and development of crops, the function of metabolism in roots, enzyme activity, photosynthesis, formulation of yield, absorption and transportation of nutrients, and other physiological and biochemical problems. They have also studied the effects of light, heat, water, air, and fertilisers, while using PFT, on the germination of seeds, vegetative and reproductive growth, and the development of individual plant and crop population. They have put forward a theory of the "Relatively Stable Effect of PF on the Environment." The important conclusions are that the effective accumulated

Table 1-2: The Total Area of Crops Covered with PF in China (1979-1986)

(Unit: Hectare)

Year	The Total Area	Cotton	Vegeta-bles	Peanuts	Rice Cul-tivation Seedlings	Melons	Dryland Rice Culti-vation	Sugarcane	Beets	Tobacco	Maize	Other Crops
1979	442		433	07								02
1980	1,667	53	1,500	67		13						33
1981	20,733	3,927	7,147	2,513	1,400	327	37					0,050
1982	118,333	57,067	20,667	20,113	13,920	4,820	0,440					1,307
1983	629,133	437,980	50,527	39,200	72,333	20,933	1,093	3,000	0,320	1,180		2,567
1984	1,333,333	853,333	58,000	92,000	187,333	58,667	1,500	6,320	4,067	1,193	16,667	54,253
1985	1,466,667	589,333	99,333	266,000	212,000	143,333	5,400	14,200	5,533	7,200	40,667	83,667
1986	1,800,000	466,000	142,333	265,667	302,000	319,533	9,333	20,667	3,800	17,333	98,000	155,333
Grand Total	5,369,913	2,407,693	379,553	685,56	788,987	547,627	17,807	44,187	13,720	26,907	155,333	297,213

Source: Chinese Association of Plastic Film Technology: A Complete Value of Plastic Film Technology, 1988 temperature of each growing season can be increased by 200° to 300°C by using PF. Crops grow and develop seven to 10 days earlier because the PF helps to retain heat; PF enables some crops to be cultivated further north by about 2° to 5° in latitude, i.e., northwards by 500 kilometres. These conclusions provide a new scientific basis for the rational distribution of crops and rational land use.

Research on and manufacture of PF and its application machines advanced at a rapid pace. In 1979, PF of a special kind was developed for covering cultivated crops. Following this, new types, such as various shades of PF, light-reflex PF, weed-killing PF, light-degrading PF, long-lasting PF, and PF with slits, were manufactured. In 1983, two types of ultra-thin PF (HDPE and L-LDPE) were developed and these ultra-thin PFs enabled farmers to reduce the required amount of PF per unit area and also to reduce the cost. In the same year, the Ministry of Light Industry of China promulgated the standard of PF manufacture, through which the quality of PF was guaranteed and PF became easily available in the market. In 1980, the first application machine was manufactured and, in 1984, more than 60 types were developed, one after another, and, by the end of the year, the total number of application machines was more than 12,000. These machines increase efficiency tenfold. In addition, they can guarantee good operating quality, save the amount of PF required, and ensure that seasonal farming activities are carried out on time. These machines have been widely adopted on some big State farms in the northwest and the north of China. By the end of 1984, the area on which PF machines were used reached 133,333 hectares, accounting for 10 per cent of the total PF applied area.

Economic Benefits of Plastic Film Technology

Generally, PFT enables various crops to mature five to 20 days earlier than normal, increases the yield by 30 to 50 per cent, and increases output value by 40 to 50 per cent. By using PF, vegetable yields can be increased by 1,1250 to 22,500kg per hectare and the harvest period can be shifted or prolonged by 40 to 60 days. Cotton plants also bear more bolls before the hot summer days and more flowers before the frosty period, if PF is used. The cotton fibres also grow longer than normal. Peanuts grow vigorously and bear more fruit and seeds when PF is used. Compared to other methods, the yield of peanuts can be increased by 1,125 to 1,875kg per hectare with PFT. When water melon fields are covered with PF, the fruit matures 10 to 20 days earlier than normal and the sugar content increases by one per cent. When orchards are covered with PF, fruits, such as apples, grapes, and peaches, mature earlier and the quality also improves. For example, sugar content and Vitamin C increase and the colour of the fruit is better. It is found that when PF is used in rice nurseries, the quality of young seedlings improves and the cost is one-sixth of that of nurseries using small canopies.

The direct economic benefits from PFT accrue to farmers, extension workers, and decision makers. Table 1-3 shows the direct economic benefits obtained by farmers in two provinces of China.

When these seedlings are transplanted into the rice fields, their restoration period is shortened, more tiller seedlings are produced, and rice yield increases by 450 to 600kg per hectare. In forest nurseries, if PF is used, the percentage of successive

Table 1-3: The Economic Benefits due to Polythene Film Technology (PFT) from Different Crops in China

Unit : US$

Crops	Using PFT Output Value/ha	Without PFT Output Value/ha	Polythene Film Cost/ha	Net increased Value/ha	Ratio Input: Output
Yunnan Province			1985-1987		
Maize	411.6	184.8	48	136.8	1:2.85
Maize	688.8	450.0	60	178.8	1:2.98
Rice	468.8	300.0	48	120.8	1:2.50
Sugarcane	2044.8	1644.5	48	380.3	1:6.92
Watermelon	2586.6	1707.2	63	816.4	1:12.96
Tobacco	1191.6	744.5	60	387.1	1:6.45
Peanut	672.1	264.5	48	359.6	1:8.49
Jiangsu Province			1980-1982		
Potato	760.0	140.7	108	511.3	1:4.73
Cucumber	2978.4	1709.7	108	1160.7	1:10.74
Cucumber	1628.4	946.0	108	820.4	1:7.59
Chilli	2237.8	1385.7	108	746.6	1:6.88
Kidney bean	1146.0	828.0	108	213.0	1:1.97
Cowpea	918.2	622.9	108	187.3	1:1.73
Radish	665.1	230.9	64.8	369.4	1:5.70

Source: Collected by the author from various Chinese documents

seedlings can be transplanted earlier than normal. Plastic Film has been found to increase the output and value of sugarcane; because PF encourages the growth of stubble cane sprouts, the yield of sugarcane also increases by 4.5 to 15 tonnes per hectare. If PF is used, the yield of beet increases by 30 to 80 per cent without a reduction in the sugar content and the extracting season for beet is brought forward. Plastic Film raises the yield of food crops such as corn, wheat, Chinese sorghum, potatoes, and sweet potatoes by large margins.

From 1982 to 1984, the total PF area in the whole of China reached 2,095,000 hectares. When PF was used, the yield of ginned cotton increased by 407,000 tonnes, peanuts by 229,500 tonnes, vegetables by 1,896,500 tonnes, rice by 1,115,000 tonnes, and melons by 1,048,500 tonnes. PFT application also promoted the transformation of traditional agriculture into modernised agriculture, resulted in better crop zonation, in wider distribution of varieties, and improved the use of land resources. A few examples are given below.

In northern, northeastern, and northwestern China, the climate is characterised by inadequate rainfall and short frost-free periods. In order to promote the early maturation of cotton, peanuts, and corn, the farmers used to grow varieties having short maturation periods, or the early-middle varieties for which the yields and qualities were not good. After these crops were covered with PF, the accumulated temperature increased and the growing season was prolonged. The middle or middle-late maturing varieties, for which the yields and qualities are much better than the early varieties, could be grown on large areas, and the use of PF greatly increased the total output of these areas. In other words, various crops, which were not cultivated there before, can now be cultivated in the north, thereby making fuller use of land resources.

Earlier, farmers adopted the wild flooding irrigation method in which a lot of water was wasted and the crops were infested by insects and diseases. As PF conserves soil moisture and enables the root system to penetrate deep into the soil, PF is drought-resistant and its use can reduce water requirements and also the frequency of irrigation. Thus, water resources can be used fully and effectively.

Formerly, in order to retain moisture, farmers used to plant crops on low ridges. This had drawbacks such as making the soil hard and impervious, lowering soil temperatures, and inhibiting development of the root system. Plastic Film can be used to cover the ridges in high ridge farming, thus retaining the heat and moisture. Fertilisers are mainly applied on the ridges and the soil can maintain its wet, porous condition. Therefore, high ridge farming with PF can promote the emergence of seeds, accelerate the growth of plants, and cause crops to mature earlier.

How to improve and exploit saline-alkali soil is a complex agricultural problem. At present, effective measures are being used to improve saline-alkali soil, e.g., using lots of water for irrigation, mixing the soil with sand, digging deep furrows, and cultivating crops by transplanting seedlings. All these measures are successful, but the application of PF on saline-alkali soil produces better results because it effectively restrains salts and protects seedlings.

The information provided in this chapter gives cited evidence of the effectiveness of PFT. This technology requires quite low investments and yields rapid results with high benefits. It is considered to be a very significant innovation in agricultural development. Because of its multiple effects, it is suitable for application on diverse crops, therefore, it can be used not only in the plains and mountains, but also on low-lying, saline-alkali land and where rainfall is insufficient, or where drought frequently occurs. At present, this technology is rapidly becoming popular in both developed and developing countries. It has been successfully applied in Japan, the United States, Germany, France, and China. It is and will be an indispensable and important link in the development of cultivation technologies and will play an important and stabilising role in sustainable agriculture as a whole.