II. The Basic Principles of Plastic Film Technology

PF can transform solar energy absorbed by the soil increasing into thermal energy, thereby increasing the evaporation of water from the soil and facilitating the activity of soil microorganisms, thereby decreasing the rate of fertiliser use and improving the soil's physical properties. In comparison to open land, both the soil and the environment of the land covered by PF improves considerably. This integrated effect strengthens the physiological functions of crops and accelerates its growth and development processes, resulting in high yields and good quality.

Enhancement of Reflex Light and Increase in the Intensity of Photosynthesis

Enhancement of Reflex Light

Crops use solar energy in photosynthesis. Through this process, organic compounds (especially carbohydrates) are formed from carbon dioxide and water, resulting in the liberation of oxygen from chlorophyll-containing plant cells. The growth, development, ripeness, yield, and quality of crops depend on the hours of sunshine and the intensity of sunlight. When sunlight is received by the leaves on the surface, it is reflected among the rest of the leaves. In vigorous crops, the middle and lower leaves wither quickly because they do not receive enough light. By using PF, this additional light can be received from the reflex light of PF and from the drops of water which are trapped by the PF, thus enabling more light to penetrate between leaves and between rows.

According to research carried out by the Department of Horticulture of the Northeastern Agricultural College, China, 15cm above the earth surface the reflection from fields covered by PF is 14 per cent, but the reflection from open land is only 3.5 per cent, i.e., an additional 10.5 per cent of light energy will be used in photosynthesis with the use of PF. In 1981, Shanxi Institute of Cotton Cultivation observed that the reflection from cotton fields in which PF was used was higher by 28.2 to 40.8 per cent in comparison to open land. The Vegetable Institute of the Tianjin Academy of Agricultural Sciences discovered that the intensity of light reflected differed owing to altitudes and the width of ridges.

In the case of narrow high ridges, 20, 40, 60, 80, and 100cm above the bottom of the ridge, the reflection intensities are higher by 13, 98, 31.7, 12.1, and 9.2 per cent respectively and in the case of wide high ridges, they are higher by 91.6, 142.2, 116.4, 78.8, and 63.4 per cent respectively. It was concluded that the land between rows and plants received more sunshine on high wide ridges than on high narrow ridges.

PF can evidently increase the amount of sunshine received by crops, especially at 30 to 35cm above the earth's surface. At this point, the intensity of light reflected from PF is higher in comparison by 1,000 to 1,500lux. This increased sunshine not only accelerates the maturation of wheat and increases the weight of grains, but also facilitates the early emergence of cotton seedlings that are bigger and stronger.

The intensity of light reflection differs according to the colour of PF used. According to research carried out by Cao Xiao Zhi, the Horticultural Department of the Zhejian University of Agriculture, the highest intensity is received from silver PF and the lowest from black PF.

Usually, fruits growing inside the crown of a tree receive less sunshine. When orchards are covered by PF, the light reflected improves the colour and quality of apples, peaches, and grapes.

Prolonging the Effects of Light

Photosynthesis in crops can take place only under a certain intensity of light, the minimum intensity of light being the compensation point. With increasing intensity photosynthesis is strengthened and more organic matter synthesised. However, when the intensity of light crosses saturation point, the effects of photosynthesis do not increase and the crops will be harmed by the too strong light. PF not only increases the amount of sun-shine received by the land between rows and plants but also gives added light reflection and fuses scattered light, enabling crops to attain maximum light intensity and also preventing the light from decreasing to compensation point. In other words, PF can prolong the duration of efficient light, increase the intensity of light, and promote the utilisation ratio of light. Thus, the effects of photosynthesis are enhanced. Hence, PF can increase crop yields and promote earlier ripening.

Enhancing Photosynthesis and Strengthening Crop Functioning

The intensity of photosynthesis depends upon the duration of light, the intensity of light, the concentration of carbon dioxide, the amount of absorbed inorganic salts, the temperature of leaves, and the chlorophyll content. PF can enhance photosynthesis by providing more energy through increased intensity of reflected light and prolonged duration of light.

According to an experiment conducted by the Department of Horticulture of the Northeast Agricultural College, when a tomato field was covered by PF, the pure intensity of photosynthesis was 50.82mg while in the control field it was only 27.61mg. PF increased the intensity of photosynthesis by 23.21mg, i.e., 85 per cent in comparison to the control field.

According to another experiment conducted by the Department of Horticulture of Northeast Agricultural College, when a tomato field was covered by PF, the total area of the leaves was 94.15dm^2 (sq. dm.) and the coefficient of the leaf area was 4.49, while in the control area the same were 75.22dm^2 and 3.58 respectively, i.e., 23 per cent and 25 per cent less respectively. The content of chlorophyll increased by 25 per cent, the total sugar content by 26 per cent, and the ratio of C/N by 23 per cent. PF improves various physiological processes, strengthens the synthesis of organic matter, and increases the accumulation of dried materials, thereby enabling crops to increase their yields and to ripen early.

Effect of PF on Temperature

One of the important effects of PF is the increase in land temperature. PF provides thermal energy for the emergence of seeds, the growth of root systems, and for microbacterial activity in the soil.

Effect of PF on the Heat Exchange of Soil

The heat exchange pattern of soil covered by PF differs from that of open land. On open land, when solar radiation penetrates the soil, light energy is transformed into thermal energy. Thermal energy heats the air near the soil by exhausting efficacious radiation from the soil surface, enhancing the temperature of the soil surface, and evaporating water from the soil. During the night, thermal energy in the soil is emitted into the air by means of long-wave radiation. When the soil is covered by PF, the exchange and balance of natural thermal energy changes. During the day, sunlight penetrates the soil directly through PF and increases the temperature of the soil surface, consequently thermal energy shifts to the lower soil layer. Obstructed by PF, thermal energy is not emitted into the air and the amount of heat exhausted by the air flowing near the surface decreases, meanwhile, evaporated water is trapped by PF and the heat of gasification also decreases. This thermal energy is deposited in the soil and shifts to an under layer. So soil under PF receives more thermal energy than open land and the temperature in the cultivated soil layer also increases.

Effect of PF on Temperature and Its Changing Patterns

It has been proved by experiments and practices in different places (see Table 2-1) that PF can increase temperature. The degree of increase depends upon soil type, weather, season, region, and the growth stage of different crops. The increase in temperature range, resulting from the use of PF, is restricted by the kind of ridge constructed and the quality and kind of PF used.

According to an experiment carried out by the Institute of Cotton Research of the Chinese Academy of Agricultural Sciences, when slight and mid-saline-alkaline soil were covered by PF, the average temperatures were higher than on open land by 3.9°C and 2.7°C respectively. When flooded sandy soil, sandy loam soil, and slight sandy loam soil were covered by PF, the average daily temperatures were higher than on open land by 3°C, 3.3°C, and 43°C respectively. With increase in temperature by using PF, the rate of emergence and the stability and healthy growth of seeds can be enhanced. When PF is used to cultivate cotton, problems such as low temperatures of saline-alkaline soil in the first seasonal stage, plants that fail to emerge, late emergence, delayed maturation, and low yields of cotton can be solved. The Jingzhou Institute of Agricultural Sciences found that, notwithstanding the weather conditions, the temperature of the soil layer cultivated with peanuts increased when PF was used.

Different colours have different effects on temperature. According to research carried out by the Department of Horticulture of Zhejian Agricultural College, the range of temperature increase for various colours of PF was one to four degrees centigrade; e.g., opal PF, bi-coloured PF, and green PF can increase the temperature by two to three degrees centigrade; black PF and PF that is black on one side can increase the temperature by one to two degrees centigrade; and silver light reflecting PF can reduce the ground temperature by one to two degrees centigrade at noon within a five-day period but can increase the ground temperature by two degrees centigrade in the morning and evening. During the middle to late growth stage, when plants grow vigorously and shade the ground, PF does not increase the temperature of the soil, but, on the contrary, it decreases the temperature by one degree centigrade compared to open ground.

Table 2-1: Effects of Plastic Film on Soil Temperature

Increase in Soil Temp. (°C)	Test Time	Depth of Soil Layer (cm) 0	(0+5)/2	5	(5+10)/2	10	(10+15)/2	15	(15+20)/2	20	Average Temp. Increase (°C)
Plastic Film		33.6		28.5		25.2		24.5		23.6	
Open Land		27.8		25.0		22.4		22.0		21.6	
Value of Increased Temp.	8:00	5.8	4.7	3.5	3.2	2.8	2.7	2.5	2.2	1.8	3.3
Plastic Film		41.2		33.2		30.3		25.7		25.8	
Open Land	14:00	33.0		29.5		27.4		23.5		23.7	
Value of Increased Temp.		8.2	5.9	3.7	3.3	2.9	2.6	2.2	2.2	2.1	3.8
Plastic Film		26.9		28.0		27.4		26.4		24.6	
Open Land		22.3		24.4		24.3		24.1		23.0	
Value of Increased Temp.	20:00	4.6	4.1	3.6	3.4	3.1	2.7	2.3	1.9	1.6	3.0
Increase in Temp. per Day		6.2		3.6		2.9		2.3		1.8	
Range of Variation of Increased Temp.		3.6		0.2		0.3		0.3		0.5	3.4
Difference between Adjacent Layers			2.6		0.7		0.6		0.5		

Source: Northeastern College of Agriculture 1980

Accumulated Temperature

Crop growth and development take place under certain temperatures. Ground temperature influences the germination of seeds and affects the adhesiveness of solutes in soil solution. In other words, ground temperature has a very important influence on the growth, maturation, yield, and quality of crops because it affects the absorption intensity of water and inorganic salts through root synthesis and the physiological functions of roots. Therefore, ground temperature is more important than air temperature.

According to the experiment carried out by the Department of Horticulture of the Northeastern College of Agriculture, PF can effectively increase the accumulated temperature by 15°C which means that PF can increase the days of high temperature. For example, when kidney bean fields are covered by PF, the active accumulated temperature is higher by 190.9 per cent than on open land and it enables the plant to emerge 10 days earlier (see Table 2-2).

Table 2-2: Growth Period of Kidney Beans with and without PF Use

Growth Period	Sowing-Emerging		Emerging-Flowering		Flowering-Fruiting		Fruiting Harvesting		Total Days
	Date	Days	Date	Days	Date	Days	Date	Days	
Plastic Film	29 April - 7 May	8	7 May - 28 May	21	28 May - 29 June	7	4 June - 29 June	24	60
Without Plastic Film	29 April - 17 May	18	17 May - 4 June	18	4 June - 11 June	7	11 June - 3 July	23	66
Difference in Days		+10		-3		0		-1	+6

Source: North-eastern College of Agriculture 1980

The increase in active accumulated temperature can provide enough thermal energy for the emergence of seeds and the growth and development of crops so that they mature and bear fruit earlier. In this way, PF increases the yield of kidney beans and promotes early maturation. In the areas of early-maturing cotton in Liaoning Province, the active accumulated temperature from the date of sowing to the middle of July increased by 23°C, and this accelerated the emergence of seeds and the growth of young seedlings despite the damage caused by cold to the young seedlings in early spring. PF can provide precious thermal energy for early emergence, accelerated growth, and increased cotton yields.

The results of a trial carried out in maize fields in Hanghe County, Inner Mongolia, are given in Table 2-3.

From this table, it can be observed that the use of PF in maize fields can promote early emergence, strengthen the root system, accelerate growth, make full use of light and thermal energy in the early stage of growth, and overcome the effects of inadequate heat and of damage caused by cold, thereby increasing maize yield.

Previously, peanuts could not be cultivated on open land in Yichun, Heilongjiang Province, and Changtu, Liaoning Province. With the use of PF, peanut cultivation became possible; yields reached 2,250 to 3,000kg per hectare, and the area under peanut cultivation is gradually increasing.

In the north of Daqingshan, Inner Mongolia, watermelon did not ripen in many cases because of an inadequate accumulated temperature and a short frost-free period. The use of PF not only enabled the maturation of watermelon but also increased its yield.

As PF can facilitate a stable increase in accumulated soil temperature of 300°C, it is possible to cultivate improved, high-yielding varieties, increase the yield per unit area, and expand the area under thermophilic crops in northern China. Therefore, PF is

Table 2-3: Effect of PF on Accumulated Soil Temperature and Maize Yield

	Date of Sowing	Date of Emergence	Accumulated T. in 0 to 5cm Soil	Daily Average T.	Yield/ha
Maize Field with PF	4 May	15 May	295.0°C	24.6°C	10,470.3kg
Maize Field without PF	4 May	15 May	455.5°C	20.3°C	7,307.5kg

Source: Wang Yaolong et al. 1988

very useful in the exploitation of natural resources, appropriate use of land, and in the regional distribution of crops.

Acceleration of the Mineralisation Process of Fertilisers and Improvement in Soil Fertility

PF can maintain a wet, loose (porous), warm, and fertile environment by adjusting the balance of water, fertiliser, air, and heat. As a result, the activity of microbes in the soil is strengthened and the process of mineralisation of fertilisers is accelerated. The available nutrient elements and fertiliser efficiency also increase. PF enables the maintenance of a high level of soil fertility and provides a favourable environment for the growth of crops.

The Agricultural Bureau of the Xingjiang Autonomous Region has determined that, after using PF, the content of nitrobacteria and anaerobic bacteria in the soil increases ten times and the content of actinomycetes increases by 80 per cent. As the activity of these microbes increases and the mineralisation process of organic matter is accelerated, the available nutrients in the soil increase considerably during the early stages of growth. In an experiment carried out by the Institute of Vegetable Research, Shandong Academy of Agricultural Sciences, the content of available nitrogen in the fields in which PF was used was 165ppm in comparison to 110ppm in the control field, i.e., an increase by 50 per cent. The phosphorous and potassium content also increased when PF was used.

The nutrient content of a field covered by PF is evidently higher than that of an open field in both the full bloom stage and in the fruit-bearing period, and the exhaustion rate of nutrients is also higher than that of open fields. Therefore, it is necessary to apply more basic manure, additional fertiliser, and to maintain a high level of soil fertility to overcome the premature decay of crops and obtain sustainable high yields.

Reduction in Water Evaporation from the Soil and Maintenance of Moisture Content

The Law of Movement of Soil Water

Irrigation, precipitation, and groundwater are the water sources of soil. The main causes of water loss are evaporation from the soil surface, transpiration of crops, seepage of water into the ground, and less runoff on the soil surface. PF can change the natural distribution and movement of water in the soil and form a special law of distribution and movement. Firstly, it controls the evaporation of water from the soil surface and deposits the evaporated water under the

PF. This water that is deposited in the narrow space between the PF and the soil increases the atmospheric pressure of water and the saturation deficit is reduced. When the dew-point temperature increases, the water-drops are condensed and absorbed by the soil, especially in the mornings and evenings. With increase in temperature, they evaporate and, when the temperature decreases, are condensed again. This special water-cycle is constantly maintained with the use of PF.

When PF is used, more water is deposited in the cultivated soil layer, and this is absorbed by the crops. Secondly, due to capillary action the water in the deep layer rises to the cultivated soil layer through the capillaries. Rain or irrigation water cannot seep perpendicularly into the ridge that is covered with PF, but it can seep horizontally into the place where the roots are distributed. Generally speaking, this process lasts 24 hours. During this period, damage and/or crop failure caused by water-logging are prevented by the timely drainage of water. PF can also prevent the alluvial loss of soil nutrients caused by perpendicular water seepage. Water loss under PFT is mainly through the transpiration process. A certain amount of water runoff occurs from the crop holes on the PF (from the ridges). Therefore, retention of water evidently depends on the size and quality of PF.

Maintaining Water Content

Maintaining the water content of the soil is one of the main attributes of PFT, and this has been proved through practice. So PFT can be considered to be a drought relief measure that is simple and easy to deal with.

An experiment that was conducted in Helan by the Institute of Cotton Research of the Chinese Academy of Agricultural Sciences revealed that, before sowing, the water content in the soil was 20 per cent, and thirty days later, in the soil covered with PF, 1.3 per cent of the water was lost; in the soil in which PF was not used, 2.8 per cent was lost; and from 0 to 5cm under the soil covered with PF, 6.8 per cent was lost. Plastic Film evidently maintains the moisture content of the soil. It was also determined that, after 10 days of sowing 0 to 40cm under the soil, the open land lost 1.2 per cent water but the land covered with PF did not lose water. On the contrary, water increased by 1.2 per cent, showing that PF can make water rise from the deep soil layer to the upper layer.

In Lianing Shanxi, Inner Mongolia, the rate of soil evaporation is two to three times higher than that of precipitation. The effect of PF on water retention is very evident in these provinces.

According to a three-year research programme carried out by Liaoning Institute of Cotton-flax Research, during May, evaporation is very strong and the water content 0 to 5cm under the soil covered with PF is from 4.1 to 6.9 per cent higher than on open land at 10cm. Under soil covered with PF, it is 1.2 to 5.1 per cent higher than on open land. From 20cm under soil covered with PF, it is 0.58 to 2.31 per cent higher than that on open land. The tendency of water to rise from the deep soil layers has also been proved. It seems that if PF is used, contrary to natural law, the water content in the soil decreases progressively from the surface of the soil to the lower layer.

Water-saving Irrigation

Plastic Film can conserve moisture as well as increase moisture content. PFT can be applied to develop new methods of water-saving irrigation, leading to the economic use of water.

According to an experiment carried out by the Tianjin Institute of Vegetable Research, PF not only saves water but also increases yield. In the cooperative experiment carried out by China and Japan during 1986-1987 in Beijing, Shanghai, Shenyang, and Dalian respectively, vegetables were grown on ridges. The surface of the ridges was covered with PF and, above the ridges, there was a big canopy made of plastic film. Under the PF, vegetables were irrigated by drip irrigation and thus 20 to 40 per cent of water was saved. In addition, PF increased the intensity of photosynthesis, decreased moisture under the canopy, and prevented the occurrence of diseases and pests.

Improving the Soil's Physical Properties

As PF can prevent soil erosion caused by wind, rain, and irrigation and can reduce the hardening and imperviousness of the soil caused by treading by man or machine, water can seep into places where the root system is distributed along the sides of ridges, thus keeping the soil in a loose and ventilated condition. Three phases of soil can be changed by the use of PF. In other words, the volume of the solid phase reduces the volume of the liquid phase and the volume of the air phase increases. Soil covered with PF is evidently less compact and low than that of open land. This ensures a sufficient supply of oxygen for the growth of the root system and enables the root system to penetrate deep into the soil layer. A strong root system helps maintain a high absorption capacity enabling plants to resist drought. It also provides a good foundation for the growth and development of crops above the soil, increases yield, and promotes early maturation. However, if the soil is too loose, tall crops may lodge.

Effect of Keeping a Full Stand of Seedlings by Restraining Salts

The salt movement in soil is always facilitated by water. On open land, when water evaporates, salt is carried up to the surface of the soil where it gradually accumulates. Once the seeds emerge, the saline-alkaline soil causes the death of many young seedlings. As stated earlier, a special water-cycle is maintained under PF which washes the salt into the deeper soil layers. This results in a cultivated layer with lower salt contents on the soil surface, creating relatively favourable conditions for the emergence of seeds. Although PF cannot reduce the total content of salt in the soil, it can change the salt distribution pattern. As a result, it has the effect of keeping a full stand of seedlings by restraining salts and resulting in soils with slight and medium degrees of saline-alkaline contents.

According to an experiment carried out in Jiangsu Province, the salt content was reduced by 53 to 89 per cent after the field was covered with PF, and the percentage of full stand string bean seedlings raised from 62 to 66 per cent. Full stand Chinese wax gourd seedlings increased from 94 to 98 per cent but, on open land, full stand Chinese wax gourd seedlings reached only from 12 to 23 per cent even after filling up spaces by transplanting seedlings twice.

According to an experiment carried out by the Liaoning Institute of Cotton-flax Research, on low-lying saline-alkaline land with 0.2 to 0.4 per cent salt content, PF helped reduce the salt content by 27.2 per cent, full stand cotton seedlings reached 96 per cent in a field where cotton could not be cultivated in the past, and the yield of ginned cotton reached 1,575kg per hectare. This successful technology was popularised over 66.6 hectares of cotton fields, and the average yield of ginned cotton reached 1,350kg per hectare. Another experiment, which was carried out by the Institute of Cotton Research of the Chinese Academy of Agricultural Sciences in saline-alkaline fields, showed that, when a cotton field was covered with PF, the salt content under the soil from 0 to 5cm was reduced by 19.6 per cent and from 0 to 20cm it was reduced by 48.9 per cent. Similar results were also obtained in slight, medium, and heavy saline-alkaline soil.

Effect of PF on Diseases and Pests

PF changes the ecological condition of the soil, bringing about changes in the growth patterns and in the patterns of infestations by diseases and pests. Some damage is prevented, some exacerbated, and some delayed or accelerated. The inspectors of the China Cotton PFT Group found that PF can prevent damage by cotton blight and also prevent damage caused by cutworms and cotton aphids in the early stages. But heavy damage is caused by cotton bollworms, red mites, thrips, and aphids in summer.

According to experiments and observations made over a period of two years by the Institute of Cotton Research, Shangdong Academy of Agricultural Sciences, PF can reduce the incidence of cotton blight by 37.43 per cent and the mortality rate of young plants by 26.32 per cent, and it can increase the yield of ginned cotton by 25.2 to 70.69 per cent.

According to data collected by the Beijing Agricultural Bureau, when sweet pepper and tomato fields are covered with PF, it reduces viral diseases by 1.9 to 18.0 per cent, the disease index by 1.7 to 20.7 per cent, and tomato late blight and tomato leaf mould by 20 to 30 per cent. Downy mildew in cucumber is reduced by 10 to 15 per cent and egg plant blight by 20 to 30 per cent. This happens because PF controls disease-producing germs that are spread by rainfall.

Virus disease in tobacco fields is a very serious problem. According to investigations carried out by the Institute of Tobacco Research of the Chinese Academy of Agricultural Sciences, PF accelerates the growth of tobacco, and therefore the peak period when aphids occur is avoided. The occurrence of viral diseases of tobacco in the open field is about 30 to 40 per cent, sometimes reaching 90 per cent. But covering the field with PF can reduce it to five per cent because it is aphids that cause viral diseases.

Effect of PF on Weeds

There are two reasons why PF can control or kill weeds. Firstly , once the field is covered with PF and the planting holes are tightly sealed, the air temperature between the PF and the ground surface can reach 50° to 60°C during the day, and this definitely scorches or burns the young weeds. Secondly, black, one side black, light-reflecting PF, and green PF reduce the sunlight seeping through, or change the components of light, so as to restrain or kill the weeds. For example, in the Institute of Pomology of the Chinese Academy of Agricultural Sciences, when light-reflecting PF was used to cover apple orchards, the results showed that 91.7 per cent of the weeds were controlled. According to another investigation carried out by the Agricultural Bureau of Wanrong County, Shanxi Province, before the maize fields were covered with PF, there were 105.4 weeds per square metre in May. After one month, with the use of PF, most of the weeds were scorched and only 4.8 per square metre remained. This implies that weeds are destroyed at the rate of 95.4 per cent.