III. Application of PF in Food Crop Cultivation

Cultivating Rice Seedlings with the Use of PF

Cultivating good rice seedlings is a key measure and the basis of high yield in rice production. In southern China, during the season when rice seedlings are cultivated, the weather varies a great deal. Cloudy and rainy days occur very frequently and this inclement weather can spoil rice seedlings, prolong the period of rice transplantation, and hinder the growth and development of rice.

PF creates favourable environmental conditions which protect seedlings from spoilation, and it is an effective and economic method of cultivating strong seedlings. PF has proved to be an effective measure of guaranteeing early sowing, early transplantation, early maturation, and high yields.

Increased Yields

The advantages of using PF to cultivate rice seedlings are lower costs, higher economic benefits, and easy application. According to practice, the required amount of PF per hectare is about 150kg, which is 1/6 of the amount required for canopy-covered land and the benefit is four times that of canopy-covered land. Since 1981, this technology has been used in rice production. By 1986, 788,987 hectares of rice seedling fields were covered with PF. If PF is used, rice seedlings become very strong and they take root early after transplanting. They also ripen early, and forced ripening does not occur from the effect of high air temperatures during the heading period - in double-crop rice regions, or where there are double-crop systems, PF protects rice from damage caused by the cold in mountain areas.

According to data collected from 166 demonstration plots in six provinces of China (see Table 3-1), yields increased on 162, or 98 per cent, of the plots. From these plots, the average increase in yield was 495kg per hectare, i.e., 7.9 per cent. Yields decreased on four plots (2%). On these plots, the average decrease in yield was 373.5kg per hectare, i.e., 6.2 per cent.

In the double-crop rice region, PF not only increases the yield of the first crop, but also provides extra time for the second crop. For example, if PF is used, the first crop ripens five to seven days earlier, and the second crop can be transplanted five to seven days earlier. This prolongs the effective date of tillering for the second crop and lightens or prevents the damage caused by cold during autumn in the tillering-ripening stage. Finally, the second crop yield increases. Experiments carried out in Hubei and Anhui provinces show that, if the second crop is transplanted one day earlier, the yield can be increased to 150kg per hectare.

Cultivation Methods

i) Ground Preparation and Fertiliser Application in Rice Nurseries. The rice nursery should be flat. The width of PF used to cultivate rice seedlings should be 180 to 200cm, therefore the width of the rice nursery should be 150 to 170cm. On two sides of the nursery, 12 to 15cm of PF should be sealed with mud. If PF is used to cover the rice nursery, the film clings easily to the soil.

Table 3-1: Rice Seedling Yields in Demonstration Plots

Province	Number of Plots	Ratio of Increased Plots to Decreased Plots	Yield Increase			Yield Decrease		
			Yield Per Hectare	Increased Yield Per Hectare		Yield Per Hectare	Decreased Yield Per Hectare	
			(kg)	(kg)	(%)	(kg)	(kg)	(%)
Jiangxi	58	58:0	6358.5	630.0	8.87			
Hunan	4	4:0	7399.5	409.5	5.86			
Hubei	-	-	-	450.0	7.00			
Zhejian	22	18:4	5914.5	397.5	7.83	5707.5	373.5	6.15
Anhui	24	24:0	-	421.5	7.93			
Guizhou	58	58:0	6676.5-8889.0	663.0	9.93			
Average	166	162.4	6586.5-7183.5	495.0	7.9	5707.5	373.5	6.15

Source: Chinese Association of Plastic Film Technology 1988

If the PF clings too closely to the soil for three days, the young seedlings will die. So the correct method of tilling and preparing the nursery is to work on a fine day, three to five days before sowing, and to flatten (or level) the surface by irrigation. In this way, the nursery will be soft, loose, full of oxygen, and permeable.

The following principles should be adhered to in applying basic fertiliser in rice nurseries. Firstly, as PF decreases the loss and volatility of soil nutrients, an adequate amount of fertiliser is available in the soil. In order to avoid absorption of excess nitrogen by young seedlings, organic manure should be predominant in the base fertiliser used, and it is better to apply more phosphorous and potassium fertiliser; it is not convenient to apply these afterwards. The amounts of fertiliser needed are as follows: 18.8 to 22.5 tonnes per hectare of human/ animal excreta, 113 to 150kg per hectare of potassium chloride, 450 to 750kg per hectare of calcium magnesium phosphate, and 300 to 450kg per hectare of calcium super phosphate. Thirdly, organic manure and potassium fertiliser should be applied when the land is tilled or the nursery is prepared and the manure and fertiliser have to be mixed thoroughly with the soil. Phosphorous fertiliser should be applied when the nursery is already flattened or levelled and the seed is sown.

ii) Sowing Period and Sowing Rate. The sowing period depends on the temperature (the minimum temperature needed for the growth of rice seedlings is 12°C), the local conditions of light and heat, and the effect of PF on increase in temperature. According to experience, when the average diurnal temperature stabilises at nine degrees centigrade, the conditions are favourable for sowing cultivated rice seedlings by using PF.

Sowing should be carried out on a fine day. Usually, the sowing period is one week earlier than on open land.

If PF is used, the emergence of seedlings is 15 to 20 per cent higher. The sowing rate depends on the size of the seedling, e.g., when a seedling with three leaves is transplanted, the sowing rate should be 3,000 to 4,500kg/hectare; when a seedling with three to five leaves is transplanted, the sowing rate should be 1,125 to 1,500kg/hectare; and when a seedling with more than five leaves is transplanted, the sowing rate should be 600 to 900kg/hectare. In the case of hybrid seeds of early season rice, the sowing rate should be 225 to 300kg/hectare and, in the case of hybrid seeds of mid-season rice, the sowing rate should be 150 to 187.5kg/hectare.

iii) Seed Decontamination and Soaking. If PF is used to cultivate rice seedlings, diseases easily occur because of high temperature and high humidity caused by the film, so the seeds have to be carefully treated with chemicals. The normal treatment methods are as follows: the seeds are soaked in one per cent of lime solution for 48 hours; in areas affected by rice blast, the seeds are soaked in Formalin solution (0.5kg of Formalin mixed with 25kg of water) for three hours or in Kitazine solution (one kilogramme of water-dispersible powder of Kitazine mixed with 200 to 400kg of water) for 24 hours; in areas where there is rice bacterial blight, the seeds are soaked in Streptomycin solution (one ampule of 0.5 million unit Streptomycin mixed with 2.5kg of water) for 48 hours.

The decontaminated seeds have to be washed in order to remove the chemicals. After that, the seeds have to be soaked in water for three to four days, enabling them to absorb sufficient water (the saturation capacity of water is about 4% of the seed weight). Under proper temperatures, the soaked seeds can germinate well and emerge evenly.

iv) Covering Method and Separating Materials. Usually, in practice, PF is spread flat on the bed. In order to prevent the plastic film from sticking to the muddy bed after sowing seeds, it is necessary to spread a thin layer of plant ash mixed with husk so as to separate the PF from the muddy bed. The separating materials could be crop ash, excrement of animals, and crop sticks and husk, or a mixture of all these materials. These separating materials not only prevent the PF from sticking to the muddy bed, but also increase temperature, protect roots, and enhance the effects of fertiliser. After the separating materials are spread, it is time to cover the bed with PF. Normally, the suitable covering period is for about 15 to 20 days, depending upon weather conditions, the maturation period of varieties, and the required leaf age of seedlings. The appropriate time to remove the PF is when the daily average temperature reaches 14°C, when the minimum temperature is not less than 10°C, and when the seedlings have reached the required leaf age.

v) Care of Seedling Beds during and after PF Application. The main precautions that should be taken while using PF are to ensure that the seedling beds are sealed by PF, to prevent PF from

sticking to the muddy beds, and to protect the seedlings from withering so as to increase the rate of emergence and promote a strong and dense growth of seedlings.

When it rains, the water that accumulates on the PF should be drained away in good time. The water that accumulates on the PF should not be kept for more than two days, otherwise the seedlings will suffocate or will be pressed down. With increase in leaf age, the resistance of seedlings will gradually decrease under the high temperatures brought about by the use of PF. When the seedlings have grown a couple of leaves, the PF cover should be removed to ventilate the seedling beds and decrease the temperature, so that the seedlings can adapt to the natural environment outside. According to research, when the daily mean temperature on a fine day is more than 25°C, the extreme maximum temperature of the PF can reach more than 40°C. In practice, when the temperature under PF reaches 32°C, the two ends of the PF should be drawn back to ventilate the seedlings and decrease the temperature during the day and then be replaced again in the evening.

After the PF is removed, additional fertiliser should be applied to the seedling beds. Usually, it is necessary to apply urea and potassium chloride at the rate of 60kg and 75kg per hectare respectively or to apply thin dung water at the rate of 6,000 to 7,500kg per hectare. Five to seven days before, urea should be applied at the rate of 60kg per hectare so that the seedlings can develop new roots. In the case of hybrid seeds, as the seedlings need more tillers, fertiliser should be increased one or two-fold.

Low temperatures and cold may damage the seedlings after the PF is removed. If this occurs, the seedlings should be covered with PF again or the seedling beds should be irrigated to protect the seedlings from damage caused by cold. The surplus water should be drained off after the temperature rises.

Cultivating Upland Rice with PF

It is possibile to shift rice cultivation from the traditional water fields to dry land by using PF, and this is called upland rice cultivation. It is thought that, where annual rainfall is more than 600 to 700mm pf, especially if there is more than 300mm of rain during the two months before head sprout, upland rice cultivation under PF does not require a planned irrigation system. When rainfall is inadequate, upland rice cultivation under PF is possible and a good harvest can be expected. During the key period of rice growth, irrigation should be carried out twice or thrice.

The Economic Benefits

According to experiences over a long period in the Liaoning and Jilin provinces of China, where, for most of the time during the whole season of growth, PF-covered upland rice fields were not provided with irrigation facilities, rice yields still reached 5,250 to 6,000kg/hectare. In 1985, in the three north-eastern provinces of China, the weather was characterised by low temperatures, little sunshine, serious droughts and floods, and a considerable decrease in the water on irrigated rice fields. However, the upland rice yields from a 5,333 hectare area reached

5,625kg/hectare when PF was used. In some places, the yields even exceeded the yields of wetland rice. For example, in Union township, Shuihua city, Helongjiang Province (N-47°), PF was used on 67.3 hectares of upland rice. The yield from 11.1 hectares reached 6,493.5kg/hectare, and this was higher than the normal yield of wetland rice (5,836.5kg/ha) by a factor of 11.3 per cent. It was estimated that, if the cost of PF was less than 375 *yuan* (about 69.4 US$) per hectare and the yield of upland rice under PF reached 3,000kg/hectare, PFT could be considered economically beneficial. In practice, a yield of more than 5,250kg per hectare is possible if PF is used to cultivate upland rice.

Cultivation Methods

Places that are suitable for cultivating upland rice by using PF are low-lying land, easily flooded land, mountain land with adequate rainfall, and sloping land. Heavy saline-alkaline land, clayey land, soil that leaks water, land that is waterlogged throughout the year, and regions with little rainfall and without irrigation facilities are not suitable for upland rice cultivation under PF.

i) Preparing the Ground and Fertiliser Application. Ploughing, harrowing, and constructing ridges can be carried out during autumn or spring, but it must be ensured that the ground is fine, flat, and tight. Stones, root residues, weeds, and wasted PF should be removed.

As it is difficult to apply fertiliser after the land is covered with PF, application of basic manure is necessary and it should be carried out after the first harrowing. Harrowing should be carried out again to ensure that the manure is mixed evenly. In the first year, excess nitrogen and chemicals should not be applied in order to avoid overgrowth, diseases, and lodging.

During the later stage of rice growth, if the rice plants lack fertiliser, proper application of additional fertiliser is necessary. One method of application is to mix the chemical fertiliser in water when rice plants are irrigated. The other method is to apply chemical fertiliser on the PF before rainfall, so that the fertiliser can be carried by rain to the plant beds.

ii) Treatment of Seeds. Before sowing, the seeds have to be exposed to the sun for two to three days. In order to improve the quality of seeds, they have to be soaked in salt water or ammonium sulphate water. The solution is prepared by adding 10 to 11kg of salt or 10 to 12.5kg of ammonium sulphate to every 50kg of water. The amount of seeds poured into the solution should not be more than half of the solution, and they should be carefully stirred. After a while, the shrunken seeds and other impurities float to the surface and these should be removed from the solution. The plump seeds that sink to the bottom should be selected for sowing and have to be washed twice in clear water.

The selected plump seeds should be decontaminated by soaking them in a caustic lime solution. If the temperature of the solution is 10 to 15°C, the seeds should be soaked for six days, and if the temperature is 15 to 20°C, four days are enough. It has been demonstrated that if seeds are soaked in Topsin solution (70% of water-dispersible powder is mixed with

800-1,000 times of water) for 72 hours, or in Bavistin solution (10% of water-dispersible powder is mixed with 300 to 500 times of water) for 48 hours, rice blast can be prevented. The decontaminated seeds have to be soaked in warm water to hasten germination. If the temperature of water is more than 15°C, four to six days are enough. When the seed husk is broken, the time is right for sowing.

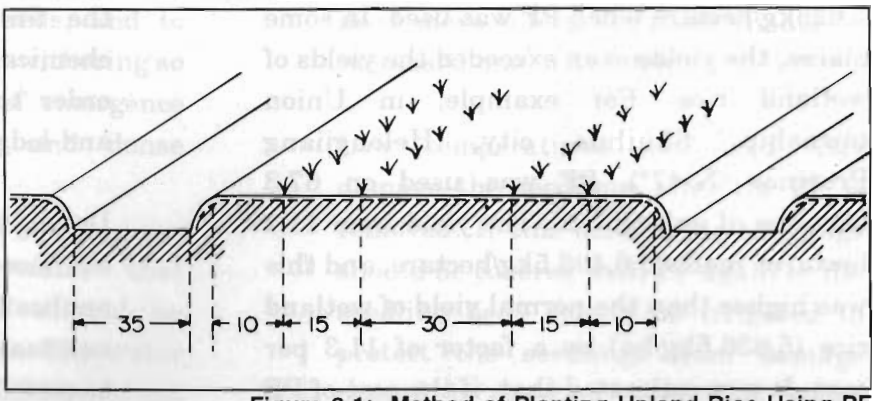

Figure 3-1: Method of Planting Upland Rice Using PF (Unit: cm)

iii) Planting Method. At present, plantation of four lines per ridge is practised (see Figure 3-1). Common plastic films are one metre wide, so the width of the ridge should be 85cm. On the ridge, the space between double lines should be 30cm and the space between the two lines should be 15cm. The distance between the edge of the ridge and the sideline should be 10cm and the distance between two plants should be 10 to 15cm. The walking furrow should be about 35cm. The method of planting and the density of plants can vary, depending upon the features of the plant variety, soil fertility, planting season, and method of cultivation.

iv) Sowing Seeds. After the flat ground is ready, sowing should be carried out according to the planned distance between rows and plants. When the mean temperature over a ten-day period reaches eight to nine degrees centigrade, the temperature of the soil surface under the PF should be more than 12°C and is suitable for sowing. The current practice is to sow the seeds first and then to cover the seeds with PF. Seeds are either sown by hand or with a planter, and eight to 10 seeds are planted in each hole. After sowing, the holes have to be covered with one to two centimetres of soil and pressed tightly. In order to control weeds, weedkillers should be applied before covering the seeds with PF.

v) Controlling Subterranean Pests. Moles, crickets, and grubs are the main pests that damage the seedlings, sometimes they almost destroy the whole rice field. Experiments have proved that Thimet (phorate) is effective in controlling these pests. Usually, 22.5 to 30kg of five per cent Thimet granules are mixed with 225kg of fine sandy soil on one hectare of rice field. This mixture can be applied within rows, or evenly spread on the ridges. If these pests occur again, when the seedlings grow three or four leaves, the same pesticide mixture can still be used by mixing it with 300 to 500 times the amount of water and pouring it into the holes where the seedlings grow. In this way, 95 per cent of the pests can be controlled. Dylox (dipteryx) can be used as a poison for the effective control of pests.

vi) Controlling Weeds. Cultivating upland rice under PF can fail if weeds are not

controlled. When the rice field is covered with PF, it is impossible to carry out inter-cultivation and weeding. The only way to control weeds is to sprinkle weedkillers before covering the field with PF. Application of a mixture of Nitrofen and Saturn (the commercial names of weedkillers) has proved to be effective; the former has a broad-spectrum effect and the latter's effects are prolonged over a longer period. When they are mixed together, the joint effect is better than that of any single weedkiller. If the ground is carefully prepared, weedkillers can be sprinkled evenly. To make the application effective, the soil should not be moved and covered immediately with PF. If some weeds do grow and push up the PF, earth should be placed on the PF. This will cause the weeds to die under the high temperatures.

vii) Covering the Soil. There are two ways of covering the soil with PF, i.e., manually or by machine. Depending upon the width of the ridge, shovel enough earth to press the edges of the PF, make two furrows on the two sides of the ridge, and then roll and spread the PF tightly against the surface of the ridge. The two sides of the PF are placed on the furrrows and earth is shovelled on to press them down. Finally, shovel some earth on to the surface of the PF at the required distance in order to prevent the PF from being torn off by the wind. The other method is by machine. After preparing the ground, use manpower, animal power, or tractor to roll and spread the PF on the ridge. Meanwhile, make furrows on two sides of the ridge and cover the edges of PF with earth. Some machines can carry out a series of operations such as ploughing, applying fertiliser, sprinkling pesticides, and spreading PF.

viii) Removing Seedlings. In most cases, the seeds are first sown and then covered with PF, therefore, the seedlings have to be removed after emergence. In order to maintain heat and save labour, it is reasonable to remove the seedlings twice. As the seedlings are heat tolerant, they should first be removed when 70 per cent of them emerge and removed again when all the seedlings emerge. In some places, seedlings are removed only when all of them emerge. Seedlings can be removed by making an "X shaped" hole with a knife or with fingers. It should be ensured that when the hole is made, the seedlings are not damaged. The hole should not be too big and, when the seedlings are taken out, some wet earth should be immediately put around the hole to seal it and prevent moisture from escaping.

ix) Irrigation. There are two water-sensitive stages during the growth of rice. During these two stages, adequate water content in the soil is required, otherwise the growth and development of rice is negatively affected. These two stages include the date of revival from transplanting and one month before heading and flowering. During these two periods, if the water content in the soil is less than 60 per cent of the maximum field capacity, proper irrigation is needed. If there are no irrigation facilities, in order to stop the loss of rainwater it is necessary to construct some checkdams at a certain distance from the walking furrows. If there is too much rainfall, these checkdams can be dug to divert excess water flow.

Maize

Maize is one of the most important food crops, especially for mountainous areas. Maize is also a high yield crop. In 1981, globally, the average yield per unit was 3,360kg per hectare, but, in China, it was 2,985kg per hectare. It is a big challenge to increase the unit yield. Application of PF in maize cultivation is one effective measure of increasing yield. During the last 10 years, maize yields have increased greatly as a result of PFT.

The Biological Characteristics of Maize and Its Adaption to the PF Environment

Maize needs a lot of water; 368 units of water are necessary to produce each unit of dry material. The need is less than those of cotton and wheat but more than those of sorghum and millet. During the period of vigorous growth, a single plant consumes 2.5kg of water every 24 hours. Every kilogramme of dry grain consumes 1,000kg of water during its lifetime. In northern China, water supplies are inadequate during certain stages of maize cultivation. In the seedling stage, over a ten-year period, drought occurs during nine of those years at that stage; in the growing stage, summer drought occurs; and annual evaporation is four times that of rainfall. In dealing with these unfavourable factors, PF has the advantage of being relatively waterproof and airtight, and this can be effective in preventing water vapour from escaping. In spring, when maize fields are covered with PF, water melts and can be maintained under the PF. This provides sufficient water for seed germination and emergence.

On the other hand, the most natural precipitation is stopped by PF and the water flows into the furrows which are not covered with PF. The water then flows crosswise and soaks the soil under the PF, consequently being absorbed by the maize roots.

Maize originated in middle and southern America and is a thermophilic plant. Normally, the growth period of early maturing varieties is about 80 to 95 days and they need an accumulated temperature of 2,100 to 2,300°C; the growth period of middle-maturing varieties is about 95 to 120 days and they need 2,400 to 2,600°C of accumulated temperature; and the growth period of late maturing varieties is about 120 to 140 days and they need 2,600 to 2,800°C of accumulated temperature. Seeds begin to appear between 8°C to 10°C and the minimum temperature required for emergence of the crop is 10° to 12°C. Below 0°C, the seedlings would be damaged. During the period of vigorous growth, the daily average temperature should be 22° to 26°C. If the temperature during the day is below 17°C and at night below 12°C, it would delay the growth of maize. If the temperature is higher than 32° to 35°C, and drought occurs, it would hinder the normal pollination process and if the temperature is lower than 16°C, and rain occurs, it would also hinder pollination and the subsequent growth of grain.

The minimum temperature that is required during the period from sowing to emergence is 0°C and the accumulated temperature is 75° to 120°C. When the maize fields are covered with PF, the required accumulated temperature is reached earlier than in the open field. Compared with the open field, the date of emergence may differ, but the accumulated temperature is almost the same. PF increases the active accumulated temperature. According to research, if PF is used, the accumulated temperature is maintained at 3,105°C from the date seeds are sown throughout the growth period and

the daily average temperature is 20.7°C, whereas that of open land is 2,797°C and 18.6°C respectively. This means that PF increases the accumulated temperature, at five centimetres' depth, by 308°C, i.e., a daily increase of 2.1°C. In other words, PF prolongs the season of growth by one month. Figure 3-2 shows the difference in temperature at a depth of five centimetres with PF and without PF.

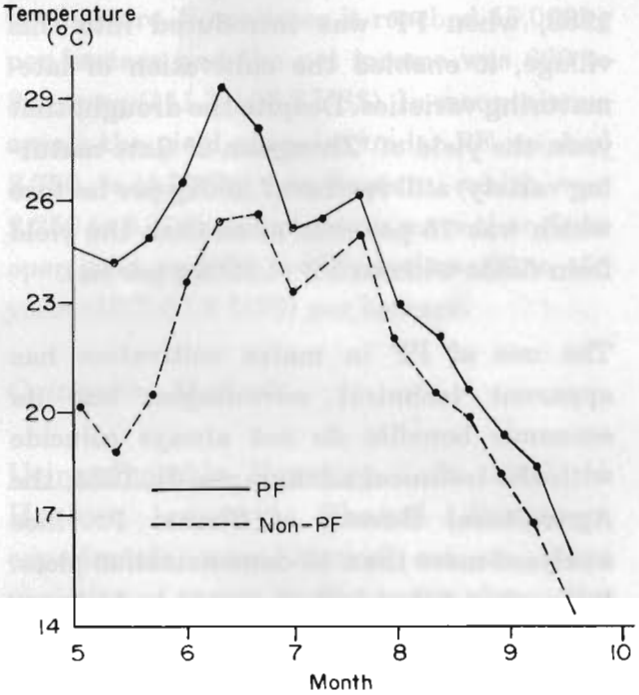

Figure 3-2: Temperature at a Depth of 5cm with PF and without PF

The remarkable feature of PF is that it promotes the early emergence and stable and strong growth of maize seedlings. Because of early emergence, the other processes of development, such as growth of stems, ears, grains, and maturation, are earlier. A significant point is that PF enables the filling stage of maize to coincide with the local season when temperatures are high. Usually, suitable temperatures for the filling stage range from 25° to 26°C. As temperatures during the period of sowing and emergence are lower on open land, the process of growth is delayed. When the maize plant reaches the filling stage, the daily average temperature might decrease between 20° to 24°C and can be sometimes lower than 16°C. Grains cannot develop well and are sometimes damaged by frost if the stage at which grains develop does not coincide with the season when the temperature is high.

If the maize fields are covered with PF, the damage caused by weeds can be reduced. According to an investigation carried out in Lobei Village, Datong County, Shanxi Province, in spring the temperature under PF reached 40° to 50°C and the maximum was 62°C. As a result, most of the annual weeds withered or died; Indian lovegrass *(Eragrostis pilosa)* and palmate meadow sweet *(Filipendula palmata)* were evidently controlled; amaranth *(Amaranthus tricolor)*, purslane *(Portulaca oleracea)*, common knotweed *(Polygonum aviculare)* became yellow and gradually withered; and hispid burnyard grass (*Echinochloa crusgalli* var. *hispidula*), yellow Elsholtzia *(Elsholtzia flava)*, and common reed *(Phragmites communis)* did not die but were controlled.

In addition, in Yanggao County, Shanxi Province, PF helped to reduce the incidence of dust brand disease that affects maize. The incidence of disease in the maize fields under PF was one per cent but in open maize fields it was seven per cent.

It was also discovered that PF can help to restrain salt movement in the soil. According to research carried out by Jinzhong Agricultural School, Shanxi Province, in May the salt content at a depth of 0 to five centimetres of soil layers under PF was 0.292 per cent but that of soil without PF was 0.438 per cent. Maintaining a lower content of salt in the surface layer is advantageous to the emergence and growth of young seedlings. When maize fields are covered with PF, a special "microclimate" is formed under the PF, and this microclimate is favourable for the biological characteristics of maize.

The Economic Benefits of Using PF

In 1979, this technology was first introduced in Lober village, Datong county, Shanxi Province. The yield per unit with PF was 9,495kg per hectare and the yield per unit without PF was 7,500kg per hectare. The rate of increase was 57 per cent. Encouraged by this successful experiment, the area of maize cultivation under PF expanded to 26,000 hectares in Shanxi Province in 1986. In 1985, Hubei Province popularised maize cultivation under PF in mountainous areas and the total area reached 22,600 hectares. The yield per unit under PF reached 4,980kg per hectare, compared to control (2,040kg per hectare) and the rate of increase was 1.4 times.

In 1985, in Bayanlour, Inner Mongolia, 680 hectares of maize fields were covered with PF. The yield was 11,385kg per hectare, compared to 6,150kg per hectare on open land, and the rate of increase was 84 per cent. In pastureland at high altitudes and with cold weather, where it is difficult for maize to ripen, 427 hectares of experimental maize fields were tested and the yield reached 8,100kg per hectare, more than in the fields without PF by 6,300kg per hectare. The rate of increase was 3.5. At Baoyintusamu fodder farm, at an altitude of 1,450m, and with an annual average temperature of only 3.9°C, PF was used on 6.3 hectares of maize field and the yield reached 9,564kg per hectare.

According to research conducted in Shanxi Province, maize covered with PF had the following features: the seeds were plump, the weight per ear was 200 grammes, and the weight of a thousand grains was 330 grammes, which was greater by 1.9 per cent and 13.8 per cent respectively than maize grains from open fields; available ears per plant totalled 1.21 pieces, which was greater by 0.17 pieces than the control; and the per cent of sterile plants was 1.8 per cent, which was lesser by five per cent than the central plot.

In Wanquan County, Hebei Province, there is a village called Houqizhuan which is located at 1,130m where the frost-free period is 120 days. Formerly, only the middle-maturing varieties could be grown there. In 1983, when PF was introduced into this village, it enabled the cultivation of late-maturing varieties. Despite the drought that year, the yield of "Zhongdan-2" (late-maturing variety) still reached 7,650kg per hectare which was 78 per cent more than the yield from fields without PF (4,290kg per ha).

The use of PF in maize cultivation has apparent technical advantages, but its economic benefits do not always coincide with the technical advantages. In 1984, the Agricultural Bureau of Shanxi Province analysed more than 40 demonstration plots. It was found that both the yield and income of nearly 80 per cent of the plots increased, yields increased on some plots but income remained the same, and some plots increased their yield but the income decreased. Further study showed that the absolute increased yield was more than 1,875kg per hectare, i.e., the output was more than the input. It can be stated that both the yield and the income increased. In Inner Mongolia, similar results were obtained, i.e., the ratio of input and output was 1:3.42. In Hubei Province, it was calculated that the investment of maize cultivation under PF was 858 *yuan* (159 US$) per hectare, the total income was 1,554 *yuan* (288 US$) per hectare, and the net profit was 699 *yuan* (129 US$) per hectare, which was 528 *yuan* (98 US$) more per hectare than maize cultivated without PF.

Since PF showed great potential for increasing the yield of maize, this technology

became popular very quickly. In 1989, the total area in China reached 57,466 hectares, the average yield was 6,395kg per hectare, and the increased yield was 2,772kg per hectare. In 1991, the total area of maize cultivation under PF in China reached 1,155,667 hectares, or twice that of 1989.

Usually, in the plains, the yield of maize covered with PF reached 6,000 to 7,500kg per hectare. Sometimes it reached 15,000kg per hectare and the net income was 600 to 900 *yuan* (111.1-166.7 US$). In mountainous areas, the yield of maize under PF reached 3,750 to 4,500kg per hectare, which was 2,250 to 3,000kg per hectare more than from open land, and the net income was 90 to 450 *yuan* (16.7-83.3 US$) per hectare.

Cultivation Methods

Using Suitable Varieties. In 1989, in Heshun county, Shanxi Province, experiments were carried out on three varieties of maize in the same place. The varieties were "Jidan-101", "Liguan-4", and "Yinglizhi". They were cultivated under PF, and all three varieties performed very well, but the yields differed. The increased yields per hectare were 3,165kg, 2130kg, and 2,190kg respectively. The difference in increased yield between "Jidan-101" and "Yinglizhi" was 975kg, accounting for 44.5 per cent of the latter. The results showed that selection of suitable varieties was of primary importance.

Preparing the Ground and Basic Fertiliser Application. After ploughing, the maize fields should be irrigated to ensure that the soil contains about 15 per cent water. When the maize fields are covered with PF, it is difficult to apply fertiliser, therefore careful preparation of the ground has to be combined with the application of basic fertiliser. Basic fertiliser should mainly consist of organic manure and proper chemical fertiliser. In Shanxi Province, the maize yield under PF on irrigated fields reached 10,500kg per hectare and the maize yield under PF on upland areas reached 6,000kg per hectare. To obtain these yields, 60 to 70 tonnes per hectare of organic manure, 600 to 750kg per hectare of ammonium bicarbonate, and 450 to 600kg per hectare of calcium superphosphate are required. All these fertilisers should be applied simultaneously when the ground is being prepared.

According to another study conducted in Shanxi Province, to produce 100kg of maize seeds, the plants have to absorb 4.25kg of nitrogen, 1.59kg of phosphoric acid, and 3.51kg of potash oxide (5:2:4) from the soil. If the expected yield is 7,500kg per hectare, the total fertiliser should consist of 375kg of nitrogen and 105kg of phosphoric acid. From the stage when joints appear to the stage when ears appear, the maize plant needs additional nutrients which can be provided by the soil only if PF is used.

Early Sowing and Increasing Plant Density. If PF is used, seeds can be sown four to seven days earlier than on open land. When the temperature of soil stabilises at 10° to 12°C, the time is appropriate for sowing. To derive full benefits from PF, it is necessary to determine the time when the local, daily average temperature is higher than 20°C, and this is essential during the silk advancing and the earing stages of maize. This affects the increase of ear weight and seed weight. Usually, the density of plants under PF is 52,500 to 60,000 plants per hectare, greater by 7,500 plants per hectare than plants cultivated on open fields.

Using Weedkillers. It is not possible to use PF to control weeds over large areas. Despite the fact that PF can control weeds and make

them yellow and withered, the weeds would consume water and nutrients and sometimes they would puncture the PF and emerge. It is better to apply weedkillers before covering the soil with PF. Common weedkillers, such as Lasore, Atrazine (Ametryne), and Simazine (Simetryne), can be used on maize fields. Care must be taken to apply the required amount, because usually the amount required on maize fields under PF is less by one-third than that needed on open fields.

Covering the Soil with PF, Sowing Seeds, and Removing Seedlings. The seeds should be sown and then covered with PF or vice versa. Either method can be used. Usually, the seeds are sown and then covered with PF because it is simple and advantageous if the soil moisture is retained while sowing the seeds. When the ridge is ready, a furrow should be made on the ridge. The distance between the bottom of the furrow and the PF should be about three to five centimetres. The seedlings can grow for seven to 10 days in furrows covered with PF. In this way, the seedlings are prevented from being withered and from damage caused by late frost. The PF has to be spread tightly on the ground and the edges of the PF should be pressed by wet soil (at least 10cm) so as to prevent it from being blown off by the wind.

The seedlings should be taken out after the late frost is over. Before taking them out, it is necessary to make holes in the PF (one hole should be 40cm) to let the hot air out. Sometimes, the temperature under the PF reaches 60°C. These holes lower the temperature and temper the seedlings. When the seedlings turn green and the weather is cloudy, it is time to take the seedlings out.

Economical Use of PF Material and Machine Spreading. As mentioned before, the success or failure of cultivating maize under PF depends not only on increasing the yield but also on increasing income. If farmers cannot realise substantial benefits, this technology cannot be popularised on a large scale. Decreasing the cost of PF is one way of popularising it. Firstly, it is necessary to determine the width of the ridge and furrows in the maize fields, because the amount of PF required per hectare depends on the coverage rate of PF, and the coverage rate depends on the width of the ridges as well as of the furrows. Experiments show that it is more economical and effective if the ridges are 40 to 45cm wide and the furrows are 100 to 120cm wide. In this case, if the width of PF is 70 to 75cm, the coverage rate of PF would be 65 to 75 per cent. Maize should be planted on the ridges covered with PF and other crops such as soyabeans should be planted in the furrows. Secondly, it is necessary to select appropriate PF material. In 1984, in Shanxi Province, a new PF named Linear Low Density Polyethylene (L-LDPE), with a thickness of 0.007mm and a weight of 6.44 grammes per square metre, was tested. Forty-five kilogrammes of L-LDEE is adequate to cover one hectare, therefore farmers can easily afford such PF.

Machines have been used to spread PF in some places. In Yijing Xiang (township), Yingxian, Shanxi Province, out of 800 hectares of maize fields which had to be covered with PF, machines were used to spread them on 355 hectares. According to investigations and calculations, machines were seven times more efficient than the manual method. When the PF was spread by machines, it was pulled taut, saving about eight per cent of the PF.

Wheat

Experiments on the use of PF technology in wheat cultivation were carried out in the

beginning of the 1980s in China. After two years of (1980-1981) experiments, the Agricultural Extension Centre of Gaocheng County, Hebei Province, proved that the use of PF in wheat cultivation could greatly increase the yield. After that, similar experiments were carried out in Hebei, Henan, Shanxi, and Beijing and some positive results were achieved. From 1983 to 1984, wheat cultivation under PF was carried out on 430 demonstration plots which were located in 77 counties of Hebei Province. The wheat yield reached 5,466kg per hectare, which was 1,702.5kg per hectare more than on open land, i.e., 43.8 per cent more. In 1983, in the Luoyang area of Henan Province, wheat cultivation under PF was carried out on 38 experimental plots which were located in 13 counties. In the wheat fields covered with PF, the average increased yield per hectare was 255 to 3,120kg, and the increase rate was from five to 53.5 per cent.

The Biological Characteristics of Wheat and Its Adaptation to PFT

Wheat is the second staple grain crop in China, and its cultivated area, which is only less than that of rice, accounts for between 1/4 to 1/5 of the total area of grain crops in the whole country.

Emergence of wheat requires a temperature of 15° to 20°C, loose soil, and sufficient oxygen and water. Under these conditions, wheat seedlings emerge after seven days. For the tillers of wheat to emerge, a temperature of 13° to 15°C is required and, if the temperature is lower than from two to four degrees centigrade, tillers cannot grow. When the soil water capacity is equivalent to from 70 to 80 per cent of the saturated soil water capacity, the primary roots grow well and conditions are also favourable for the growth of wheat tillers. If seeds are sown too late, the temperature of the soil will be low and the accumulated temperature will be insufficient for wheat tillers to grow before winter. In spring, the wheat tillers grow again. Usually, these tillers are not productive and the head sprouts do not grow well. If seeds are sown too early and too densely, the seedlings spindle; do not take secondary roots and tillers; fall over easily; cannot resist cold; and eventually die during the period of overwintering.

Winter wheat will sprout heads only after the vernalisation and photophases. During the vernalisation stage, winter wheat requires a temperature of from zero to five degrees centigrade for 35 to 50 days. If temperatures are not satisfactory, winter wheat cannot sprout heads and flower. Spring wheat requires a temperature of from five to 20°C for five to 15 days during the vernalisation stage. When wheat undergoes stem growth, its endurance to cold evidently decreases. Suitable temperatures for wheat flowering are from about 15° to 20°C and suitable temperatures for filling and maturing are from about 20° to 22°C.

The purpose of cultivating wheat under PF is to create favourable conditions for germination, emergence, and growth of seedlings and tillers. PF increases the soil temperature. According to investigations carried out in Henan Province, the overwintering period of wheat is about 51 days. Under the PF, the accumulated temperature on the surface of the soil increases to 102°C, that under five centimetres of soil increases to 96.9°C, and that under 10cm of soil increases to 102°C. Doubtless, the increased accumulated temperature has a positive effect on the emergence, growth, and tillering of wheat. On the other hand, the PF also provides the root system of the wheat with a relatively stable and wet environment. According to

investigations carried out in Ehijiazhuang, Hebei Province, 111 days after covering with PF, the water content in from 0 to 20cm of soil was higher than in soil on open land by two to four per cent. Another investigation was carried out in Shanxi Province, and it was found that the water content in from 0 to 10cm of soil under PF was higher by 2.9 to 5.5 per cent compared to that of soil on open land. It was also discovered that, under PF, water had a tendency to move from the lower layer towards the soil surface, and this is advantageous for overwintering wheat and for the growth of tillers.

Changes in soil nutrients under PF were studied by the Institute of Crop Research, Hebei Academy of Agricultural Sciences, and it was observed that decomposition, release, and consumption of nutrients in the soil were promoted and increased if the period under PF cover was prolonged (see Table 3-2).

Besides the availability of nutrients in the soil, the use of PF also brings about conditions that are favourable for the growth of the root system of wheat, e.g., loose soil and good air permeability.

Table 3-2: The Changes in PF Covered Soil Nutrients during Different Seasons

Soil Nutrients	Layer of Soil (cm)	Before PF (6 Dec. 1983)	After PF is taken away (5 March, 1984)			
			Contrast	Autumn Covering	Winter Covering	Spring Covering
Organic matters	0-20	2.15	2.16	1.88	2.07	2.22
(%)	20-40	1.85	2.11	1.29	1.47	1.27
Alkali hydrolysed	0-20	94.8	104.9	90.9	105.6	94.8
Nitrogen (ppm)	20-40	85.1	96.2	65.0	76.0	64.7
Available	0-20	11.7	61.3	47.6	70.0	51.3
Phosphate (ppm)	20-40	10.4	46.4	22.7	29.5	29.0
Available	0-20	247.5	187.5	210.0	163.8	181.3
Potassium (ppm)	20-40	187.5	148.8	115.0	138.8	113.8

Source: Chinese Association of Plastic Film Technology 1988

The Substantial Effects of PF on Wheat Cultivation

From 1983 to 1984, the Shanxi Institute of Crop Research investigated the overwintering period of wheat. It was found that the mortality rate of wheat seedlings without PF was 30 per cent but no seedlings died under PF. In spring, PF could decrease the mortality rate of seedlings by 18 per cent. In 1984, the Chaoyang Institute of Agricultural Sciences, Beijing, carried out a similar investigation and it was discovered that, during the period of overwintering, the mortality rate of wheat stems on open land was seven per cent and that no stems died under PF. According to an investigation carried out in Qianan county, Hebei

Province, in 1984, the average mortality rate of seedlings collected from 88 open plots was 22.9 per cent and that of seedlings collected from 32 plots under PF was 14.7 per cent. This meant that PF could decrease the mortality rate by 8.2 per cent.

Some investigations showed that PF was useful for forming strong seedlings, e.g., in Wanrong county, Shanxi Province, wheat was sown on the 13th of November, which was 50 days later than the normal sowing period, but those under PF emerged eight days earlier than normal and tillers started to grow 76 days earlier than normal. The Institute of Crop Research, Hebei Academy of Agricultural Sciences, discovered that, in the case of "Jimai-20", plants under PF had one more tiller, two more leaves on the main stem, 0.9 more secondary roots, and 91.6 square centimetres more leaf area than the control and in the case of "Jimai-7", the plant under PF had 1.3 more tillers, two more leaves on the main stem, 2.8 more secondary roots, and 61.8 square centimetres more leaf area.

Under PF, the respective stages of wheat growth, including maturation, shifted, and the period of each growth stage was prolonged as a result of which the number of spikes, number of grains, and the weight of grain increased. High temperatures, dry-hot winds, early summer rains, and hailstones, which occur in the late stages of wheat growth, were avoided. These weather patterns can be avoided by changing the timing of the late stages of wheat growth. According to data collected from Yiyang, Yichuan, and Limbao counties, Henan Province, under PF the elongation stage would move forward 20 days, the stage when heads sprout would move four to eight days the stage when grains develop would move five to eight days forward, and the maturing stage would move three to seven days forward.

Many facts have already proved that wheat cultivation with PFT has significant potential. In northern China drought and long cold periods are very common constraints in wheat cultivation. In this area, due to lack of water and low temperatures, the sowing of wheat is always postponed, seedlings cannot grow well, and the wheat is always forced to mature in the late growth stages. Therefore, the wheat yield is not much. Cultivating wheat under PF is an effective measure of overcoming these constraints and avoiding natural disasters, but there are still some problems. Firstly, if wheat alone is cultivated, the benefits are not high because of the cost of PF. Secondly, the variation in wheat yield depends on comprehensive factors which are created by a series of agronomical measures. Therefore, if the other measures are not coordinated with the use of PF, an evident yield increase cannot be expected. Some suggestions are given below.

i) A single sheet of PF can be used for multiple purposes. Firstly, the PF can be used to cover wheat. After the wheat seedlings turn green, the PF can be removed and then re-used to cover other crops such as cotton, vegetables, rice seedlings, and cash crops. According to information collected from different places, when PF is used to cover wheat, 70 to 80 per cent of the PF remains in a good condition and can be used again. For example, the amount of PF used to cover one hectare of wheat can be used to cover one hectare of cotton and several hectares of melons and vegetables, thereby getting maximum benefit out of the cost of PF.

ii) It is better to use PF on wheat fields without irrigation facilities and if wheat has been sown too late. The

common constraints are lack of adequate supplies of water, fertiliser, and heat, and therefore the seedlings grow slowly and are weak. PF overcomes these disadvantages and enhances the efficiency of water, prolongs the active period of growth, and increases the accumulated temperature. If PF is combined with enough fertiliser, the weak seedlings become strong, the growth stages are accelerated, and, finally, the yield of wheat increases.

Cultivation Methods

Preparing the Ground for Wheat Cultivation.
In order to obtain high yields, an adequate amount of basic fertiliser is necessary. Besides common barnyard manure, human/animal faeces, urine, and oilcake can be used to prepare basic fertiliser. In addition, chemical fertilisers should be mixed with organic manure and applied as part of the basic fertiliser. Usually 600 to 750kg per hectare of ammonium bicarbonate and 450 to 600kg per hectare of calcium superphosphate are required for wheat cultivation. The ground should be carefully prepared and all stones, big clods of earth, and root residues removed. It should be ensured that the wheat field is very flat so that the PF is not torn or worn out.

When the wheat field is covered with PF, the size of the wheat colony enlarges and the height of plants increases, so that the wheat plants easily fall over and are damaged by diseases and insects. Therefore, low-stalked, lodging-resistant, disease-resistant, and high-yielding wheat varieties should be selected.

Because PF increases temperature and creates favourable humid conditions, if fertiliser is adequate the wheat seedling colony grows fast, and the individual plants grow vigorously and grow more tillers. The sowing rate of wheat covered with PF should be less than on open land and the seeds should be sown evenly, but not deeply. When the seedling density is excessive, seedlings should be thinned and, if the seedlings fail to sprout, over-drilling is required. In order to control the damage from pests under the soil, pesticides should be applied before the wheat seeds are sown.

How to Spread PF and When to Remove It.
The PF can be spread in autumn, winter, and spring. In autumn, PF is spread when the seeds are sown, in winter it is spread when the wheat has emerged, and in spring it is spread when the seedlings turn green.

There are three methods of spreading. The first method is overall spreading in which all the wheat seedlings are covered with PF; the second method is punch-hole-spreading in which the wheat field is first covered with PF, then small round holes with a diameter of one to two centimetres are punched in the PF at the required distance, and seeds are sown in the holes (after the seeds germinate and emerge, they are removed from the holes and are grown in the open air); and the third method is micro-hole-spreading in which the first operation is the same as overall spreading, but when the PF is already spread, a certain quantity of micro-holes (each cm^2 has one hole) are made in the PF by using awls or needles, but the wheat seedlings still grow under the PF.

Generally, the time when PF is spread depends upon the status of the seedlings. If the colony of wheat is small and the seedlings are weak, then PF should be spread early. If the size of the colony is big and the seedlings are strong, the PF can be spread later. According to experience, the overall spreading method is better than the others.

During the period when PF is spread, it is necessary to inspect the wheat field in order to prevent man and animals from trampling. If there are spaces between the PF and the ground, immediately cover the spaces with earth. During winter, strong winds can lift the PF, so, to prevent this from happening, place some lumps of earth on the PF to press it down and prevent it from being worn and torn and to prevent the evaporation of heat and moisture.

PF should be removed in winter or in spring. If the PF is spread early and the seedlings are strong enough, the PF can be removed before winter (usually before December). In most cases, PF is removed in spring. When the air temperature stabilises at three degrees centigrade, it is time to remove the PF. In spring, if the seedlings are weak, the PF should be removed later on in the season, but, if they are strong, it should be removed earlier. Should the seedlings turn green and begin to develop joints, the PF has to be removed, otherwise the seedlings will be overcome by hot air and water. Four to five days before removing the PF, partially lift the edges of PF and let cool air in. This is called "hardening the seedlings", and it enables the seedlings to adapt gradually to the environment outside the PF. If the PF is suddenly removed, because of a low level of adaptability, the leaves of wheat seedlings would become yellow or withered.

Field Management before and after Spreading PF. Wheat fields that do not have enough moisture in the soil should be irrigated and then the PF should be spread before overwintering. Wheat fields in which PF is removed after winter require 75 to 150kg of urea per hectare combined with irrigation. After PF is removed, if the wheat seedlings become yellow and grow slowly, 60 to 90kg of urea per hectare should be applied. At the same time, more attention should be given to controlling weeds and pests. In some wheat fields, the seedlings are sprayed with Cycocel (plant growth retardant) in order to control the height of seedlings and some wheat fields are sprayed with rust preventer in order to control wheat rust disease.