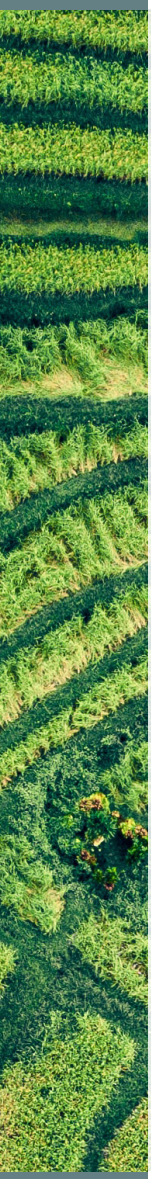
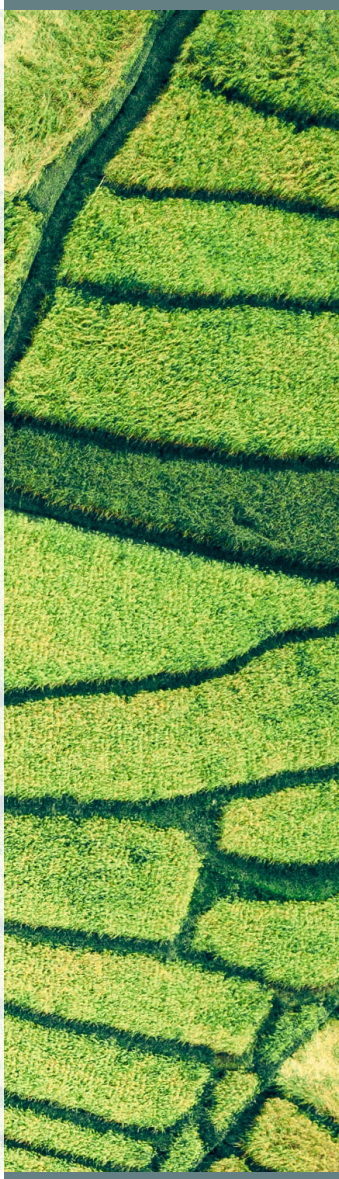




Summary Report on Sino-German Project for Upgrading Plastics Management in Agriculture

(Condensed Edition)

&

2023

Series Report of Sino-European Sustainable Transition towards Circular Economy

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Imprint

Commissioned by the Federal Ministry for Economic Cooperation and Development (BMZ) and under the framework of develoPPP.de Programme, Sino-German Project for Upgrading Plastics Management in Agriculture is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, together with Reifenhäuser GmbH & Co. KG Maschinenfabrik, Zhuhai Kinfa Biomaterial Co., Ltd and TÜV Rheinland Shanghai Co., Ltd. Commencing in 2020 September, the Project aims at tackling "white pollution" caused by inappropriate agricultural film management in China. The Project will, for one thing, enhance the recycling efficiency of PE mulch film by digitalized tracking system; for another, promote the utilization of full-biodegradable mulch film. Five pilots will be implemented in Gansu, Heilongjiang, Inner Mongolia, Hubei and Beijing, respectively. Against the Project's best practices, technical specifications and political suggestions will be generated to facilitate the upgrading of agricultural plastic management in China.

Publisher

Sino-German Project for Upgrading Plastics Management in Agriculture
Commissioned by the Federal Ministry for Economic Cooperation and Development (BMZ)
Funded by developPPP.de programme

Implemented by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
100600, No. 14, Liangmahe South Road, Chaoyang District, Beijing
Tayuan Diplomatic Office Building 2-5
c/o

Responsible Person of the Project

HOU Jingyue, GIZ

Authors

XU Yunyun, HU Yunfeng, FENG Weifan, GIZ

Office of Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in China
Address: 1100, Sunflower Tower, No. 37 Maizidian Street, Chaoyang District, Beijing, China
Postcode: 100125
Tel.: +86 10 8725 5180
E-mail: giz-china@giz.de
Website: www.giz.de/china

Sino-German Project for Upgrading Plastics Management in Agriculture
Address: Tayuan Diplomatic Office Building 2-5, No. 14, Liangmahe South Road, Chaoyang District, Beijing, China
Postcode: 100600

Content

Preface

Negotiations on global treaty to tackle plastic pollution is in full swing, and the shortage of food supply caused by the world population growth remains unresolved. The use of mulch film, which links both food security and plastic pollution in rural areas, counted as a severe challenge in China. In order to solve this problem, China has taken a series of measures in reduction and substitution scientifically, formulation and supervision of quality standards for mulch film products, recycling & utilization, and monitoring of mulch film pollution, so as to gradually promote the control of mulch film pollution and improve the recycling rate of mulch film.

To assist in solving the problem of mulch film pollution in China and promote international cooperation, the"Sino-German Project for Upgrading Plastics Management in Agriculture" has started since September 2020, which has been commissioned by the Federal Ministry for Economic Cooperation and Development (BMZ) under the develoPPP.de Programme. The Project has been implemented by the Deutsche Gesellschaft f ü r Internationale Zusammenarbeit (GIZ) GmbH together with Reifenhäuser, Zhuhai Kingfa Biomaterial Co., Ltd. and TÜV Rheinland Shanghai Co., Ltd., so as to jointly solve the environmental challenges brought by mulch film and reduce the worries associated with the utilization of plastic in agricultural field. The Project absorbs advanced international concepts, and carries out the pilot demonstration in five regions in China, including Gansu, Heilongjiang, Inner Mongolia, Hubei, and Beijing. Through the summary of experience gained in the pilot demonstrations, it forms the technical specifications as well as the policy recommendations, and promotes the upgrading of plastic management in rural areas of China.

The Project implementation team hopes to take this report as an opportunity to share our thoughts while summarizing the Project results; explain the topic of mulch film and agricultural production to the public in easy-to-understand language; and tell the stories of the rural areas in China to the world. We sincerely hope that more attention will be paid to the topic of scientific management of mulch film, and we also welcome domestic and international experts and all people related to provide suggestions, brainstorming and gain rich ideas to solve problems, and jointly contribute to the green and sustainable development of rural areas in China.

Background

I. Attention Needed on Mulch Film Pollution in China

Mulch film, i.e. a layer of plastic film covering the soil, can increase soil temperature, retain moisture, and prevent weeds, etc. It could change the production environment of crops and effectively increase the yield. From a global perspective, no country in the world uses mulch film as widely and extensively as China. However, the pollution caused by mulch residual after use occurs as well. To some extent, plastic pollution is a global issue, while mulch film residue is a unique issue in China.

(I) Indispensable for Chinese Agriculture

Since learning the mulching technique from Japan in the late 1970s, China now has become the country with the largest amount of mulch used and the widest area covered in the world. Annually, nearly 1.4 million tons have been used here in the country, accounting for approximately 3/4 of the total amount in the world. The coverage area of agricultural crops has been up to 17.6 million ha, accounting for about 13% of the total cultivated land area in China.

The mulch film could guarantee the crops yields and contribute to early maturity. Meanwhile, it could expand the planting area of the crops, prevent the erosion of rainwater, reduce the loss of fertilizers, inhibit the growth of weeds, reduce the harm of diseases and insects, and effectively improve the quality of crops. Preliminary estimates show that the direct economic benefits brought by the mulch film for increasing the crop production reaches EUR 15-17.6 billion/year in China.

(II) Pollution and Loss Brought by the Problem of Mulch Residues

During producing mulch film locally, the film has become much thiner compared with Japanese ones, considering economic factors and practical application effects. Since then, along with its widely application and pursuing lower costs, the mulch film has become thinner and thinner. In 2019, the relevant authority randomly purchased 104 mulch film samples through E-commerce platforms and sales markets and entrusted a third-party agency to test the indicators in accordance with the National Standard on mulch film (GB13735-2017). However, the results showed that the unqualified rate of the samples reached 98.1%, even more than 60% of the mulch film equiped with thickness less than 0.006mm.

According to the Second National General Survey of Pollution Sources, the result of 721 monitoring points showed that, nationwide the cumulative average residual amount of mulch film in 2017 was 34.0 kg/hm^2, and the pollution situations of mulch film in Northwest and North China were relatively serious.

II. Remarkable Results Achieved by China's Measures

(I) Policies & Regulations

1. Laws and Regulations

The scientific utilization of mulch film, pollution prevention, recycling & treatment have been included in many laws, such as the *Soil Pollution Prevention and Control Law*, the *Law on the Prevention and Control of Environment Pollution Caused by Solid Wastes*, the *Law on the Promotion of Revitalization of Rural Areas*, the *Product Quality Law*, the *Agricultural Product Quality and Safety Law*, the *Agriculture Law*, the *Cleaner Production Promotion Law*, and the *Circular Economy Promotion Law*, etc. In July 2020, the Ministry of Agriculture and Rural Affairs, the Ministry of Industry and Information Technology, the Ministry of Ecology and Environment, and the State Administration for Market Regulation jointly issued the *Measures for the Administration of Agricultural Film* to build a whole-process supervision system covering the entire life cycle of agricultural film.

2. Policy Documents

In the process of mulch film pollution prevention and control, relevant ministries and commissions have successively issued policy documents, such as the *Agricultural Film Recycling Action Plan*, the *Opinions on Accelerating the Prevention & Control of Agricultural Mulch Film Pollution*, the *Opinions on Further Strengthening the Control of Plastic Pollution*, the *Measures for the Administration of Agricultural Film*, the *Notice of Actively Participating in Promoting the Work Plan for Agricultural Film Management by Supply and Marketing Cooperatives*, and the *Technical Guidance for the Scientific Utilization & Recycling Pilot of Mulch Film*, etc., to guide the market behaviors and establish a sound agricultural film collection & recycling system.

3. Standard & Specification

To standardize the recycling process of waste mulch film, China has formulated a series of technical standards. 18 standards have been formulated so far, including 4 National Standards, 3 Industry Standards (one of which has been abolished), and 11 Local Standards (one of which has been abolished). The content of these standards and specifications includes the product standards for mulch film, collection machines for mulch residue, the operation quality/procedure during the mulch residue recycling process, the film residue investigation and amount limit, and waste mulch film processing, etc. In addition to the National Standards, provinces and cities have formulated various Local Standards as well.

4. Local Rules & Regulations

Since 2019, Zhejiang, Gansu, Chongqing, and many other places with amount of demonstration counties for mulch film management, have successively formulated provincial and municipal laws & regulations to facilitate local waste mulch film management.

(II) Work Results

From 2012 till now, China has invested above EUR 0.3 billion to the projects such as agricultural cleaner production demonstration, agricultural film collection demonstration counties, etc. Nearly 300 mulch film clean production counties, 100 agricultural film pollution control counties, and above 700 mulch film residue monitoring points have been established. In the past years, China has also supported more than 400 waste mulch film recycling & processing enterprises and 3,000 mulch residue collection stations. At present, the collection rate of waste mulch film in demonstration counties and pilot areas of China has reached about 80%, and the "white pollution"of farmland has been prevented and controlled effectively.

III. Challenges

However, mulch film management still faces challenges in many aspects such as economy, technology, awareness, mechanism, etc.

From the economic aspect, farmers, as consumers of mulch film, are highly sensitive to prices. Hence, the mulch film has become thinner and thinner. However, for the recycling market, there is a lack of economic value due to the high impurities rate of waste mulch film and high processing costs.

In terms of mulch film collection technology and equipment, the existing ones cannot meet the demands, and the net collection rate in continuous large-scale operations is lower than 80%.

Regarding the application scale and mode, high coverage rate and a varitey types of crops to be mulched generate huge challenge. Different types of crops, modes, and broad areas inevitably require diversity in collection methods, tools, and forms as well. There is no unified approach for all.

From the perspective of farmer's awareness and behavior towards mulch film collection, time and energy is required with no economic motivations. More importantly, many farmers lack awareness of the consequences of mulch film pollution, or the environmental benefits and social responsibilities of mulch film collection. They even believe that government should undertake the responsibility for mulch film pollution control. Thus, farmer are unwilling to take actions.

In terms of governmental and industriell supervision, the cross-department management still faces challenges and has not fully formed a joint force till now.

Project Implementation

To promote the scientific utilization and management of mulch film, the Sino-German Project for Upgrading Plastics Management in Agriculture (hereinafter referred to as the "Project") mainly carries out two aspects of work, i.e. one is to improve the recycling efficiency of conventional plastic mulch film, and the other aspect is to promote the scientific application and standardized certification of the biodegradable mulch film.

I. Polyethylene (PE) Mulch Film

To improve the recycling efficiency, holistic approach has been introduced. The Project starts with the production of high-strength weather-resistant mulch film that are easy to collect. Meanwhile, the project has developed a digital traceability tool, which enabled the whole life cycle supervision of the product and contributes to an effective extended producer responsiblity (EPR) scheme. Lastly, the project explores high-value mechanical and chemical recycling, in order to guide the healthy development of mulch film production and recycling, and try to provide the reference solutions for opening up the value chain and realizing the market-oriented operations.

(1) Pilot Overview

1. Pilot Selection

Given the high amount of film application and residue in farmland, pilot in the North-West region has been considered. In the meantime, Gansu Province is the first province to formulate local policies and regulations concerning pollution control of waste mulch film, running at the forefront national wide with a good foundation. Thus, the project has started the PE pilot in Longzhong area, the center of Gansu Province.

2. Overview of Pilot Area

(1) Utilization Status of Mulch Film

Gansu Province is dominated by arid and semi-arid areas, where precipitation is the main source of soil moisture. The average annual precipitation is just over 300 millimeters, while the precipitation period does not coincide with the water demand period for crops, making it difficult to meet the growth demands of crops. In addition, the temperature in early spring is relatively low, which makes the crops mature late. The use of mulch film could reduce the ineffective evaporation of soil moisture, fully absorb and reserve the precipitation, increase the soil temperature of the plowing layer, promote the early maturity and increase yield of crops. With all these benefits, mulch has been widely used. Especially in the context of climate change, drought and other natural disasters, mulch film is an indispensable means of production for stabilizing grain yield.

With the promotion of mulch film technology in recent years, the intensity of mulch film utilization in Gansu Province has increased from 13kg/hm^2 in 2010 to 20kg/hm^2 in 2020, and the mulching area has nearly doubled. The utilization amount of mulch film has reached 110,000 tons, ranking 2nd place in China. The application of mulch film has stabilized the grain yield of Gansu Province at more than 10 million tons for 11 consecutive years, and the grain yield exceeded 12 million tons in 2020.

(2) Policies for Mulch Film Pollution Control

While actively promoting mulch film technology, Gansu Province has also paid close attention to the pollution issue. It is one of the first Provinces to carry out mulch film recycling & utilization in China, with a series of policies and standards have been issued. At present, Gansu has supported the establishment of the mulch film residue recycling network covering 91 agricultural counties, 297 film recycling enterprises, and 2,312 collection stations. According to the statistical results of positioning monitoring, the residual amount of mulch film has dropped from 30.45 kg/ha (799 monitoring points) in 2018 to 22.95 kg/ha (1,183 monitoring points) in 2020. So far, mulch film residue has generate no influence to the cultivated land.

(3) Overview of Longzhong Area

Longzhong area is the main mulch-covered district in Gansu Province. The regional climate is dominated by a temperate continental climate. The annual average precipitation is between 220 mm and 600 mm, with uneven distribution between years and seasons. The district is relatively rich in agricultural biological, with maize and potato as main crops, as well as wheat, rape, oil sunflower, flax, and Chinese herbs.

(4) Project Demonstration Area

Gansu Agricultural University Experimental Station: The experimental area is a typical semi-arid & rain-fed agricultural area in the mid-temperate zone, with an annual evaporation capacity of 1,531 mm and a dryness degree of 2.53. The multi-year average precipitation is 390.9 mm. The year 2021 was a dry

year with an annual precipitation of 317.3 mm. The precipitation in July and August was seriously below the multi-year average precipitation.

Lanzhou Yuzhong Demonstration Zone: Yuzhong County is located in the central part of Gansu Province and the eastern suburb of Lanzhou, the provincial capital of Gansu Province. It belongs to a typical temperate arid and semi-arid continental climate, with an average annual precipitation of 300 mm and an evaporation capacity of 1,400 mm. At present, the county has annual mulch film coverage area of over 33,333 ha, of which 11,333 ha are planted with dry-farming double-ridge trench-sowed maize; 120kg film is used in every ha of maize land, and 1360t mulch film is used in total for corn land.

Anding District Demonstration Zone at Dingxi: Anding District is located in the central part of Gansu Province as an arid to semi-arid rain-fed agricultural zone. Its annual average temperature reaches 6.3℃, 400 mm annual rainfall and 1532 mm evaporation. There is 0.11 million ha cultivated area, including 0.1 million ha mountainous dry land. Main crops planted are potato and maize. 150 kg mulch film is used for each ha, and in total 4000 t mulch film are used for maize planting annually.

(5) Overview of the Pilot Plan

a. Pre-experiment

Purpose of Experiment: to test the changes of mechanical strength from different mulch film products before and after use, and their impact on yield and collection efficiency. The experiment can then screen the main factors influencing mulch film collection and recycling efficiency (mainly manifested as parameters such as collection rate and impurity content).

Experiment Subjects: at actual planting conditions, the Project has tested the following 4 white PE films (including 3 weatherproof mulch films of different formulations [T1-T3], a common mulch film [T4]) and a biodegradable mulch film [T5], all with the thickness of 0.010 mm. All the indicators meet requirements of national standards, and a small-scale field comparative experiment was conducted using different collection methods.

Scope and Period of the Experiment: the experiment was conducted at the Gansu Agricultural University Experiment Station, and maize was sowed in mid to late April 2021, with a planting density of 52,500 plants/ha. Due to the severe drought in 2021, up to mid-September, all maize was green dried before natural maturity. As a result, there was early harvest on September 20.

b. Field Experiment

Purpose of the Experiment: A wider comparative trial of German mulch and ordinary ones was carried out at Yuzhong and Dingxi demonstration plots and experiment stations, with the focus to compare results in terms of economic benefits, recycling efficiency and film residues. Planting crops, areas, methods and implementation entities of the three test sites are given below.

Table 1. Planting crops, areas, methods, implementation entities and planting patterns at the three test sites

Category	Location	Crops	Area	Technical guidance provider	Implementation subject	Planting patterns
Experiment station	Lijiabao Town, Anding District, Dingxi City	Grain maize	1.67 ha (German mulch film, Jialemi film, common film, mulch in spring)	Gansu Agricultural University		Drip irrigation under mulch at double ridges trench sowed corn land with full mulch film coverage, 52,500 plants/ha density
Field	Daying Village, Xinying Town, Yuzhong County	Forage maize	20 ha (17.3 ha German mulch film, 10 ha in autumn, 7.3 ha in spring, and 2.67 ha common film)	Yuzhong County Ecological Environment Protection Station	Yuzhong Junmei Farming Cooperative	Double-ridge trench sowed corn land with full mulch film coverage, with 60,000 plants/ha density
Field	Lujiagou Town/Village, Anding District, Dingxi City	Fruit / fresh maize	13.3 ha (11 ha German mulch film for spring mulching, 2.3 ha common film)	Anding District Agricultural Technology Promotion Service Center	Dingxi Wotu Agriculture and Farmers' Cooperative	Drip irrigation under mulch at double-ridge trench sowed corn land with full mulch film coverage, with 66,000 plants/ha density

In actual implementation, Yuzhong Demonstration Area compared autumn mulching and spring mulching. Both Dingxi Demonstration Area and test station continued the pre-test method for spring mulching. Autumn mulching was conducted in early November 2021, and spring mulching time by mid-April 2022 (after surface thawing). Maize seeds were sown with seeder in late April 2022 and harvested in early October. During crop growth, manual weeding and fertilization were carried out at the same rate as in high-yield fields.

(II) Product Standards and Design

1. Comparison of Product Standard Requirements

Ultra-thin films and low-quality films are prone to breakage after use and cannot be fully collected, which is the primary cause of mulch residue pollution. Table 1 summarizes 5 reference product standards or requirements, including:

1. The 2017 newly revised mandatory national standard GB13735-2017 - Polyethylene Blown Mulch Film for Agricultural Uses

2. The 2019 revised local standard - Polyethylene Blown Mulch Film for Agricultural Uses in Gansu Province (DB62/T2443-2019)

3. The thickened high-strength mulch film standard proposed in 2022 by the Ministry of Agriculture and Rural Affairs, Ministry of Finance for pilot scientific mulch film application and recycling

4. The group standard - General Guidelines for the Evaluation of Plastics Products' Easy-to-Collect & Easy-to-Regenerate Design initiated in 2022, by China National Resources Recycling Association and China Petroleum and Chemical Industry Federation along with universities, research institutions and industry enterprises

5. Voluntary standard developed by CEN (Standards Board) in 2018 - Plastics - Thermoplastic Mulch Films Recoverable after Use, for Use in Agriculture and Horticulture (EN 13655: 2018)
Focus was laid on comparison of requirements for product thickness, usage time, mechanical properties, weather resistance and other indicators that affect mulch film collection.

Table 2. Comparison of mulch film product standards

Standard requirement		Chinese standard GB13735-2017		Gansu Province standard DB62/T2443-2019	2022 requirements for thickened high-strength mulch film	2022 group standard	European standard EN 13655: 2018
Product thickness		≥ 0.010mm		≥ 0.010mm	≥ 0.015mm	≥ 0.010mm	≥ 0.020mm
Usage time		Class I≥ 180 days Class II≥ 60 days		Class I ≥540 days Class II≥ 360 days Class III ≥180 days	≥180 days	--	Grade N2: ≥ 65 days Grade A: ≥ 330 days Class B: ≥ 585 days Class C: ≥ 975 days Class D: ≥ 1340 days
Mechanical property	Nominal tensile strain at break (longitudinal/transverse)	0.010 - 0.015mm 0.015 - 0.020mm 0.020 - 0.030mm	≥ 260% ≥ 300% ≥ 320%	≥ 300% ≥ 320% ≥ 350%	Not lower than national standards	Not lower than national standards	Longitudinal≥ 250% Transverse≥ 350%
	Tensile strength (longitudinal/transverse)	0.010 - 0.015mm 0.015 - 0.020mm 0.020 - 0.030mm	≥ 1.6 N ≥ 2.2 N ≥ 3.0 N	≥ 1.7 N ≥ 2.3 N ≥ 3.2 N	Not lower than national standards	100 points: ≥2.5 60 points: 2.0-2.5 30 points: 1.6-2.0 0 point: <1.6	≥2.0 (Converted based on ≥20 MPa)
	Right-angle tearing load (longitudinal/transverse)	0.010 - 0.015mm 0.015 - 0.020mm 0.020 - 0.030mm	≥ 0.8	≥ 0.8 ≥ 1.2 ≥ 1.5	Not lower than national standards	Not lower than national standards	Other indicators

Standard requirement		Chinese standard GB13735-2017	Gansu Province standard DB62/ T2443-2019	2022 requirements for thickened high-strength mulch film	2022 group standard	European standard EN 13655: 2018
Weather resistance	Retention rate of nominal tensile strain at break	Class I: longitudinal ≥50% (Aging test 1a)	Longitudinal 50% ≥ (Aging test 1b)	≥ 50% (After use)	› 60% (Aging test 1a)	≥ 50% (Aging test)
Recyclability	Tensile strength (longitudnal/ transverse) for collection according to service life	--		Retention rate≥ 50%	100 points: ≥ 1.8 50 points: 1.5-1.8 30 points: 1.2-1.5 0 point: ‹1.2	--

Note:

1. The test method complied with provisions of GB/T16422.2-2014, and Method A was used for irradiation, with (340 nm) 0.51 W/ (m^2 · nm) narrow-band irradiance. Black standard thermometer was used for temperature control, and exposure cycle applied cycle number 1. Duration (a) was 600h as per national standard type I; (b) Gansu Province standard type I 800 h, type II 700 h and type III 600 h.

2. The covering usage time given in the standard text is the test value obtained at 50% longitudinal nominal breaking strain retention rate after aging at artificial irradiation conditions. According to the relationship between artificial irradiation conditions and natural light (3 different climate zones) in the annex to the standard and the climate region where China is located, usable time in China before aging (except for a small part of southwestern region) is calculated.

2. Baseline

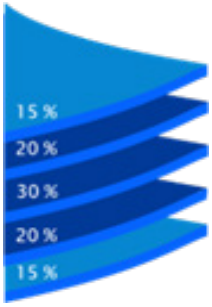
Although governments at all levels are fighting against the use of mulch film products that do not meet mandatory national standards, but in random interviews with farmers at Longzhong area, result shows that 20% of farmers are still using mulch film with the thickness of 0.008 mm or even below, indicating that unqualified products are still circulating in the market.

Fig 1. Film residue in fields

3. Innovative Design in the Pilot

High-strength and traceable mulch film has been designed and used in the project. This product (hereinafter referred to as "Germany mulch film") was jointly developed and designed by project partner Reifenhäuser, ExxonMobil and Clariant with the thickness of 0.0125 mm. Thanks to the innovative five-layer structure, it has much higher mechanical strength than common products with the same thickness, and the use of certain amount of metallocene linear low-density PE and aging-resistant and UV-resistant additives improves mechanical properties and weather resistance of the product.

Fig 2. Five-layer structure design



Two German mulch films - white and black were tested respectively. For comparison, mulch film from Jialemi, a film exporting to Japan (white and black films with 0.015 mm thickness, hereinafter referred to as Jialemi film) and high-quality white mulch film commonly used in Gansu were selected (as control group, the same as T4 for baseline test, thickness=0.01 mm).

Table 3. Comparison of mechanical properties of high-strength mulch film products

Mulch film products	German mulch film White	German mulch film Black	Jialemi film White	Jialemi film Black
Product thickness	0.0125mm	0.0125mm	0.015mm	0.015mm
Nominal tensile strain at break (longitudinal/transverse)	359%/846%	339%/822%	506%/936%	564%/900%
Tensile Strength (Longitudinal/horizontal)	4.5N/4.1N	4.1N/4.3N	4.0N/4.3N	4.8N/5.4N
Right-angle tearing load (longitudinal/transverse)	1.4N/1.6N	1.6N/1.6N	-	-

Due to impact of COVID-19, mulch films were not collected in a timely manner after maize harvest in October 2022, but only till sowing in the next season in April 2023. In actual production in Gansu Province, farmers often prefer this model, which can to some extent maintain soil moisture and reduce transpiration. This also conforms to the usage time defined in product standard issued in Gansu Province, which means that autumn mulching usage period is 18 months, equals to Class-I film in Gansu Province standard, Spring mulching with 12-month usage period as Class-II film, and 6-month mulching as Class-III.

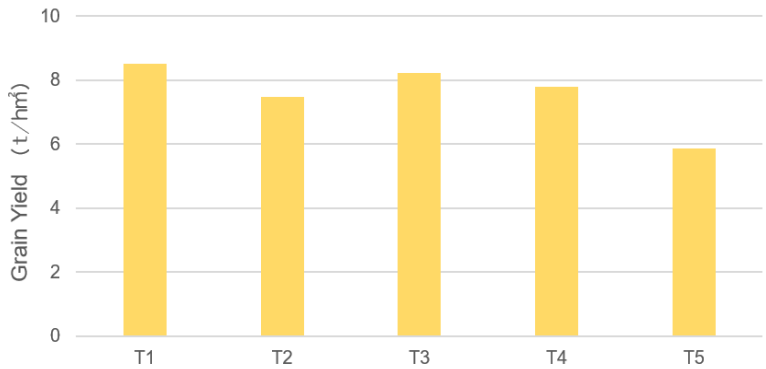
(III) Field Experiment of High-strength and Weather Resistant Mulch Film

1. Impact of Different Mulch Films on Crop Yield

(1) Result of Pre-experiment

During the experiment, as there was severe drought and maize did not fully mature, grain output is lower than that in normal production years (see Chart. 1). No significant differences in grain yield have shown up between weather resistant mulch film (T1-T3) and high-quality common mulch film (T4), but the yields using biodegradable mulch films are much lower (T5).

Chart 1. Impact of different mulch films on maize grain yield in Gansu



Note: T1-T3: 3 high-quality weather-resistant mulch films; T4: high-quality common mulch film (T4) and a domestically produced biodegradable mulch film (T5)

(2) Result of Field Experiment

At the three test sites (test station, Yuzhong, and Dingxi demonstration areas), use of high-strength and weather-resistant mulch film resulted in higher yields compared to use of common mulch film, but for different types of maize, influence varies from each other.

Test station (grain maize): Use of different PE mulch films has minor impact on maize yield. Use of German mulch film gave rise to only 1-3% higher output than using common ones, and increasing the output value per a hectare with only EUR 31.25-87.5. For farmers who cultivate their own land, they do not have the motivation to use the more expensive mulch films from an economic perspective alone.

Yuzhong demonstration area (forage maize): Use of different PE mulch films has minor impact on maize yield. Net income per hectare of land of using German mulch film is only 1-3% higher, generates additional income of EUR 21.25-50. When mulch film collection is considered, the collection cost will be decrease by EUR 18.75, and net income can increase by up to EUR 68.75 per hectare. From the economic perspective, the number is still not attractive to farmer cooperatives.

Dingxi demonstration area (fresh/fruit maize): Planting density of fresh maize is higher, associated with slightly higher impact on yields by using different PE mulch film. Using German mulch film arises the output by only 5% comparing with common ones, and net income per hectare was 8% higher, with nearly EUR 612.5. When mulch film life-end is considered, using German mulch film will save the collection cost by EUR 93.75. To sum up, using the high-strength German film, net income of nearly EUR 700 can be generated for a cooperative, which is certainly attractive from economic aspects.

Table 4 Output value, cost and income of maize planting at Yuzhong and Dingxi demonstration areas

Location	Mulch film	Yield	Gross output value	Total investment	Net income
		kg/hm^2	EUR /hm^2	EUR /hm^2	EUR /hm^2
Yuzhong	Common white film	56,405	2,462.5	975	1,487.5
	German white film for autumn mulching	57,300	2,512.5	975	1,537.5
	German black film for autumn mulching	56,900	2,487.5	975	1,512.5
	German white film for spring mulching	57,535	2,512.5	975	1,537.5
	German black film for spring mulching	57,000	2,500	975	1,525

Location	Mulch film	Total yield	Spike output value	Straw output value	Total investment	Net income
		Spike/hm^2	EUR /hm^2	EUR /hm^2	EUR /hm^2	EUR /hm^2
Dingxi	Common white film	63,000	11,025	250	2,775	8,500
	Germany white film for spring mulching	66,450	11,625	250	2,775	9,100
	Germany black film for spring mulching	66,000	11,550	250	2,775	9,025

Note: fresh maize is sold at EUR 0.175/spike. Straw is sold at EUR 243.75/hm^2 (including labor and machinery cost).

Cost (EUR/hm^2)	Yuzhong demonstration area	Dingxi demonstration area
	Silage maize	Fresh maize
Maize seed	112.5	150
Chemical fertilizers	187.5	300
Mulch film	225	225
Mulching machinery	93.75	93.75
Mulching labor	93.75	93.75
Ear harvesting labor	-	375
Film recycling machinery	112.5	112.5
Film recycling labor	150*	300*
Water, electricity and other expenses	-	1,125
Total	975	2,750

Note: high labor cost at Dingxi is due to the use of drip irrigation technology under the film, and film collection is thus more labor-intensive. Yuzhong has no condition for drip irrigation.

Agricultural knowledge

In modern agricultural science system, maize can be roughly classified into three categories based on its harvested product and purpose:

- Grain maize: a common maize which was planted in the largest area in China, from which grains are harvested that are used as foodstuff, feedstuff and raw material for industrial products; Dry straw as by-product can be used as additive for breeding feed.
- Forage maize: harvested when the grains are not mature, and all maize plants (including maize ears) are crushed and processed through fermentation, in order to produce animal feedstuff for cattle, sheep and other livestock.
- Fresh/fruit maize: also known as vegetable and fruit maize, waxy corn, etc. available on the market, which has low yield, high harvesting costs and the highest economic benefits.

2. The Relationship between Change of Mechanical Strength and Collection

(1) Result of Pre-experiment

- Dynamic Changes in Mechanical Strength

Before use: initial mechanical strength of the four high-quality PE films was much higher than that required by national standard, and longitudinal tensile strength was 2-times higher than the requirement specified in national standard (1.6 N).

One month after use: physical parameters of various PE films showed no significant decreasing compared to the initial values.

Three months after use: physical parameters of PE film showed significant decreasing. Biodegradable mulch film broke up in the 3rd month and its mechanical strength did not meet the requirements in the corresponding functional period.

Five months after use: mechanical strength indicator of the common mulch film was significantly lower than that of three weather-resistant mulch films. Longitudinal tensile strength and retention rate of nominal tensile strain at break of the three weather-resistant mulch films conform to standards, while the common mulch films does not.

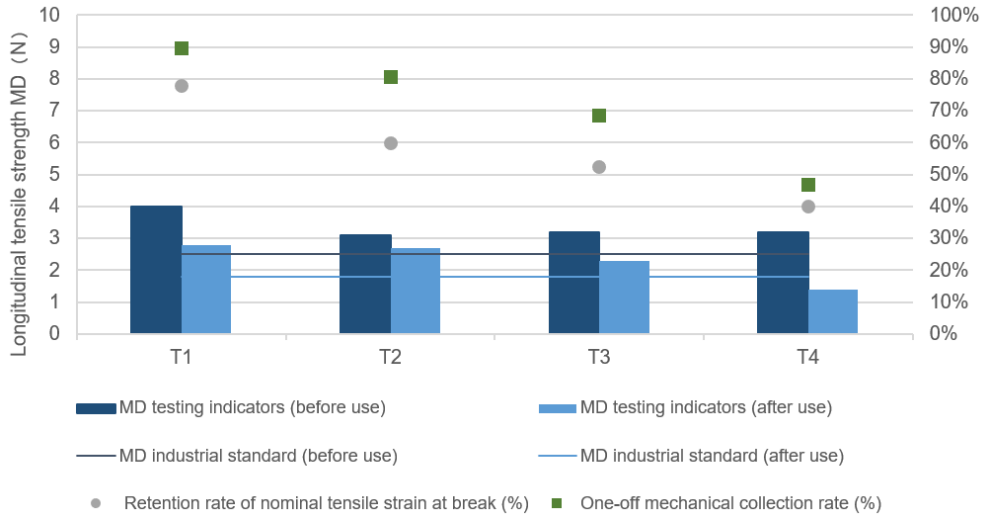
- Relationship between physical properties of mulch film and collection rate

Core indicators reflecting mechanical strength of mulch film: two indicators matter here: longitudinal tensile strength and retention rate of nominal tensile strain at break, while the impact of transverse tensile strength has low relevance. Higher mechanical strength after use results in higher collection rate of mulch film residue.

In this experiment, there was positive correlation between longitudinal tensile strength and retention rate of nominal tensile strain at break with the one-off collection rate (weight of pure mulch residue without impurities by one-off mechanical or manual film collection / weight of mulch film usage) of mulch film residue. After mechanical collection and subsequent manual picking, the mulch film collection rate can reach 85% and above.

High mechanical strength before use does not results in high strength after use, while the latter guarantees easy collection. Initial mechanical strength of commonly-used mulch film (T4) is even higher than that of T2, but T4's mechanical strength decreases significantly during use, resulting in low weather resistance. The film has broken during collection with a relatively low collection rate. Special film structure design and the use of UV resistant additives can greatly improve weather resistance of mulch film.

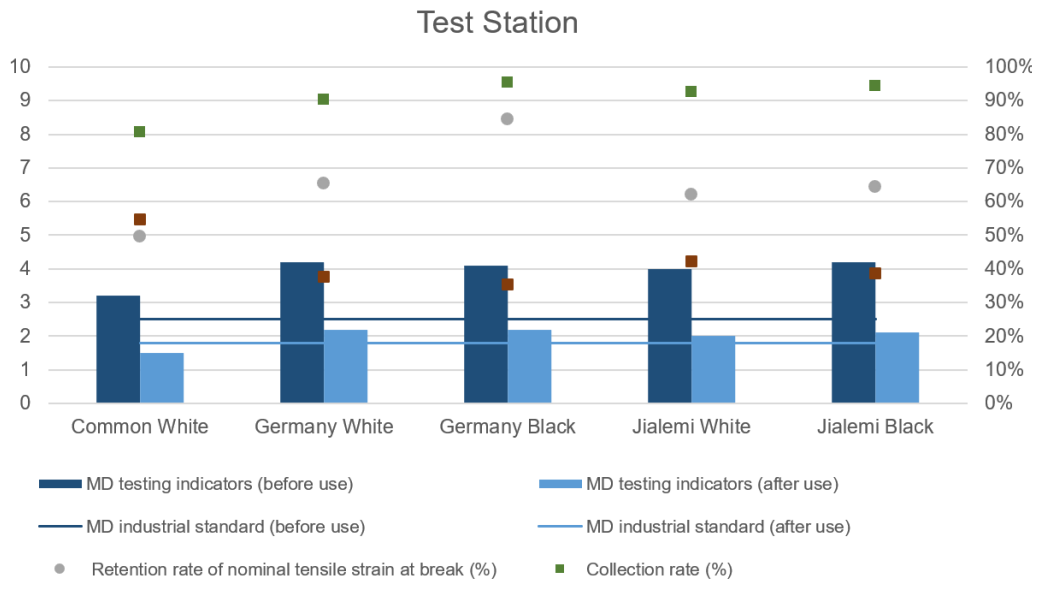
Chart 2. Comparison of parameters of four mulch films after usage



(2) Result of Field Experiment

• Mechanical strength of mulch film after use: after 12 months of mulching, longitudinal tensile strength and retention rate of nominal tensile strain at break of German and Jialemi mulch film were still high and better than the requirements specified commonly in standards. Meanwhile, they've shown better results than the three types of domestic produced weather-resistant mulch films used in the pre-test, with the thickness of 0.010 mm after use of 5 months.

Chart 3. Comparison of parameters of five mulch films after usage



Note: Jialemi film used in this experiment is a type of mulch film exported to Japan.

• Mulch film Collection: at the test station, one-off collection rate of German and Jialemi mulch film reaches 90% and above, with the impurity content about 40% (including maize straw). After film collection, almost no mulch residue can be seen in the farmland (as shown below). Commonly white film had breakage, and after mechanical collection plus manual picking, collection rate was up to 80% with impurity content of 55%.

Fig. 3. Status of German mulch film and Jialemi mulch film during collection

• In the fields, different farmland management and planting methods had significant impact on result of mulch film collection.

Dingxi demonstration area: drip irrigation under mulch was applied with high planting density. The farmland has experienced multiple human-machine operations with ordinary straw harvesting equipment. This results in many broken holes in mulch film and high impurity content. Due to the impact of COVID-19, at Dingxi, film was collected just before land preparation and cultivation for the next year, and soil was relatively damp after rain. In this experiment, film residue collection rate at Dingxi was 90% with relatively high impurity content of 80%.

Fig. 4 Film collection at Dingxi demonstration area

Yuzhong demonstration area: no drip irrigation was applied and low planting density. The high mechanization rate results in few trampling by people. And farmers paid increased attention to land with better land management skills. Film was collected when soil was dry, although dust while collection was inevitable. In this demonstration, film collection rate reaches 95% with impurity content of 60%.

Fig. 5. Film collection at Yuzhong demonstration area

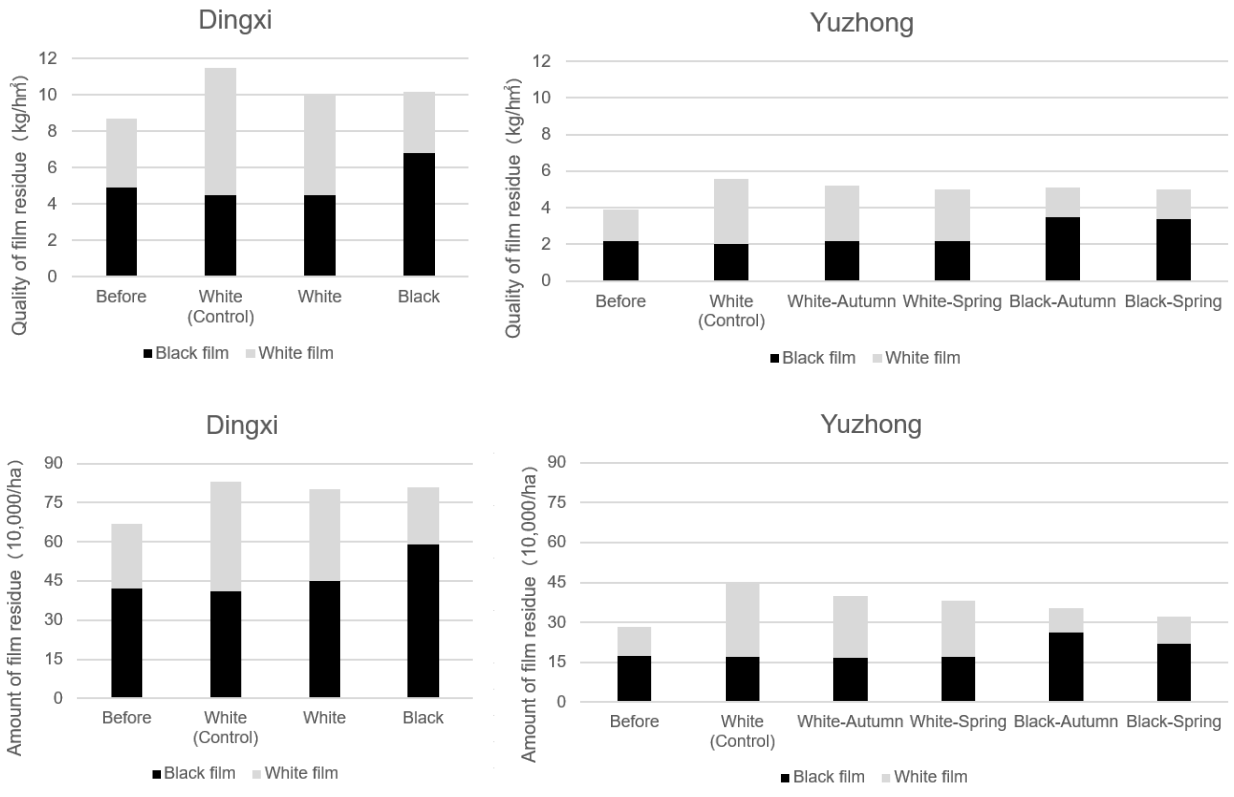
- Comparison of mulch film residue content before and after mulching: total residual film content at the two demonstration areas was lower than average level of the monitoring stations in Gansu Province (22.95 kg/hm^2). Film residue at Yuzhong was much lower than that at Dingxi, which was consistent with the film collection rate from the project practice.

Fig.6 Mulch film residue in quadrat

- German mulch film had higher integrity and collection rate during film uncovering than the common film, thus mulch film residue can be effectively reduced. At Yuzhong, autumn mulching had higher residue than spring mulching, indicating that long period of mulching can lead to higher degree of mulch film aging and fragmentation, resulting in growing amount of film residue which is not easily collectable.

Chart 4. Mulch film residue before and after mulching at the pilots

(Before=before mulching. White control=common white film. White=German white film. Black=German black film. Autumn=autumn mulching. Spring=spring mulching)



• Prediction on mulch film residue: use of mulch film in farmland will give rise to plastic residue in the soil. At the well-managed Yuzhong demonstration area, using high-quality weather-resistant film for 12 months will also increase the residual film content by 1.1 kg/hm^2. If this number increases year by year and without cleaning the existing residual film in the farmland, on the basis of the 3.9 kg/hm^2 residual film content in 2022, after 65 years of use, plastic content in the farmland will be up to the limit of 75 kg/hm^2 (GB/T25413-2010). Based on the usage of common film at Dingxi, number of years to reach this limit will be shortened to 24 years. Therefore, growing attention must be paid to mulch film collection.

3. Impact of Different Mulching Methods on Collection Result

During the test, result has been found out that mechanical collection is more effective to the farmland with mechanical mulching, while manual collection is more suitable for the area using manual mulching.

In manual mulching, farmers usually apply "film on film" during application, which to some extent increases the cost of film use. The mechanical collection may miss the lower layer of film in the "film on film" structure or increase the probability of film breakage. Thus, manual film collection is more suitable for the farmland which has used manual mulching at the beginning.

Fig 7. Manual mulching

In comparison to that, mechanical mulching will turn the soil automatically according to preset breadth. "Film on film" will not appear. This allows high efficiency of mechanical film collection with lower film tearing-up.

4. Impact of Different Collection Methods

The "rotary folding machine" has been used in field experiment for collecting the mulch film residue, which is also commonly used in the local area (see Fig. 8), which is counted as an equipment with acceptable result in the region.

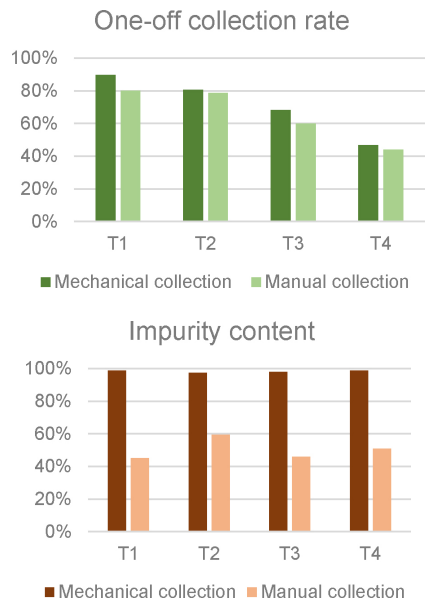
Fig. 8 Rotary folding machine for film residue collection

• Impact of different collection methods on film collection rate: collection rate of mechanical approach is higher than manual means, while the speed is almost doubled.

• Impact of different collection methods on impurities: impurity content using mechanical collection is close to 100%, while the number in manual film uncovering collection only limits to 40-60%.

In agricultural production practices, for large-area, mechanical collection will be firstly applied, followed by manual picking to minimize the film pollution in the farmlands.

Chart 5. One-off collection rate and impurity content



(IV) Traceability System

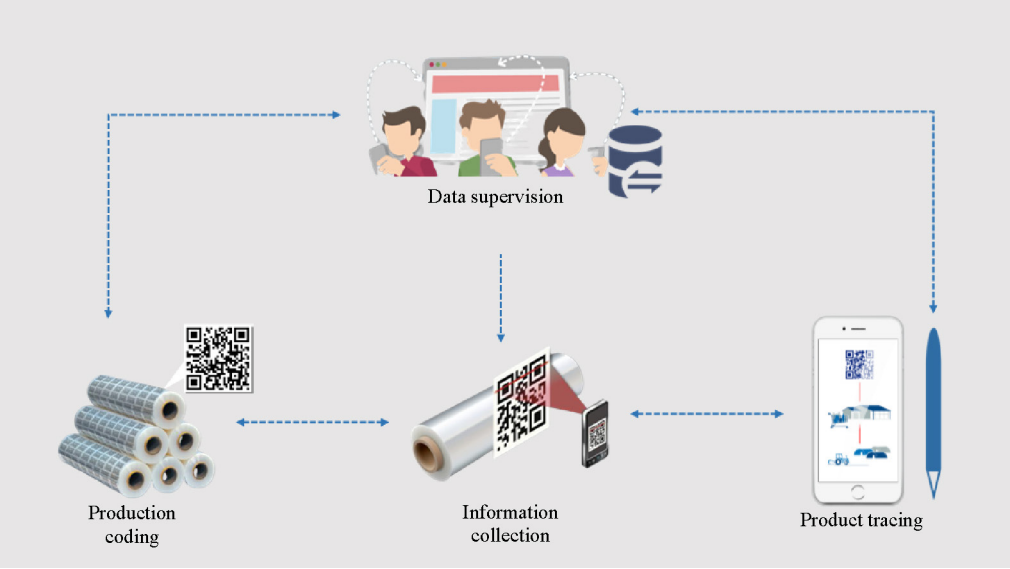
1. Baseline: Ledger System

China has established ledger system to manage mulch film use and collection. A supervision system covering the whole life-cycle has been established, including the production, sales, use and collection of agricultural film.

2. Pilot Implementation

On the basis of the mulch film ledger system and referring to the European concept - "Digital Passports for Products", a mulch film traceability system has been developed by the project. The system allows electronically recording all information during production, sales, use and collection of the PE mulch film used at the pilot areas. This is the first attempt worldwide to use digital tools managing the entire lifecycle of agricultural plastics.

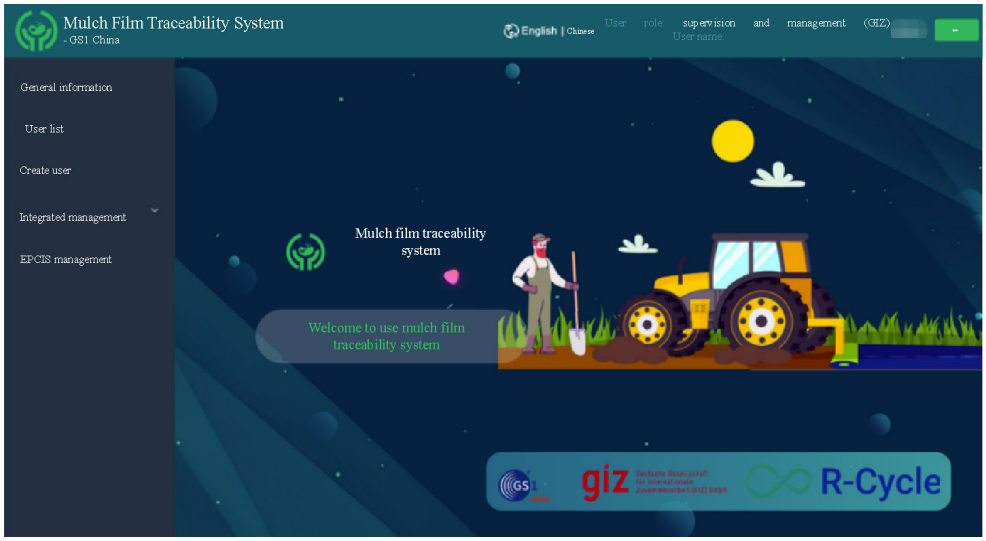
Fig 9. Traceability System (Copyright: Reifenhäuser R-Cycle Initiative)

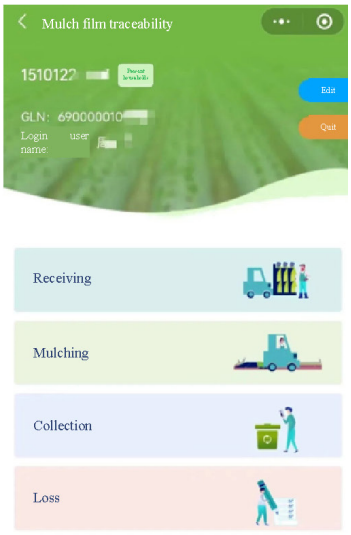


(1) Mulch Film Traceability System

The mulch film traceability system developed by the project is based on the GS1 EPCIS standard. The system can be seen as a digital platform for information recording with mulch film producers, farmers, recyclers and authorities as main users. Web versions and WeChat program targeting at different stakeholders have been developed in the project.

Fig 10. Login interfaces for web and WeChat program





Functions of the traceability system for different steps and stakeholders can be divided as follows:

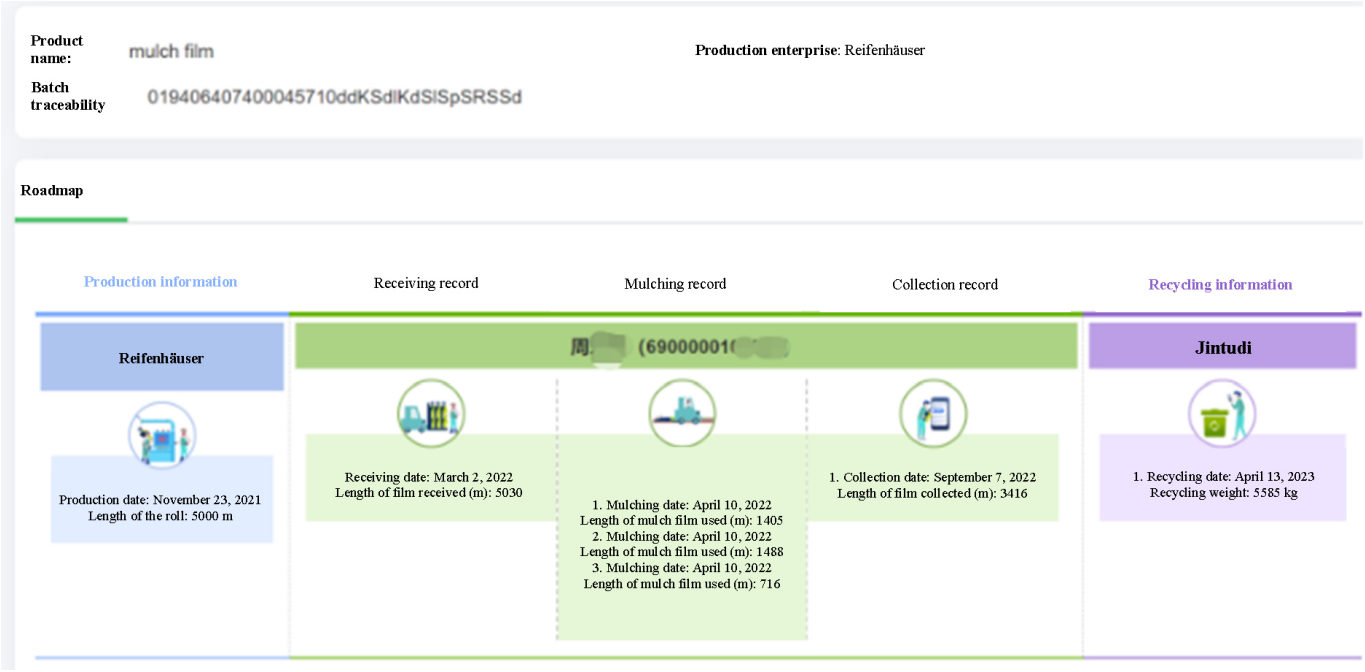
• Production and manufacturing: The producer assigns a unique traceability code to the mulch film product. The code contains basic information of the product, including material composition (e.g. ingredient list, additive list, recyclable materials, bio-based content, etc.), physical properties (e.g. length, width, thickness, surface weight, density, mechanical properties, etc.), production batch, date, manufacturer and other information. And this will provide a traceable "digital twin" for mulch film.

• Mulch film application: Farmers need to enter information while they purchasing/receiving mulch film, using and collecting them back. By tipping the starting and ending number on the mulch film, the length of mulch film used and collected will be automatically calculated. Based on that, using the weight coefficient of new film and gross weight of film residue plus impurities, the collection rate and impurity content can be calculated.

• Recycling: Recycler needs to weigh and enter the gross weight of the film residue plus impurities. Meanwhile, recyclers have the right to check upstream information such as the basic information of the product or the usage status. This function provides accurate basis for processing and recycling of waste mulch films.

• For authorities: The policy makers and officers can check the information along the entire value chain at any time (as shown below). With support of digital platforms, regulatory agencies can easily and effectively identify weaknesses in mulch film management to improve its collection and recycling rate. This offers the opportunity to effectively combine the supervision on film quality, investigate the responsible enterprise produced unqualified mulch films. In a long run, it will promote healthy development of mulch film market.

Fig 11. Traceability information of the entire value chain



(2) QR Code

1) Comparison of Different Digital Coding Techniques

Coded mulch film is the foundation of the traceability system. Manufacturers need to print exclusive QR codes on their products to assign them an "electronic ID card".

Digital coding approaches:

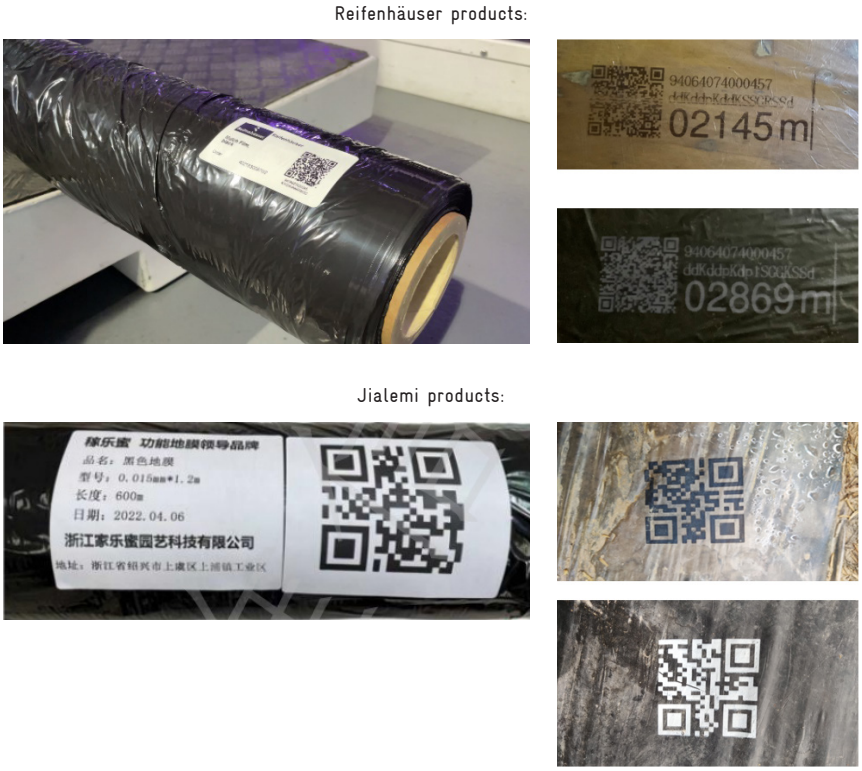
Jet printing: Reifenhäuser uses jet printing, which allows to adjust the printing content at any time. The QR code and information on every meter of mulch film can be different. But the overall cost of the process is relatively high. For producing 100 t mulch film in a same batch, jet printing cost reaches EUR 1.59/ha.

Gravure: gravure requires a gravure plate for each batch, with the same information to print. Jialemi has used this process on their film. The lower the quantity of a batch, the higher the cost

of an average gravure plate. But other costs along this process are relatively low. For producing 100 t mulch film in a same batch, gravure costs EUR 0.53/ha.

Compared to the mulch film cost of EUR 15/ha in China, the traceability approach using digital coding will increase the cost ratio with less than 1% with extreme minimum impact on the price.

Fig 12. Traceability code on outer packaging of mulch film and the ones on film surface



2) Recognition of QR Codes under Different Conditions

Drip irrigation, excessive human trampling or mechanical operation will have great impact on the durability of QR code.

Fig 13. Field code reading

Table 5. QR code recognition

Location	Mulch film	During mulching	2 months	3 months	4 months	5 months	6 months	7 months	8 months
Yuzhong	German white film for autumn mulching	100%	90%	80%	80%	40%	20%	10%	0%
	German black film for autumn mulching	100%	90%	80%	80%	50%	30%	20%	0%
	German white film for spring mulching	100%	80%	80%	80%	40%	10%	0%	
	German black film for spring mulching	100%	90%	80%	80%	50%	20%	0%	
Dingxi	German white film for spring mulching	100%	80%	80%	50%	20%	0%		
	German black film for spring mulching	100%	90%	80%	60%	30%	0%		
Experimental Station	German white film for spring mulching	100%	100%	100%	80%	60%	40%	10%	
	German black film for spring mulching	100%	100%	100%	80%	70%	50%	20%	
	Jialemi white film for spring mulching	100%	100%	100%	90%	70%	50%	30%	
	Jialemi black film for spring mulching	100%	100%	100%	90%	70%	50%	40%	

Note: QR code recognition = number of successful scans/number of scans × 100%; in this experiment, number of code scans was 10 (random).

(3) Main Findings and Optimizing Opportunities

Coding: Drip irrigation, excessive human trampling or mechanical operations will have great impact on the durability of QR code. It is advised that size of QR code be enlarged and color of the code on the surface can be darkened. In addition, QR code on white mulch film is difficult to be scanned due to light reflection. Thus, a black background is suggested to be printed below the QR code on white film.

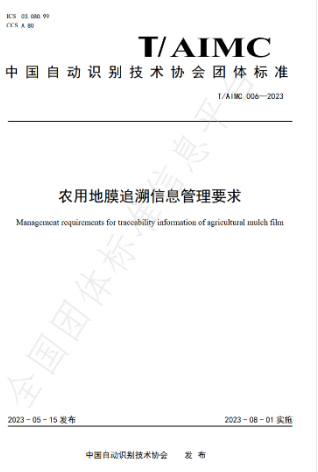
Information collection: Current version requires high participation of farmers, and entering information is not easy enough. At present, many farmers are the elderly generation and not well-educated. They are not familiar with scanning using mobile phone, which greatly limits the use of this system. Local partner has advised to modify the traceability system to cover production, logistics, sales, use and recycling processes. Information of mulching and collection processes can be entered not only by farmers, but also by sellers and collection stations to ensure the integrity and accuracy of the information.

Product traceability: Through mulch film traceability system, all stakeholders in the value chain are allowed to read the product information. Farmers can check whether the mulch film meets their usage needs and product standards. Recyclers will have the ability to fetch upstream information such as basic product information and usage status of mulch films for better processing and recycling waste mulch films. Governmental authorities can trace the unqualified mulch films, which will promote the healthy market development gradually.

Data supervision: Supervision authorities can monitor mulch film collection rate and impurity content in any area by using the mulch film traceability system (automatically calculated by the system) and check all information of the entire value chain. This allows effective identification of weaknesses in the mulch film management and greatly improve precise tracking and visualization of the whole life cycle of the product.

Through communication and exchange among project partners, the film tacking system as a technical tool has been adopted as a part of the group standard entitled Management Requirements for Traceability Information of Agricultural Mulch Film (T/AIMC 006-2023), which was officially released in May 2023. The above project experience and suggestions are reflected in the group standard as well.

Fig. 14 Management Requirements for Traceability Information of Agricultural Mulch Film (T/AIMC 006-2023)


ICS 03.080.99
CCS A 00

T/AIMC

中国自动识别技术协会团体标准

T/AIMC 006—2023

农用地膜追溯信息管理要求

Management requirements for traceability information of agricultural mulch film

2023-05-15 发布　　2023-08-01 实施

中国自动识别技术协会　发布

(V) High Value Recycling

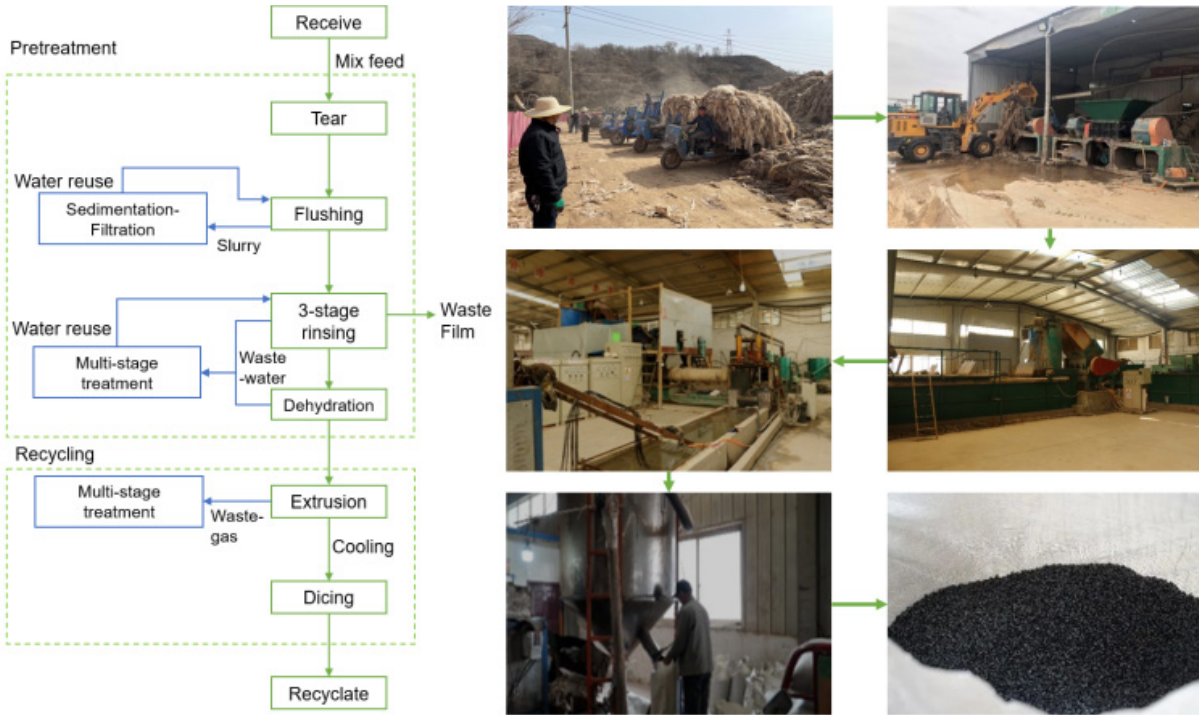
The significance of recycling and treating waste mulch films with extremely high impurity content is very limited, so the main disposal method at present is incineration. For clean waste mulch film, existing mature recycling method is mechanical recycling. Meanwhile, industrial stakeholders are actively engaged in deliberations regarding the technical and economic viability of chemical recycling as a potential alternative method.

1. High Value Application of Mechanical Recycling

(1) Implementation at the Pilots

Mechanical recycling consists of waste film crushing, cleaning, melting and granulating, which is followed by molding and processing. Thanks to the single material of mulch film, mechanical recycling of mulch film requires no sorting. The following diagram shows recycling and processing process of Lanzhou Jintudi Plastic Products Co., Ltd. (hereinafter referred to as "Jintudi"), the largest waste film recycling and processing enterprise at the pilot area.

Figure 15. Flowchart of mechanical recycling of mulch film



Mr. JIN Xinhai, General Manager, Lanzhou Jintudi Plastic Product Co., Ltd. speaks highly of the performance of German mulch film in the recycling and processing line and the quality of the recyclates:

- The application of electrostatic removal and matte finishing treatment on German mulch film surfaces significantly facilitates the cleaning of waste film during flushing and dust removal processes. This innovative approach substantially reduces both the frequency and associated costs of flushing.

- After use, the German mulch film still has a complete film surface (except for the holes at maize stubble) and high mechanical strength. In stage-3 rinsing, no small film fragments are generated, and waste proportion is low with increased yields of recyclates.

- The pellets quality and the test performance of the German mulch film is higher than the ones of the class-I products specified in enterprise standard, so it can be used for recycled products of higher value. Pellets reaching class-I standard can be used to produce intermediate layers of three-layer composite film, three-layer large liquid containers, plastic bags, pipes, plates, etc. Pellets reach class-II standards can be used for producing fruit tree turnover baskets, geomembranes, PE water supply and drainage pipes, conduits, etc. If requirements for hot melt granulation for producing plastic pellets are not met, other auxiliary materials such as plasticizing agent, lubricant, stabilizer, colorant can be used for production of manhole cover, tree comb, wire pile sign shells, etc.

Fig 16. Example of high value and low value products using waste film

High value products:


Low value products:



(2) International Experiences

Japan: Most mulch film recylates are exported to foreign countries, and a small portion is used to make pallets, artificial trees, construction and civil engineering materials and horticultural materials.

Europe: In early 2022, the French A.D.I.VALOR alliance initiated the construction of the CLEANFILM agricultural film pretreatment plant, boasting an impressive annual production capacity of 10,000 tons. This facility is adept at providing the market with exceptionally pure waste LDPE plastic fragments, which can be directly employed in the production of new film products.

Meanwhile, Green World Compounding in Spain has established a substantial agricultural film recycling plant, with an impressive annual capacity of 100,000 tons. Notably, it has introduced a dedicated pretreatment line specifically designed for cleaning mulch films. Additionally, the soil adhering to the film is recycled and processed to concrete.

Currently, in Europe, mulch film residues are commonly used to produce garbage bags, construction films or other thick material, such as “plasticized wood” employed in the manufacturing of park benches.

2. Chemical Recycling

Chemical recycling is a process of decomposing waste plastics into monomers or low molecular compounds through chemical reactions or catalytic pyrolysis. Then these compounds are used to synthesize new plastics or other products. As an emerging plastics recycling technology, different technological paths of chemical recycling are under exploration worldwide.

In project execution phase, we learned that some enterprises in China had carried out chemical recycling using mulch film as feedstock with good results. Only the economic efficiency of the technology needs to be verified.

Japan started chemical recycling of LDPE agricultural film long ago, which was used as reducing agent (containing hydrogen) for blast furnace injection.

(VI) EPR Mechanism

1. Baseline

(1) Mulch Film EPR Mechanism Development in China

Extended Producer Responsibility (EPR) scheme extends the environmental responsibility throughout the entire life cycle of mulch films with mulch film producers as the center. Under the EPR scheme, producers should improve mulch film quality, e.g. optimize the raw material selection and film blowing technology, to facilitate the recyclability. They should undertake the corresponding collection and recycling responsibilities of waste film, guaranteeing the sold film are sent to proper recycling/ disposal at its life end.

In 2017, Ministry of Agriculture and Rural Affairs (formerly Ministry of Agriculture) has selected 4 counties in the country to pilot EPR scheme for waste mulch films collection/recycling. In 2020, Ministry of Agriculture and Rural Affairs, Ministry of Industry and Information Technology, Ministry of Ecology and Environment and State Administration of Market Regulation jointly issued Regulations for Agricultural Film Management, which clearly stipulated the responsibilities of mulch film producers for recycling.

(2) Pilot EPR Mechanism Implementation

Core principle of EPR system is that the producer bears all net cost of waste collection, transportation and recycling. The difficulty in mulch film EPR system design lies in unwillingness of producers to bear high costs when mulch film selling price is extremely low. In actual execution of EPR pilot projects in China, the main approach is "rewards instead of subsidies". The government provides different forms of rewards to plastic film producers, users, collection stations and recyclers who complete recycling goals. Therefore, collection and recycling of mulch film residues in China relies heavily on governmental subsidies.

2. Implementation at the Pilots

(1) New EPR Mode

In early 2022, after multiple rounds of discussions with experts, a new EPR mode was put into practice in the pilot areas. Considering actual situation of government procurement of mulch film, "producers undertake collection/recycling tasks" will be the prerequisite for joining the procurement bidding, i.e., regarding mulch film collection/recycling as a market entry threshold.

(2) Economic Analysis of the New EPR Mode

Analysis of economic benefits of the entire industrial chain in Yuzhong County as an example:

- Income of mulch film producers have been increased by EUR 1.2 million, from sales of high-strength weatherproof mulch film.

- Thanks to the price arising of film residue with EUR 12.5 Euro per ton, collection stations can overall income increase of EUR 18,750.

- As the mulch film producer in the project scope is also the mulch film recycler, the price of recyclates increased EUR 62.5 per ton, with the net profit increasing of EUR 218,750.

- Farmers' cooperative can save cost of EUR 112,500 during mulch film application and collection. If the crops yields has been considered as well, the increase in production value will range from EUR 65.6-600 per ha of maize land.

3. Main Discovery and Optimization Opportunities

Responsibility fulfillment by the producers does not represent unlimited responsibility, while the mulch film recycling scheme requires support from all stakeholders, e.g. users, collection stations etc.

Economic benefits of waste film processing enterprises are highly sensitive to the price of recylates. When the market for recycled materials is prosperous with high price, economic benefits of mechanical recycling can be guaranteed. However, if prices of recycled materials fall to a low point, the enthusiasm for recycling will also severely impaired. Therefore, we provide the following suggestions:

- Provide a price protection mechanism for mulch film recycling. Through economic cost analysis, considering demand of recycling enterprises for profitability, the prices range of recycled material should be determined. If the recycling market is depressed, and the recyclers are unable to make profits independently, the government can consider providing deficiency payment to them.

- Develop Chinese Certified Emission Reduction Project (CCER) for residual film recycling. Considering limited revenue from mulch residue recycling, a CCER project can be considered to compensate the recycling enterprises, allowing them to reserve carbon asset and trade the carbon ib domestic market.

(VII) Main Conclusions and Prospects

A new-type of high-strength and weather-resistant mulch product was developed by the project, with a new management tools demonstrated. The experience and suggestions derived from the project are summarized as follows.

1. Improve Mechanical Strength and Weather Resistance Requirements in Mulch Film Product Standards

It is advised that product standard of PE mulch film should be raised, and thickness should not be limited to 0.015 mm. Mechanical properties and weather resistance indicators need to be significantly improved, e.g., tensile strength (longitudinal/transverse) over 2.5 N, nominal tensile strain at break over 300% and retention rate of nominal tensile strain at break over 60%. Requirements for indicators such as tensile strength on service life basis can be increased. The above indicators are still to be determined through field experiments on typical crops and climate environments in China considering agricultural production results and mulch film collection and recycling.

2. Enhance Research and Application of Mulch Film Collection Machinery

Current film collection equipment has no film cleaning function so that impurity content is very high, which has great impact on economic benefits of subsequent recycling and processing. An innovative tractor towing RAFU film collection machine is used in a pilot in France, which can simultaneously complete film collection, cleaning upper and lower surfaces of mulch film and film rolling during crops harvesting. The film rolling speed automatically adapts to the vehicle speed to ensure appropriate film tension and prevent the mulch film from cracking. This technology can reduce the impurity content of the mulch residue from 75-80% to about 40%, and is also applicable under wet conditions. At present, researchers have customized different film collection machines suitable for various crops such as carrot, salad, and onion in their agronomy. However, compared with developed countries, China's agricultural mechanization and agricultural machinery still need further transformation and upgrading, and more efforts shall be made to support the research and promotion of mulch film collection machinery.

Fig 17. French RAFU film collection machine

Fig. 18 Examples of film collection equipment in China

Parts of residual film collection tractor invented by Gansu Agricultural University

Film rolling equipment for small plots and mountainous area

3. Explore Farmland Management Methods with Less Mulch Film Residue

Explore better timing for film collection based on agronomic requirements. In the actual production, especially in the northwest arid areas, farmers tend to uncover the films close to the next season of sowing, because the mulch films used still retain certain properties, which can maintain soil moisture and reduce transpiration to a certain extent. However, this leads to further prolongation of mulch film exposure time, decrease of elongation at break, higher degree of aging and fragmentation, which generates more residual film and not conducive to collection. For scientifically use and collection of mulch film, timely collection is crucial. The test in Yuzhong demonstration area showed that even after 18-months use of high-strength weather-resistant mulch film, the mechanical strength is still higher than the standard requirements. However, comparing with 12-months application, the film residue pieces has also increased by 20000 to 40000 pieces/ha. Therefore, film collection shall be conducted as soon as possible after crop harvesting.

4. Economic Cost of Using High-strength Weather-Resistant Mulch Film

Farmers who cultivate their own farmland will collect the film by themselves without additional cost of employment. Thus, they may only consider the cost of mulch film procurement and the earnings of crop yields when calculating the overall economic benefits. From an economic point of view alone, farmers have no motivation to make changes without subsidies. Under the principle of "Just Transition", appropriate subsidies for film procurement can be given to farmers with low-income.

For subjects such as farmers' professional cooperatives and large farmland owners, in addition to the yield-increasing effect, the cost of collection should be considered as well. As the mechanical strength of high-strength weather-resistant mulch film is higher during film collection, which results in lower labor cost for secondary picking, which also generates increasing income of crop yields. Thus, even if the price of mulch film increases to a certain extent, their net incomes are higher than that of using ordinary mulch film. For crops with high economic value, the overall economic benefit of using high-strength weather-resistant mulch film is significantly better than that of common mulch film, and users have enough motivation to make changes.

5. Upgrade the Data Traceability System and Strengthen the Supervision and Evaluation throughout the Whole Process

Under the gradual refinement and landing of the EU's "Green New Deal" policies, growing information on product environment/carbon footprint will be disclosed in the "Digital Product Passport". Electronic means have become an irreversible trend. China has been trying to establish a mulch film management ledger system to record all information along the value chain, containing mulch film production, use, collection and recycling. Local authorities in some areas are trying to integrate the mulch film use and collection into their existing agricultural management platform. Drawing inspiration from the traceability management approach of the EU's "Digital Product Passport", it is recommended to use digital tools, such as QR codes, to upgrade the management ledger to a unified national/regional information platform, merging agricultural materials including pesticides, fertilizers, and mulch films, and achieve systematic management.

6. Extended Producer Responsibility (EPR)

The Extended Producer Responsibility is the core of establishing a long-term mechanism for mulch film collection and recycling. The EPR system of the pilot, in a form of market entry scheme, determined limited mulch film producers to join the governmental bidding by setting the mulch residue collection as a mandatory precondition. Along with the market development, government subsidies can be gradually withdrawn.

II. Biodegradable Mulch Film

Biodegradable mulch film is considered to be an environment-friendly product that may replace conventional PE mulch film. However, due to uncertain factors in relation to its effectiveness, degradation performance and safety, the market is filled with various types of products that are only claimed to degrade. To this end, the project will start with field pilots and standardized certification to promote the proper use of bio-film.

(I) Baseline

1. Regulations and Policies Related to Biodegradable Mulch Film

In 2017, the product technical standard *Biodegradable Mulching Film for Agricultural Uses* (GB/T35795-2017) was formulated, which specifies its definition and the requirements in terms of product properties, testing methods, marking, packaging, transportation and storage. In 2019, the *Soil Pollution Prevention and Control Law* was officially implemented, which clearly states that "The state encourages and supports agricultural producers to use biodegradable mulch films". In 2020, the *Law on the Prevention and Control of Environmental Pollution Caused by Solid Wastes (Revised Draft)* explicitly encouraged the research, development, production, sale and use of agricultural mulch films that are degradable and cause no harm to the environment. In 2022, it was pointed out in the *Technical Guidance on Pilot of Scientific Use and Recycling of Mulch Film* that biodegradable mulch film would be promoted to be used in approximately 333 thousand hectares of land.

2. Market of Biodegradable Materials and Mulch Films

(1) Overview of Biodegradable Materials and Mulch films

Biodegradable materials are those that degrade under natural or composting conditions (mulch film products in the soil) through microorganisms, they ultimately completely degrade into carbon dioxide, methane, water, mineralized inorganic salts and new biomass materials.

Biodegradable mulch film is a kind of mulch film produced by biodegradable materials, added with appropriate proportions of starch, cellulose, and other environmentally friendly inorganic fillers and functional additives. The main components in bio-films can be PBAT, PLA, PPC, etc., accounting for 80%-98% of the film, and some additives such as calcium carbonate and starch can be added as well. At present, bio-films are available only in three colors: black, milk white, and green (for weed resistant).

(2) Current Development of Biodegradable Material and Mulch Film Industry

With the recognition and promotion of biodegradable materials and mulch films, in recent years, the biodegradable materials industry has developed rapidly, there are continuous technical breakthroughs achieved, production capacity has rapidly expanded, and prices have gradually decreased (see the table below).

Table 6 Production capacity, main suppliers, and prices of common biodegradable materials

Biodegradable Materials	International Suppliers	Domestic Suppliers	Production Capacity	Price (EUR 10,000/ton)
PLA	NatureWorks (United States), Total Corbion (Netherlands), Hycail (Finland), Musashino Chemical (Japan)	22 companies, including Zhejiang Hisun, Jilin COFCO, HI-TECH CHANGJIANG, Esun Industrial, BBCA, Henan Jindan, Wuliangye Group, Space Sanjiang, Henan Tianren, Youcheng Holdings, and others	>Million tons	0.30
PBAT	BASF (German), Reverdia Novamont (Italy), PTTMCC Biochem (Thailand), Mitsubishi and Showa Denko (Japan), S K Chemical and Ire Chemical (South Korea)	Zhuhai Kingfa, Lanshan Tunhe, Jinhui Zhaolong, Xinfu Technology, Anqing Hexing, Esun, Nantong Longda, Mogao Juhe; there are 9 suppliers under construction, including Hebi Lairun, Shandong Lantian, and Inner Mongolia Dongyuan, and also 7 proposed	230,000 tons, production capacity under construction and proposed >500,000 tons	0.25
PPC	-	Zhongke Jinlong, Henan Tianguan, Jilin Boldere	70,000 tons	0.23
PHA	Metabolix (United States), Kaneka and Mitsubishi Gas Chemical (Japan), Biocycle and PHB INDUSTRIAL S/A (Brazil), Biomers (Germany)	4, including Ningbo Tian'an, Tianjin Green, Beijing Bluepha, and ECOMANN	< 10,000 tons	

(3) The Market of Biodegradable Mulch Films Remains to be Regulated

Due to the high price of bio-films, extensive promotion by the government, and the lack of farmers' awareness, some companies, in order to seek more profits, misled the customers and sell fake biodegradable mulch films under the name of "ecological degradable mulch films", which are explicitly prohibited from being sold or used by the state.

In addition to fake products, the quality of bio-films varies to a large extent, some products follow industrial composting and household composting standards in their certification, but the condition for degradation in such scenarios are much better than that in the soil, and products that degraded in composting scenarios may not necessarily degrade in the soil. At present, there is no compulsory certification for bio-films in China, and the product standards are also out of date compared with international standards.

3. The Market Acceptance of Biodegradable Mulch Films is Limited

Based on the current prices of raw materials, the cost of bio-film is high, which is about 2-3 times that of conventional PE mulch film, so its market acceptance is not ideal. The state vigorously promotes bio-films in areas suitable for application, but the promotion still much relies on financial subsidies.

(II) Implementation at the Pilots

1. Application of Bio-film for Organic Rice Production at Paddy Field in Heilongjiang

This pilot tests whether the bio-film can meet the needs of local rice production and achieve the goal of saving water and herbicide.

(1) Pilot Plan

The films for the experiment are provided by partner Zhuhai Kingfa Biomaterial Co., Ltd. (hereinafter referred to as "Zhuhai Kingfa"). According to the condition of local rice production, three K-series products are used for testing. The bio-films are all black and 0.012mm thick, and its basic properties are in line with the requirements of the national standard (see Table 7).

Table 7 Basic properties of biodegradable mulch film for pilot in Heilongjiang

Product Number	Thickness (um)	Vapor Permeability g/(m^2·24h)	Tensile Strength (N)		Nominal Tensile Strain at Break (%)		Right Angle Tearing Load (N)	
			MD	TD	MD	TD	MD	TD
K8	12	261.8	3.20	3.11	386	548	1.8	1.7
K9	12	366.3	3.10	2.57	378	490	1.4	1.6
K10	12	224.8	3.12	2.74	320	543	1.3	1.8
National Standard	10≤d<15	<800 Class A	≥2.0	≥2.0	≥150	≥250	≥0.8	≥0.8

The demonstration area is about 53 hectares. In mid-to-late April, the integrated mulching and transplanting machine invented by the local cooperative was used to mulch, punch holes on the film surface, and transplant seedlings in the hole. During the whole rice planting process, no weed control work was done, but because the water of the experimental field came from nearby Xiaoxingkai Lake and flowed via other farmland, and other farmland was sprayed with herbicides, so a small amount of herbicides may flow into the experimental field with irrigation water. The rice harvest is at the end of September.

Figure 19. The site of mechanical mulching and transplanting of rice seedlings of the pilot in Heilongjiang

(2) Main Results

1) Degradation of Biodegradable Mulch Film

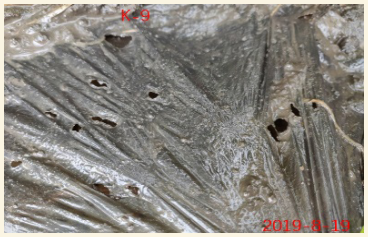
After three months' mulching: All three types of mulch films remain complete, with some parts located below the water, and a few holes can be seen in the mulch film above the surface of water. As time goes on, the three types of mulch films gradually rupture and degrade, the mulch film above the surface of water has a larger number of holes, or a larger area of rupture, the part under the water is generally relatively intact, but with a slight force, it will rupture.

At five months' mulching: In the absence of external forces, all mulch films remain relatively intact in form, but they will rupture in the event of external forces. After the soil loses water, it cracks, and the mulch film also ruptures where the soil cracks, indicating that the mulch film has lost its strength; Among them, K10 has the best degradation degree, reaching level 3, while the rest are at level 2.

After five months' mulching: The degradation of several types of mulch films is good, the pulling force has been lost, and the mulch film does not wrap around working equipment during mechanical harvesting.

Overall, the effective service life of the three types of mulch films is 90 days. The starting time of degradation of bio-films corresponding to the national standard type Ⅱ can meet the needs of rice growth. However, compared with planting in dry land, the mulch film rupture and degradation speed under flooding conditions is slower, therefore, further test of thinner and less anti-aging agent bio-film can be conducted, it can be expected to further reduce cost.

Table 8. Degradation of biodegradable mulch film

Date	K8 Bio-film	K9 Bio-film	K10 Bio-film
7.30			
8.19			
9.10			
9.20			

2) Effects of Biodegradable Mulch Film on the Growth and Yield of Rice

Water saving effect: The water consumption of unmulched plots reached 5550 m^3/ha, and the irrigation amount of paddy fields mulched with three types of mulch films was 4470-4635m^3/ha (the lowest for K10), which saved about 20% water per hectare compared with that of unmulched plots. The main reason is that mulch film greatly reduces water evaporation in rice fields. At the same time, mulch film reduces the amount and growth rate of weeds, reducing their consumption of water.

Warming effect: The rice mulched was harvested 10 days ahead of schedule.

Weeding effect: In the case of no herbicide, the weed density of the unmulched plot reached 125 plants/m^2 at the time of harvesting, while the weed density of the mulched plot was only 1-2 plants/m^2.

Yield impact: The yield of rice increased by 10~18% after mulching. There is significant difference in rice yield between mulched and non-mulched pilots, but there is no significant difference in rice yield among different mulching treatments.

3) Economic Analysis of Biodegradable Mulch Film

Overall, using biodegradable mulch film can increase yield by 10-18%, enable harvest 10 days in advance, save irrigation water by 20%, and save herbicides by EUR 187.5/ha. Rice that does not use herbicides can be sold as higher-value organic rice if other conditions are met, with a price increase of 50%, saving EUR 190.65/ha compared with manual weeding.

2. Application of Bio-film for Rice Production at Upland Field in Inner Mongolia

The purpose of this pilot is to evaluate the possibility of the application of bio-film for direct seeding rice on dryland in Inner Mongolia.

(1) Pilot Plan

The biodegradable mulch films used in this pilotare mainly made from PBAT provided by Zhuhai Kingfa, and are produced by three enterprises/institutions (using the abbreviation of the manufacturer's name as the test number). The mulch films are required to be black, with a thickness of 0.010mm, a width of 170cm, a service period of over 65 days, and their basic properties meet the national standards (the mechanical properties of the three products are shown in the table below). A 0.008mm-thick PE mulch film is also used for comparison.

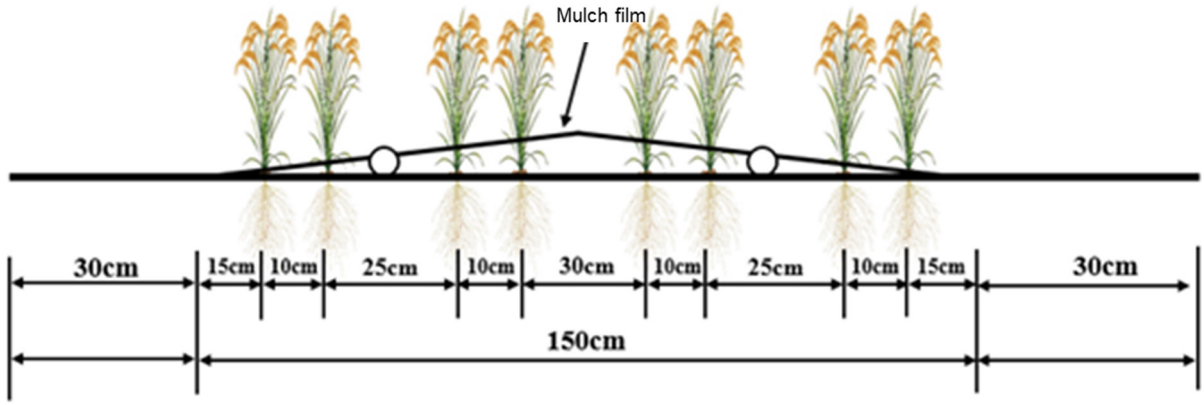
The demonstration area is about 133 hectares. According to the routine operation of direct seeding rice on dryland, mechanical mulching and sowing are carried out in mid-to-late April, with drip irrigation under film integrating water and fertilizer, and artificial harvest at the end of September.

Table 9. Basic properties of bio-films for experiment in Inner Mongolia

Mulch film	Thickness (mm)	Tensile load (N, MD/TD)	Producer
SDQT	0.010	3.3/2.1(>1.5)	Shandong Qingtian
SHHR	0.010	4.2/1.7(>1.5)	Shanghai Hongrui
CAS	0.010	3.1/1.6(>1.5)	Chinese Academy of Agricultural Sciences

Note: The requirements of the national standard are in parentheses

Figure 20. Mulching mode of direct seeding rice on dryland in Inner Mongolia



(2) Main Results

Figure 21. Site of Inner Mongolia pilot

1) Degradation of Biodegradable Mulch Film

According to the field observation, the induction period of three types of bio-films (that is, the occurrence of natural cracks or holes) is more than 65 days, which is in line with the product test. As shown in the table below, there are certain differences in the degradation of different biodegradable films. It can be seen that there are differences in degradation property of different mulch films produced using the same biodegradable materials.

At the end of September, when the rice was harvested, that is, after 5 months of mulching, the three bio-films all broke into small pieces, which did not affect the harvesting operation. Based on long-term observation, the bio-film will be completely degraded within 2-3 years, and it will not affect the cultivation in the coming year.

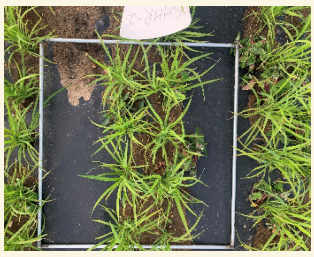
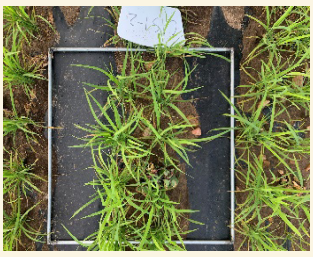
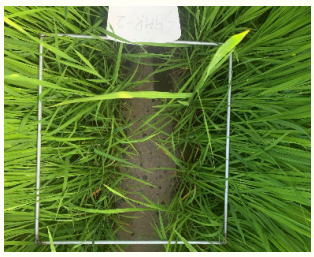
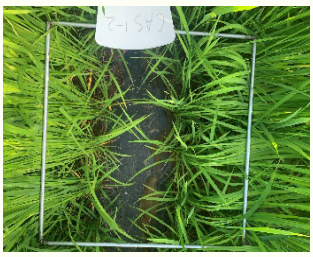
Table 10 Degradation of mulch film in the field

Unit: Days after mulching

Treatment	Induction period (A)	Cracking period (B)	Great cracking period (C)	Splintering period (D)	No-film period (E)
SDQT	65	73	82	98	2-3 years
SHHR	68	77	87	104	2-3 years
CAS	72	80	92	107	2-3 years

Note: The classification of degradation stages is based on the agricultural industry standard *Criterion for Evaluation of Biodegradable Film Mulching in Agriculture*. Induction period, that is, the time from the mulching to the appearance of multiple natural cracks or holes (diameter) ≤ 2cm (3 or more per linear meter) on the ridge (border) surface of the mulch film; Cracking period, that is, the time when natural cracks or holes (diameter) ≥2cm and <20cm appear on the ridge (border) surface of the mulch film; Large cracking period, that is, the time when natural cracks >20cm appear on the ridge (border) surface of the mulch film; Splintering period, that is, the time when the flexibility of the mulch film is completely lost, the mulch film on the ridge (ridge) surface is broken, and the maximum area of mulch film fragments is ≤16cm^2. No-film period, that is, the time when the mulch film on the ridge (border) surface cannot be seen.

Table 11. Degradation of three types of bio-films in Inner Mongolia pilot

Date	SDQT Bio-film	SHHR Bio-film	CAS Bio-film
5.15			
6.15			
7.15			
8.15			

2) Effects of Biodegradable and Conventional Mulch Film on the Growth and Yield of Rice

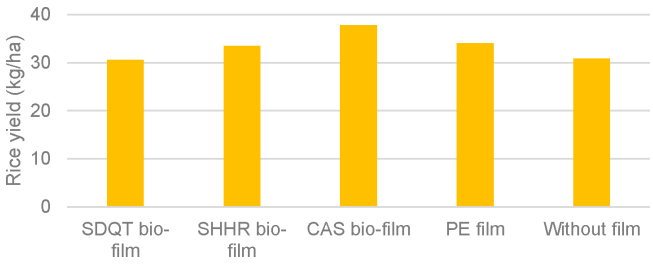
Water saving effect: The planting method of direct seeding rice on dryland with mulching saves 40% of the total water compared to conventional irrigation for rice, and 13% of the water compared to direct seeding rice on dryland without mulching. Although the water retention capacity of biodegradable mulch films is slightly inferior to that of PE mulch films, there is no significant difference in the total water consumption of different plots with mulching in practice.

Warming effect: Soil temperature monitoring shows that due to the fact that the accumulated temperature of the soil treated with mulching (including bio-film) from 0 to 100 days after sowing is about 140℃·d higher than that of the bare land, the jointing and heading stages of rice cultivated with mulching are 5-7 days earlier than that of the bare land.

Weeding effect: Weeds in paddy fields with direct seeding rice on dryland in Inner Mongolia mainly appear in the middle and early stages, and the number of weeds decrease significantly with rice growth.

Yield impact: There are great differences in rice yield among plots with different mulch films. The yield of direct seeding rice on dryland with traditional PE film is 10% higher than that of non-mulching cultivation. The yield of rice covered with CAS film with slow degradation rate is the highest, even higher than that of rice covered with PE film. The yield of rice mulched with SHHR film is similar to that of rice mulched with PE film, which basically meets the growth needs of direct seeding rice on dryland; the yield of rice mulched with SDQT film is similar to that of rice without mulching, which indicated that the film could not meet the growth needs of direct seeding rice on dryland.

Chart 6. Impact of different bio-films on rice yield in Inner Mongolia pilot



3) Economic Effect Comparison Between Biodegradable and Conventional Mulch Film

There are great differences in the properties of different mulch films produced using the same biodegradable materials. Even though the mechanical properties of CAS film are not as good as the other two, its degradation safety period is long, which can meet the growth needs of dry direct seeding rice in this pilot, and the yield-increasing effect is obvious, with better economic benefits than PE film.

Table 12. Output value, cost, and income of direct seeding rice on dryland in Inner Mongolia pilot

Treatment	Yield	Gross output value	Total investment	Net income
	(t/ha)	(EUR/ha)	(EUR/ha)	(EUR/ha)
SDQT	6.89	3,275	2,038	1,238
SHHR	7.54	3,575	2,038	1,538
CAS	8.51	4,038	2,038	2,000
PE	7.67	3,638	1,900	1,738
Bare land	6.75	3,213	1,825	1,388

Note: The purchase price of rice is EUR 0.48/kg.

Unit: EUR/ha

Treatment	Agricultural capital input					Land rental and manpower			Subtotal
	Fertilizer	Mulch film	Seed	Pesticide	Water and electricity supply	Labour	Land rental	Mulch film recycling	
SHHR	200	363	163	63	138	175	938	0	2,038
CAS	200	363	163	63	138	175	938	0	2,038
SDQT	200	363	163	63	138	175	938	0	2,038
PE	200	150	163	63	138	175	938	75	1,900
Bare land	200	0	163	138	200	250	938	0	1,825

Note: The consumption of mulch film used in this pilot is 7500m^2/ha, and the unit price of bio-film is EUR 3.94/kg, the unit price of PE mulch film is EUR 1.53/kg.

3. Application of Bio-film for Strawberry Production in Greenhouse in Beijing

This pilot is to verify the possibility of the application of bio-film in strawberry production in greenhouse. In addition, the straw after strawberry harvest and bio-film will be treated by household composting to explore the resource utilization solution of agricultural waste under the scenario of small-scale agricultural production.

(1) Pilot Plan

Six types of mulch films were selected for comparative experiment, including three types of domestic bio-films, one type of domestic silver gray functional film, one type of sunlight shrinking mulch film imported from Australia, and one type of conventional mulch film purchased locally. The width of all mulch films is 150cm, and the color, thickness, and other information are detailed in the table below.

Table 13. Basic information of films used in Beijing pilot

Types of mulch films	No.	Colour	Thickness (mm)	Producer
Bio-film	Bio-Film-1 (BF1)	Black	0.014	Zhuhai Kingfa
	Bio-Film-2 (BF2)	Black	0.012	Zhuhai Kingfa
	Bio-Film-3 (BF3)	Colourless	0.014	Chinese Academy of Sciences (CAS), Changchun Branch
Functional film	Function film1 (FF4)	Silver gray	0.010	Yunnan Xuanwei
Common mulch film	Conventional film (PE5)	Black	0.010	Purchased locally
Sunlight shrinking film	Solar shrink film (SF6)	Silver gray	0.12	Australia

The demonstration scale is 20 greenhouses, and the greenhouse is 50m long and 8m wide. Strawberries have been planted in the greenhouse for ten years, and the last batch of strawberries were harvested in May 2021. In this experiment, strawberries were planted in October 2021, mulch films were fastened and mulched in the greenhouse in mid-late October, and manual film breaking and seedling placing were conducted immediately (as shown in the following picture), strawberries were harvested in April 2022.

Figure 22. Strawberry mulching site in greenhouses in Changping, Beijing

After strawberry harvest, the residual straws and bio-films were mixed and put into a household composting bucket placed outside the greenhouse for composting, and three groups of comparative tests were set up, including adding biomass charcoal, adding microbial agent and no additives. All composting buckets are regularly flipped and sampled for monitoring.

Figure 23. Household composting buckets used in Beijing pilot

(2) Main Results

1) Degradation of Biodegradable Mulch Film

Within 5 months after mulching, the three types of bio-films remained complete, which could meet the growth needs of strawberries.

After strawberry harvesting, the household composting experiment of bio-films and strawberry straws showed that the temperature of the compost pile without addition maintained at 25-30℃, and temperature of the pile with biomass charcoal and bio-bacteria agent increased quickly in the first 10 days, the temperature could rise to 45℃, and it could be basically maintained above 30℃ in the following 2 months, and then maintained above 25℃.

After 3 months, the compost with additives can meet the fertilizer standard, which is one month earlier than the compost without additives.

The experiment proved that it was feasible to compost strawberry straws with bio-films at household, and adding biomass charcoal or bio-bacteria agent could shorten the fermentation period and improve the quality of compost. Large-scale industrial composting has low cost and flexible operation, and is suitable for small-scale agricultural production in strawberry greenhouses.

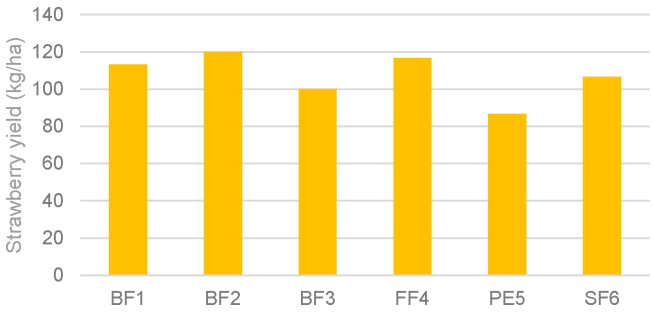
2) Effects of Biodegradable and Conventional Mulch Film on Growth and Yield of Strawberry

Water saving effect: Due to the use of drip irrigation technology in strawberry planting in Changping District, Beijing, there is no difference in soil moisture conservation effect between bio-film and PE mulch film in agricultural production.

Warming effect: Compared with other PE films, the warming effect of the tested bio-films is not significantly different.

Yield impact: The effects of different mulch films on strawberry yield are significant. The yield of strawberry with all other tested mulch films is higher than the 0.010mm black mulch film purchased locally. The commercial yield of strawberry treated with 0.012mm black bio-film (BF2) was the highest, which was also higher than that of 0.014mm (BF1) and 0.014mm colorless bio-film (BF3).

Chart 7. Impact of different mulch films on strawberry yield in Beijing pilot



4. Application of Bio-film for Winter-Sowing Potatoes in Hubei

Farmers do not have a high awareness of collecting and recycling PE mulch films potato farming, so this pilot is to explore the possibility of bio-film replacing PE mulch film in winter-sowing potatoes.

(1) Pilot Plan

The films used in this experiment are the products produced with the biodegradable materials provided by the project partner Zhuhai Kingfa, and the “Chunmiao” colourless PE mulch films are produced by Hubei Guanghe Yuansen Plastic Products Co., Ltd. The basic properties of both are as follows, both of which meet the requirements of national standards.

Table 14 Properties of different mulch films in Hubei pilot

Types of mulch films	Thickness (mm)	Tensile load (N)		Nominal breaking strain (%)		Right angle tear load (N)	
		MD	TD	MD	TD	MD	TD
Bio-Film	0.0083	3.4	2.0	215	505	1.3	0.9
GBT35795	0.010	1.5	1.5	250	250	0.5	0.5
PE	0.010	1.8	1.5	280	360	1.4	1.0
GB13731	0.010	1.6	1.6	260	260	0.8	0.8

The demonstration area is 33.3 ha. Potato sowing was conducted on January 17, 2022, and mechanical mulching was conducted on January 21, 2022. To effectively utilize the warming effect of mulch film, the mulch film is not covered temporarily after mulching. Until the potato seedlings sprout, the seedlings were placed and released manually, another arched shed was built on the ridge and was removed in April for recycling. In the middle of May, according to the growth status of potatoes, the harvesting time was determined based on observation to prevent the occurrence of heat-induced sprouting (secondary growth).

Figure 24. Potato planting site covered with mulch film in Jingmen

(2) Main Results

1) Degradation of Biodegradable Mulch Film

Two months after mulching (mid-March): some small degradation holes appeared in the Biodegradable mulch film (see figure below);

Three months later (mid-April): there were significant ruptures;

After May (mulching for 4 months): a large number of mulch films have ruptured, their strength has significantly decreased, they have lost their toughness. Even if touched lightly by hand, they would rupture;

The mechanical operation was not affected at all during the potato harvesting in the middle of May.

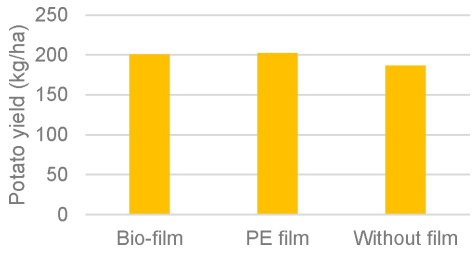
Figure 25. Different states of mulch films in Jingmen pilot

2) Effects of Biodegradable and Conventional Mulch Film on Growth and Yield of Potato

Warming effect: The warming effect of bio-film and PE mulch film is completely consistent in a small arched shed, and the growth period of potatoes is also basically the same.

Yield impact: In this pilot, the yield of winter potato field covered with mulch film is more than 45,000 kg/ha, which is 8% higher than that planted in bare land. In the pilot project in Hubei, the yield difference between bio-film and PE mulch film was less than 1%.

Chart 8. Impact of different mulch films on potato yield in Jingmen, Hubei



3) Economic Effect Comparison between Biodegradable and Conventional Mulch Film

Compared with mulching, bare land planting not only reduces the absolute yield by 8%, but also reduces the potato commodity rate by 10% (as shown in Figure26). However, there is no difference in the performance of commodity rate between bio-film and PE mulch film.

Figure 26. Effect of mulch film mulching on potato green part in Qujialing, Jingmen

However, because the purchase price of bio-film is 3 times that of PE mulch film, the application cost of bio-film in this pilot is about EUR 5,749/ha, which is still EUR 172/ha higher than PE mulch film even after considering the cost of mulch film recycling, the net income gap is 4%.

Table 15. Economic analysis of winter potato production in Jingmen pilot

Treatment	Cost (EUR/ha)	Yield (kg/ha)	Commodity rate (%)	Output value (EUR/ha)	Net income (EUR/ha)	Increase in net income (%)
Bio-Film	5,653	45,162	85	11,477	5,358	48.1
PE film	5,484	45,513	85	11,566	5,595	54.7
Bare land	5,222	42,008	75	9,029	3,617	

Unit: EUR/ha

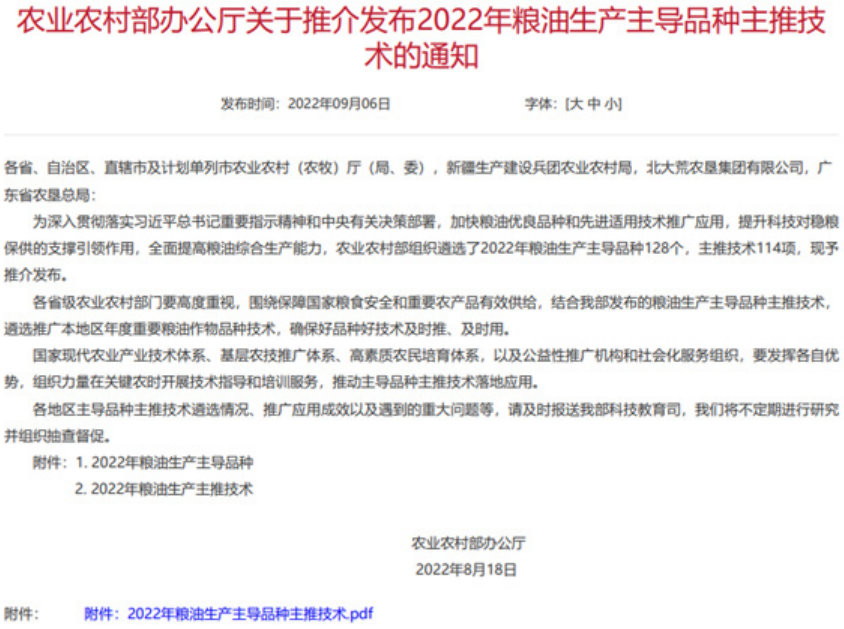
Cost type	Input	Bio-Film	PE film	Bare land
Agricultural capital input	Potato sowing	1,200	1,200	1,200
	Drip irrigation belt	281	281	281
	Mulch film	338	113	-
	Shed film	675	675	675
	Fertilizer	1,125	1,125	1,125
	Pesticide	94	94	94
	Water and electricity supply	56	56	56
Land rental and preparation and labor	Land rental	563	563	563
	Land preparation	94	94	94
	Sowing and mulching	281	281	188
	Irrigation	66	66	66
	Labor	94	94	94
Collection, transportation, and recycling	Harvesting	788	788	788
	Mulch film recycling	-	56	-
Subtotal		5,653	5,484	5,222

(III) Standards and Certifications

1. Technical Specifications

The effect of bio-film varies greatly between different regions (i.e., different climate and soil conditions) and crops, and the requirements for its functions vary, requiring adaptation to agronomic conditions of local crops. The project summarized the experience of the demonstration area and formed three sets of technical regulations for representative areas and representative crops, including the *Technical Specifications for Biodegradable Mulch Film for Direct Seeding Rice at Upland Field, Technical Specifications for Cultivation of Strawberry with Biodegradable Mulch Film Mulching in North China*, and *Technical Specifications for Biodegradable Mulch Film Mulching of Winter Potatoes in the Middle Reaches of the Yangtze River*, which provides an objective and scientific basis for application and promotion of bio-film. Among them, the water saving and efficiency enhancing technology of direct seeding rice on dryland with bio-film mulching has been included in the main technology for promotion by the Ministry of Agriculture and Rural Affairs (MARA) in 2022.

Figure 27. Partial application proof of technical specifications for bio-film



农业农村部办公厅关于推介发布2022年粮油生产主导品种主推技术的通知

发布时间：2022年09月06日　　字体：[大 中 小]

各省、自治区、直辖市及计划单列市农业农村（农牧）厅（局、委），新疆生产建设兵团农业农村局，北大荒农垦集团有限公司，广东省农垦总局：

为深入贯彻落实习近平总书记重要指示精神和中央有关决策部署，加快粮油优良品种和先进适用技术推广应用，提升科技对稳粮保供的支撑引领作用，全面提高粮油综合生产能力，农业农村部组织遴选了2022年粮油生产主导品种128个，主推技术114项，现予推介发布。

各省级农业农村部门要高度重视，围绕保障国家粮食安全和重要农产品有效供给，结合我部发布的粮油生产主导品种主推技术，遴选推广本地区年度重要粮油作物品种技术，确保好品种好技术及时推、及时用。

国家现代农业产业技术体系、基层农技推广体系、高素质农民培育体系，以及公益性推广机构和社会化服务组织，要发挥各自优势，组织力量在关键农时开展技术指导和培训服务，推动主导品种主推技术落地应用。

各地区主导品种主推技术遴选情况、推广应用成效以及遇到的重大问题等，请及时报送我部科技教育司，我们将不定期进行研究并组织抽查督促。

附件：1. 2022年粮油生产主导品种
2. 2022年粮油生产主推技术

农业农村部办公厅
2022年8月18日

附件：　附件：2022年粮油生产主导品种主推技术.pdf

2. Certification Standards

Establishing transparent standards, certification, and testing systems is crucial for the application and promotion of biodegradable products.

The national standard, *Biodegradable Mulching Film for Agricultural Uses* (GB/T35795-2017), specifies the technical requirements for bio-films, including specifications and size deviations, appearance, mechanical properties, vapor permeability, artificial climate aging performance, biodegradability and heavy metal content, etc.

There are updated product standards for bio-films internationally, including the current European standard EN 17033: 2018 (*Plastics - Biodegradable Mulch Films for Use in Agriculture and Horticulture - Requirements and Test Methods*) and the international standard certification ISO 23517:2021 (*Plastics - Soil Biodegradable Materials for Mulch Films for Use in Agriculture and Horticulture - Requirements and Test Methods Regarding Biodegradation, Eco Toxicity and Control of Constituents*). Compared to Chinese national standards, the two standards have more detailed regulations on the biodegradability, controlled metals, and other prohibited components in soil, and clarify ecotoxicity testing (including for plants, earthworms, microorganisms, etc.) to verify the safety of products.

In order to improve China's standards for bio-films and be in line with international standards, the joint partner of the project, TÜV Rheinland, and the Key Laboratory of Mulch Film Pollution Prevention and Control of MARA (hereinafter referred to as "Key Laboratory of Mulch Film Pollution Prevention and Control") drafted the *Technical Methods for Evaluating the Degradability and Ecological Safety of Bio-films*, to standardize the

composition, biodegradability, and environmental safety of bio-films and their raw materials. After several rounds of discussion, the expert review was finally completed in December 2021 and the above-mentioned Technical Methods was submitted to the relevant competent departments of MARAin January 2022.

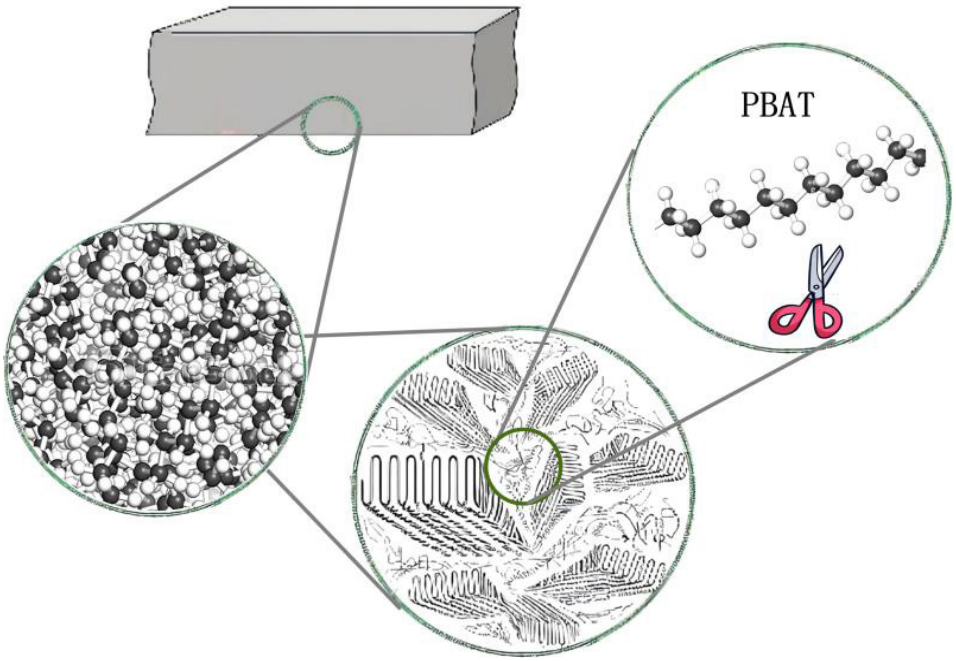
3. Laboratory Verification Results

The project partner TÜV Rheinland and the Key Laboratory of Mulch Film Pollution Prevention and Control also tested the material safety, degradability, and ecotoxicity of bio-films in parallel according to domestic and international standards.

The degradation process of biodegradable plastics is a series of processes of disintegration followed by biological mineralization. In the first stage of disintegration, some chemical bonds of the polymer chain break under the action of heat, humidity, sunlight and enzymes to form shorter polymer chains. In the second stage of biological mineralization, microorganisms completely decompose plastic fragments into carbon dioxide and water under aerobic or anaerobic conditions, while producing a small amount of biomass.

TÜV Rheinland Shanghai Laboratory, an accredited laboratory by several international biodegradation licensing authorities, offered tests to the biodegradable mulch film in accordance with the methodology prescribed by EN and ISO. Firstly, the laboratory conducted a biodegradation performance test, but after 3 rounds of attempts, the final result has not been obtained yet. The EN and ISO standard requirements for biodegradability are as follows: absolute or relative biodegradation rate ≥ 90%, and period of time taken into test should not exceed 24 months. The first attempt of test began in May 2021 with the natural soil of the pilot in Heilongjiang as test soil, the biodegradation rate of test material reached 42.9% after 6 months, but the degradation rate of the test and reference material continued to decrease afterward, so the test was suspended. The test soil was replaced in the second attempt of test and standard soil that met EN and ISO standards was used. However, the degradation rate of the test and reference material showed an even lower result than the outcome of the previous test, therefore the test was again called to a suspension. Optimization was exclusively made to the third attempt of test in July 2023, with equipment upgraded and still standard soil taken as material. Although happened a short period of time ago and no conclusion can be drawn, the parallelism of the reference material was better than that of the previous attempts. The soil can be used for subsequent ecotoxicity tests if the biodegradation rate of the test material reaches 50%, according to the EN and ISO standards.

Figure 28. Degradation of biodegradable mulch film



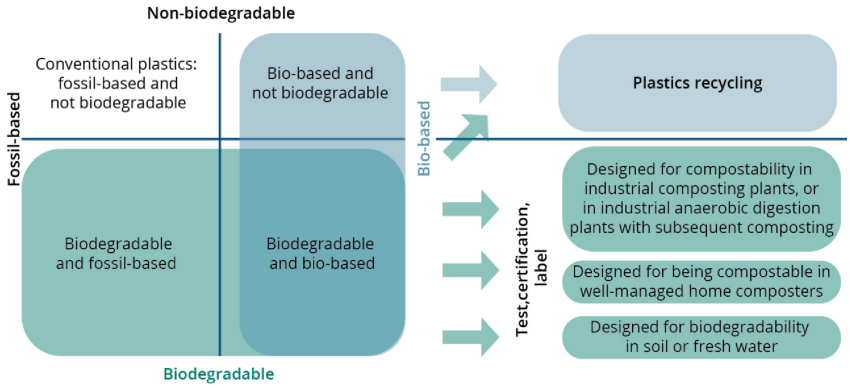
Source: LI Zhen et al., Journal of Agricultural Sciences. 2019.

The earthworm avoidance test of bio-film was carried out in the Key Laboratory of Mulch Film Pollution Prevention and Control to test its ecotoxicity. According to the test results, the concentration of microplastics produced by the disintegration of the bio-film in the project pilots does not affect the survival of earthworms.

In the market of bio-films, there are a lot of mulch film products made only from biodegradable materials that are certified to be "bio-based", "industrially compostable" and "household compostable". The confusion of these concepts also validates the urgency to improve the evaluation and certification system of bio-films in China.

4. International Certification System

Figure 29. Different categories of biodegradable and bio-based plastics



Source: European Environment Agency (EEA) 2020

The European Environment Agency made a good summary of the difference between biodegradable and bio-based concepts and the three different certifications for products. The matrix on the left of Figure 29 describes four possible combinations of two material characteristics (source and degradability): Being "bio-based" or "fossil-based" indicates the source of the material, while being "biodegradable" indicates the degradability of the polymer. The right part of Figure29 indicates how the material of a particular property can be disposed of after its life cycle.

Biodegradability is related not only to the properties of the material but also to the "system characteristics", mainly particular environmental conditions and adequate time for degradation. Biodegradable plastics degrade differently in different environments, so there are different test standards for different plastics, such as industrial composting, household composting, soil degradable in soil, degradable in freshwater, and degradable in seawater (see Table 15).

Table 16 Comparison of different degradation environments and different standards

Test objective	Specification/standard	Biodegradability requirement
Industrial composting	EN 13432, ISO17088*, EN 14995, ISO 18606*, ASTM D6400*, AS 4736	The product can be degraded for at least 90% in no more than 6 months.
Household composting (20-30℃)	AS 5810, NF T 51-800	The product can be degraded for at least 90% in no more than 12 months.
Biodegradable in soil(20-28℃)	EN 17033, ISO 23517:2021	The product can be degraded for at least 90% within no more than 24 months.
Biodegradable in freshwater (20-25℃)	EN 13432 and EN 14995, for freshwater environment; EN 14987 (water-soluble and dispersible polymers)	The product can be degraded for at least 90% in no more than 56 days.
Biodegradable in seawater (30℃)	ASTM D7081 (withdraw without replacement)	ASTM D6691 (30 ℃): The product can be degraded for at least 90% in no more than 6 months. ISO 22403 (15-25℃): The product can be degraded for at least 90% in no more than 24 months.

* Separated tests should be targeted to these organic constitutes if their dry weight accounts for more than 1% of the tota.

Source: Adapted from the German Federal Environment Agency (UBA) (2018)

Different degradation test environments also correspond to different certification logos. Common certification logos of biodegradable products and their certification types are listed in Table 17. Among others, compostable plastics are biodegraded in a special facility under controlled conditions; Industrial composting differs greatly from household composting in condition.

Bio-films are more likely to be naturally degraded in farmland soil after their life cycle so they shall be certified as "soil biodegradable". Some products might not be degraded in soil despite being "industrially compostable" or "household compostable". Of all the certification schemes, only DIN-Geprüft Biodegradable in Soil issued by DINCERTCO and OK Biodegradable SOIL issued by TÜV Austria are applicable. .

To date, only 151 products, including 93 raw materials, 25 additives or intermediates and 34 finished products, have obtained both the above two certificates. The biodegradable materials and additives for mulch films that are granted with suitable certifications are far less than we have imagined.

Table 17 Common certification logos of biodegradable products

Certification logos of biodegradable products	Certification type	Copyright owner of the logo	Evaluator	Certification logo (exampled by industrial composting)
Seedling	Industrial composting	European Bioplastics e.V. (EuBP)	DINCERTCO	industrially compostable
DINplus DIN-Geprüft	Industrial composting Household composting Soil degradable Additives	DINCERTCO		BIOWASTE BAGS DIN plus; INDUSTRIAL COMPOSTABLE DIN Geprüft
BPI	Industrial composting	Biodegradable Products Institute (BPI)		BPI COMPOSTABLE
ABA AS4736 ABA AS5810	Industrial composting Household composting	Australasian Bioplastics Association (ABA)		compostable AS4736
OK compost OK biodegradable	Industrial composting Household composting Soil degradable Freshwater degradable Seawater degradable	TÜV Austria (Belgium)	TÜV Austria (Belgium)	OK compost; TÜV AUSTRIA INDUSTRIAL
Biodegradablepla	Industrial composting	Japan BioPlastics Association (JBPA)	JBPA	Biodegradable Plastics compostable

(IV) Main Conclusions and Prospects

1. The Application Prospect of Mature Biodegradable Mulch Film Products is Promising, and They can Be Used for a Particular Crop in a Particular Area.

(1) Biodegradable mulch films cannot replace conventional mulch films completely and are only suitable for some crops in some areas.

The demonstration results of the Project on some crops in some regions have proved that bio-films produce much higher economic benefits than conventional mulch films do. However, they have no economic advantages for some pilots and are hardly welcomed by the market.

(2) At present, mainstream products at home have met the requirements of functionality and degradability.

Most of the bio-film products in the field test of the Project can meet the mechanical mulching requirements and the need to produce particular crops in particular regions. At the same time, according to the field observation, the tested mulch films can disintegrate well. They can degrade within 2-3 years, or if composted at home together with strawberry straw, within 4 months.

(3) Mature products subjected to years of field tests shall be the focus of the promotion, and products without being subject to field tests pose a risk of a drop in yield.

In the pilot project, PBAT provided by the same material supplier was used as the main raw material. Under the same basic performance requirements, the bio-film products produced by three different processing enterprises have completely different degradation performance and effects, some products cannot even meet the growth needs of crops, resulting in losses.

2. The Standards, the Evaluation and Certification System of Bio-Film Products Need to Be Improved Quickly and Shall Be Used as Mandatory Regulatory Requirements.

Transparent product standards and a transparent certification and evaluation system lay the foundation for the application and promotion of bio-films.

(1) Establish mutually recognized evaluation and certification standards for bio-films that are consistent with their overseas equivalents.

Now we have GB/T35795-2017, EN 17033: 2018, and ISO 23517:2021, which are different with Chinese national standard in terms of the requirements of functionality, biodegradability, and environmental safety. The development of unified bio-film standards can empower mutual trust and mutual recognition and break market and industry barriers, thus facilitating trade and reducing institutional transaction costs.

(2) Introduce strict standards for bio-film products and their tests and put them under compulsory supervision.

In light of bio-films in the market with varied quality, more stringent and refined product standards and testing methods will significantly improve the regulation landscape of the market. The EU has recognized the importance of mandatory regulation of bio-based and biodegradable plastics and is working to advance relevant legislation. Several suggestions are made under the framework which is worth considering:

- Make sure that products will be labeled “biodegradable” and that the environment in which they shall be used and the time (in weeks, months, or years) required for biodegradation must always be indicated. On the mulch film products, the certification methods and logos that correspond to degradation in soil shall be used, rather than those for “industrial composting” and “household composting”, and the degradation time shall be indicated as well.

- Make sure that the biodegradation test covers all parts of the product, including additives.

In addition, we suggest that the future’s bio-film market makes it mandatory to have products certified by nationally recognized laboratories and gives them authority to randomly check the certifications on a regular basis.

III. Project Result Exchanges

The Sino-German Project for Upgrading Plastics Management in Agriculture spanned a three-year duration. Throughout this period, we diligently orchestrated a series of activities to enhance our efforts. These included pilot project training, engaging the public in discussions surrounding science and technology, conducting project meetings, and launching various promotional and awareness campaigns. These activities were thoughtfully interspersed with interactive events aimed at fostering external collaboration and facilitating a deeper understanding of our work among the public. Our ultimate goal was to drive the advancement of the project while disseminating its knowledge to a wider audience.

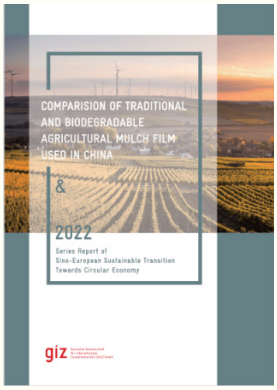
(I) Awareness Raising

1. Project Reports

Over the recent years, we have diligently generated reports derived from our extensive research and surveys encompassing the project, our operational methodologies, and our comprehensive analyses of both domestic and international industries. These reports represent a committed endeavor on our part to propagate and share the best practices and insights gleaned from global businesses operating within the industry.

Table 18 List of project reports

Report name	Cover picture	Brief introduction to the report	QR code
1. International Experience on Agricultural Plastic Application and Recycling Management		As mulch films are used on a large scale, the EU, Japan and North America are facing the risk of mulch film residues. Does the EU have any relevant research results and practical experience for our reference? What kind of integrated management mechanism has Japan established that is worth learning from? How do people in North America deal with that?	
2. Financing Circular Economy – Insights for Practitioners (Chinese Translation)		Revisiting the Imperative of Investment and Financing in the Circular Economy: Exploring Financial Tools, Challenges, and Entry Points	

Report name	Cover picture	Brief introduction to the report	QR code
3. Comparison of Traditional Mulch Film and Biodegradable Mulch Film in China		We have talked about mulch film pollution control for so long, do you know the development process of the mulch film technology? Faced with the environmental challenges posed by traditional mulch films, what is the prospect of biodegradable mulch films? What are the functional differences between the two types of mulch films? How will they affect environmental safety? How about the economic aspect?	
4. Analysis Report on Current Status of PE Mulch Film Application in China		What is the current situation of applications and residues of mulch films in China? What are the relevant policies and regulations, collection modes, and recycling situation at present? What other key problems and challenges do we have now? Facing the future, what should we do?	
5. Conventional and Biodegradable Plastics in Agriculture in EU (Chinese Translation)		How agricultural plastics are used in the EU and what is the changing trend? Are the existing collection modes and recycling processes for discarded traditional agricultural plastics satisfactory? What are the consequences of improper collection? What are the benefits and risks of biodegradable plastics? How effective is the EU's Extended Producer Responsibility (EPR) system? What policies and measures might the EU opt for in the future?	

2. International Experience Sharing

The Sino-German Project for Upgrading Plastics Management in Agriculture is committed to bolstering China's agricultural environmental protection efforts, drawing insights from global practical experiences. Within our WeChat Official Account, we have presented foreign management systems and provided translated reports on pertinent topics as valuable references for interested parties.

How Does the EPR System Help Collect and Recycle Mulch Films: Practical experience in using the EPR scheme to help people in Germany, France, Ireland, and Japan collect and recycle mulch films.

Story of Biodegradable Mulch Films in Europe: An introduction to the process of using biodegradable mulch films in Europe from the aspects of definition, usage scenarios, and certification standards.

A Systematic Elaboration of Minderoo-Monaco Commission on Plastics and Human Health on the Health Effects of Plastics (Chapter 2) (translation): A Comprehensive Assessment of Global Plastic Production: Investigating the Full Life Cycle Impacts on Human Health and the Environment

Policies and Management Measures in the Process of Circular Economy: Global Policy Initiatives for Advancing the Circular Economy: Examining the Core of Extended Producer Responsibility (EPR) Systems and Their Impact on Cost Dynamics.

Interpretation of the EU Policy Framework for Biodegradable Plastics: Specific requirements and recommendations in the EU initiative on biodegradable plastics.

3. Public Education Series

The Sino-German Project for Upgrading Plastics Management in Agriculture released a public education series to help the public understand the management of mulch films in various forms.

1) In-depth expert interview: YAN Changrong, Expert of the Sino-German Project for Upgrading Plastics Management in Agriculture, President of the International Agricultural Plastic Association (CIPA), shares his insights *on tackling "White Pollution" from Mulch Films* and proposes solutions for recycling and sustainable management in a recent *Economy & Nation Weekly* interview.

2) Public education articles: A number of articles released by the Project specify the management issue of plastic mulch films. *Physical and Chemical Recycling of Mulch Films* expounds on the main ways of recycling mulch films from various aspects. Additionally, a trilogy of articles, "Let Mulch Films Cease to be a 'Devil to Soil'" in conjunction with current national policies, aims to enlighten readers about mulching techniques, collection methods, recycling, and other relevant aspects of mulch films.

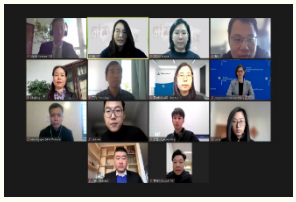
3) Educational Comics for Public Awareness: "Pictorial Dry Cultivation of Paddy Rice with Biodegradable Mulch Films" offers a visual narrative, using the pilot in Inner Mongolia for dry paddy rice cultivation as a prime example. It serves as an illustrative guide, introducing the practical application and economic advantages of biodegradable mulch films.

4) Online Learning: Within the framework of the Sino-German Project for Upgrading Plastics Management in Agriculture, a series of six informative sessions have been conducted known as the "Sino-European Cloud Course on Circular Economy." These sessions, which took place from July to September 2022, delved into the subject of mulch films. Industry experts were invited to provide a comprehensive overview, covering topics such as the current utilization of traditional plastic mulch films and biodegradable mulch films in rural settings, advancements in mulch film management systems, and collection/recycling practices.

5) Creative artworks: The Project Team collected residual films from the public and relevant parties in the industry and cooperated with artists to make an artwork, called *Five Cereals*. For this work, waste mulch films were shaped into several crops like sorghum and maize, and the red lines were used to depict the tragic scene of lifeblood being eroded.

4. Meetings and training

Table 19. Overview of meeting and training content

Title	Meeting content	Picture	QR code
Kick-off Meeting of Sino-German Project for Upgrading Plastics Management in Agriculture 2020.11.18	Discussed the current applications and problems of plastic mulch films in rural China, brainstormed solutions together, and forecasted the prospect of mulch film pollution control in China.		
Demonstration of Biodegradable Mulch Film Application in Organic Rice Paddy Farming, Heilongjiang Province 2021.05.12	Demonstrated the rice paddies mulching and rice seedlings transplanting in the fields, and discussed the policy background and ideas for the use of biodegradable mulch films.		
1st Seminar on Mulch Film Management and Pollution Control 2021.12.06	Chinese and international experts discussed solutions from various aspects such as policies and regulations, scientific research, technological innovation, mode exploration, and international cooperation to address "white pollution" caused by improper use and waste of mulch films and promote the green development of rural areas.		
German Agricultural Plastic Management Knowledge Sharing Session 2022.09.27	The Project Team shared the project outputs and China's contribution to mulch film management with the Federal Ministry of Food and Agriculture (BMEL), the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV), and German industrial representatives.		
2nd Seminar on Mulch Film Management and Pollution Control 2022.12.06	Domestic and foreign experts, scholars, and business representatives are invited to exchange the phased achievements of the Project, share practical experience at home and abroad, and jointly explore solutions to the prevent and control the mulch film pollution.		
On-site Farmer Training session for Pilot in Gansu 2023.04.12	In order to enhance farmers' understanding of the risks associated with leftover agricultural films, a field meeting was conducted to discuss the importance and methods of agricultural film residue collection.		

(II) Expert Opinions

To explore the ecological risks posed by mulch film pollution, the project has convened a panel of industry experts, addressing topics such as microplastics, plasticizers, and emission reduction associated with mulch films. These discussions incorporated the latest research findings from the academia and allowed us to present our own insights and perspectives. The aim was to foster a deeper understanding among the public regarding mulch film pollution and treatment schemes.

1. Microplastics issue of mulch films

Microplastics refers to plastic fragments and particles with a diameter of less than 5 mm.

According to Dr. YAN Changrong, a researcher from the Institute of Environment and Sustainable Development in Agriculture, CAAS, the microplastics abundance of the cultivated stratum in typical mulch film use areas of China is 15,700-36,100 N/kg, mainly including small-sized films or particles (50-250 μm) which are mainly composed of PE, followed by PP, PA and UF. In addition to agricultural plastics (mulch film, shed film, all kinds of agricultural packaging and plastic pipes, etc.), microplastics also comes from irrigation water, atmospheric deposition and organic fertilizer. Combined with the biological toxicity test of soil microplastics, Dr. YAN's perspective is that the current influence of microplastic concentration on soil organisms in China is minimal.

Dr. Tatjana Schneckenburger from Soil Pollution Protection Department of Umweltbundesamt (UBA) introduced the latest findings of Germany and Europe about soil microplastics. It is estimated that 160,000 tons of microplastics enter the soil every year, 90% of which comes from vehicle tire debris. The agricultural sources of microplastics mainly include organic fertilizers and agricultural films. The microplastics content detected in a typical agricultural film coverage area is 6.1-99.4 mg/kg PE and 1.2-2.9 mg/kg PET. For Europe, the research results have been verified. Microplastics has been found in soil all over Europe, and in some areas, agricultural film is one of the most important sources. Besides, the scientific community in Europe has collectively agreed that nano-plastics have the potential to be absorbed by soil microorganisms and plants. However, further research is required to fully understand the resultant impacts.

The EU-funded iMulch project is dedicated to research mulch films and their interaction with soil microplastics. The project has successfully established a detection method. The research findings indicate that there was no detectable increase in soil microplastic content during the use of mulch films (prior to film removal). Consequently, the primary contribution of mulch films to soil microplastics arises from residual mulch film fragments. Moreover, in the adsorption tests conducted on 0.030mm PE mulch film fragments, no significant adsorption effect on heavy metals and pesticides was observed.

2. Plasticizer Issue of Mulch Films

A plasticizer, often referred to as a plasticizing agent, is a common polymer material additive employed to enhance the flexibility of plastic products. One prevalent type of plasticizer is phthalate esters (PAEs). However, it's noteworthy that plasticizers, akin to hormones, exhibit estrogen-like properties, earning them the moniker "environmental hormones." Besides, plasticizers also carry a potential carcinogenic risk.

The Key Laboratory of Mulch Film Pollution Prevention and Control under Ministry of Agriculture and Rural Affairs (MARA) randomly sampled nearly 70 mulch films on sale for PAEs detection, including PE mulch films and biodegradable mulch films (PBAT is the main component). Among them, the total average content of six categories of PAEs in mulch film samples was 13.4 mg/kg, and the content of PAEs in biodegradable mulch film samples reached 32.5 mg/kg. In addition to DEHP and DBP, a small amount of DMP and DEP were also detected. There was no significant difference in the content of PAEs in mulch film samples of different regions and colors. The study also shows that the content of six kinds of plasticizers had no obvious correlation with the thickness, physical and mechanical properties of mulch films. According to the sampling results, the laboratory holds that the contribution of mulch films to the soil plasticizer can be ignored.

The consensus of scholars at the "Soil Microplastics" international conference is that the leakage of plastic additives and environmental health risks still need to be further explored.

3. Mitigating Greenhouse Gas Emissions from Mulch Films

Greenhouse gas emission reduction is a common action of the international community in response to the climate crisis.

Prof. LI Lingling, Dean, College of Agriculture, Gansu Agricultural University, based on the data of Gansu pilot area, analyzed the carbon footprint of mulch films in the full life cycle. The results show that the supply chain and production process of mulch films are the main carbon emission contributor.

At its life end, no matter what treatment method is applied, its carbon emission accounts for a very small proportion of the total emission, e.g. mulch film incineration only accounts for 4% of the total emission. If mulch films are recycled, emission reduction will be achieved. Therefore, if thick mulch films are used, the overall carbon emission of mulch films will increase.

In the Europe iMulch project, the carbon emission of PE mulch films and biodegradable mulch films was analyzed and compared in the full life cycle. When 0.030mm PE mulch film (80% was incinerated, and 20% was recycled), and 0.010mm PLA/PBAT biodegradable mulch film were used, there was no obvious difference in greenhouse gas emission effect between them.

Drawing upon data from the Inner Mongolia pilot project, the collaborative efforts of the New Water-Saving Materials and Agricultural Film Pollution Control team and the Biological Water Saving and Dry Farming team at the Institute of Environment and Sustainable Development in Agriculture, CAAS, undertook a comprehensive analysis of greenhouse gas emissions associated with various rice planting methods. The findings indicate that, in comparison to the conventional irrigation transplanting method, dry direct seeding led to a reduction in CH_4 emissions, an increase in N_2O emissions, but overall, with a decrease in greenhouse gas intensity and global warming potential index. Additionally, it significantly enhanced water use efficiency.

(III) Gender Equality

The GIZ Environment and Circular Economy Team has consistently prioritized gender equality as a core concern. Employing gender analysis and gender equality assessments, the team has meticulously ensured that the distinct needs and interests of various gender groups are thoroughly considered throughout the Project's planning and execution. In 2022, the GIZ Environment and Circular Economy Team organized five specialized training sessions designed for farmers, with a specific focus on agriculture and farming-related matters. These sessions had a positive influence on 94 women, empowering them within their roles. Furthermore, several prominent female speakers were featured at major conferences, serving as a testament to the prominent leadership roles that women within the GIZ team have assumed.

1. Thematic Training: "Women's Power"

Within the framework of the Project, a special presentation titled "Harnessing Women's Potential: Rural Areas and Sustainable Development" was delivered during a themed training session for highly skilled female farmers in Jingmen. Through engaging interactive activities, the sharing of knowledge, and assigned coursework, the project emphasized a fundamental message: women in rural areas possess equal potential to men. If rural women are granted the same access to resources and opportunities as their male counterparts in farming, they are fully capable of achieving equivalent results.

Figure 30. "Women's Power" training

2. Speech: Gender and Sustainable Development

On December 6, 2022, the Project Team delivered a speech on the topic of "gender and sustainable development" at the 2022 Sino-European Circular Economy Summit - 2nd Seminar on Mulch Film Management and Pollution Control:

Importance of gender issues: Men outrun women by 6% (post-2015) by degree completion of primary schools and junior high schools worldwide. Men have a 12% higher average literacy rate than women. The proportion of female senior executives remains low. There are 84 countries where women are restricted from taking up certain occupations or working in certain trades. Women spend three times as much time as men on unpaid housework and care work. In middle- and high-income countries, 10% more women than men died from unsafe water and health facilities, and lack of favorable sanitary conditions (2019). Globally, women enjoy, on average, only 75% of the legal rights of men. In some areas, women cannot even apply for passports or travel as freely as men.

Gender issues on international agenda: In 1946, the UN established the Commission on the Status of Women to monitor annual developments in gender equality. In 1948, the Universal Declaration of Human Rights was adopted, declaring that women's rights are part of human rights. In 1985, the rise of the global feminist movements made the issue of violence

against women open for discussion and the issue of gender equality globally recognized. In 1995, the 4th UN World Conference on Women was hosted in Beijing, which adopted the Beijing Declaration and Platform for Action. In 2010, the UN established UN Women, an agency dedicated to women's affairs. In 2015, women's rights officially became part of the Sustainable Development Goals.

Gender issues and cases in international development: Make optimization from the perspective of gender language. Promote inclusiveness, which means people should speak and write in a way that does not discriminate against a particular gender, social gender, or gender identity nor perpetuate gender stereotypes. Regularly assess the advances in gender equality, and use different metrics as the basis for measurement by regularly updating reports and databases. When designing a project, an international organization needs to consider whether the project meets the metrics in terms of the environment, protection and supervision, and gender management (is there any project objective that infringes women's rights or impairs gender equality).

3. Questionnaires and Data Evaluation

The team gathered pertinent data on female farmers' educational backgrounds, family sizes, income distributions, and their alignment with modern agricultural practices via structured questionnaires. Additionally, specific phenomena from a gender-oriented perspective were observed and analyzed.

- The percentage of female farmers who have received secondary and higher education remains low, and their family size is big, coupled with insufficient vocational skills, which limits women's development to some extent.

- Beyond conventional farming, rural women engage in a diverse range of commercial activities. These activities encompass earning wages from enterprises or factories and generating income through family workshops, both contributing significantly to their primary sources of revenue.

- In terms of household income and expenditure, 66% of the primary income earners are their spouses, that is, the men, while only 23% of women are primary income earners in the families. Also, men (43%) outnumber women (34%) with respect to the right to dispose of money, underscoring a pattern where women tend to wield less decision-making power in rural households compared to men.

- Furthermore, there are numerous discoveries related to the environment and circular economy. To access these findings, kindly scan the QR code provided below.

Acknowledgment

Prof. YAN Changrong, President, International Agricultural Plastic Association (CIPA)

LU Yan, Senior Technical Director, TÜV Rheinland Shanghai Co., Ltd.

GUO Defan, Strategic Project Director, Zhuhai Kingfa Biomaterial Co., Ltd.

Heino Claussen-Markefka, General Manager, ProData Group /R-cycle Initiative

For their efforts in the design and development of the Project

Mr. LIU Qin, Associate Researcher, Director, Key Laboratory of Mulch Film Pollution Prevention and Control, Ministry of Agriculture and Rural Affairs (MARA)

Prof. LI Lingling, Dean, College of Agriculture, Gansu Agricultural University

XIE Junhong, Associate Researcher, Gansu Agricultural University

Mr. JIN Xinhai, General Manager, Lanzhou Jintudi Plastic Product Co., Ltd.

Mr. FAN Yuanchen, Technical & Business Development Manager, Clariant AG

Mr. ZENG Zheng, Market Development Manager, ExxonMobil Chemical North Asia PE

Mr. ZHAO Fujian, General Manager, Zhejiang Jialemi Horticulture Technology Co., Ltd.

JIA Jianhua, Director, Product Data and Traceability Development Office, GS1 China

For their time and effort devoted to carrying out the Project

SINO-EUROPEAN SUSTAINABLE TRANSITION TOWARDS CIRCULAR ECONOMY

Contact us

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Address

No. 14 Liangmahe South Road, Chaoyang District, Bei jing Tayuan Diplomatic Office Building 2-5

Contact Info

Contact: HOU Jingyue
Phone:+86 010 8527 5589 ext. 185
E-mail: jingyue.hou@giz.de

Website

Wechat