Degradable Plastic Films for Agricultural Applications in Taiwan

Shaw-rong Yang
Tainan District Agricultural Improvement Station
350, Section 1, Linshen Road, Tainan 701, Taiwan. R.O.C.
E-mail : sryang @ mail. tndais. gov. tw
and
Chin-hsiang Wu
USI FAR EAST Corp. Customer Service Laboratory 89, Top-hu,
Hu-Nan Village, Linkou Shiang Taipe Hsien, Taiwan. R.O.C.

Summary : Tainan District Agricultural Improvement Station began in February 1991 to evaluate the feasibility of using degradable plastic films for horticultural crops production. Products from China, Korea, Israel, Germany , U.S.A and Taiwan were used for comparison. Results are summarized as follows:Macro-and micro-environmental changes in different seasons affected the degradation time of the tested degradable plastic films. The silver/black bio/photo-degradable PE films containing 20% starch from USI Far East Corporation degraded after 56 ,83 , 38, and 33 days when they were mulched in fall(October,1991), winter(December,1991), spring(April,1992) and summer (August,1992), respectively. The more starch incorporated, the faster the films degraded.No difference was observed in size, weight, yield, total soluble solids and heavy metal contents of the fruits of cantaloupe and watermelon grown on the beds mulched with various kinds of degradable PE films or traditional PE film.No difference was observed in yield as well as the heavy metal (Fe, Pb, Ni, Cu, Cd and Cr) contents in the edible part of the crops of cabbage mustard and head lettuce that were grown in the soil without or incorporated with debris of degradable PE films in 6 consecutive years. The same results were also obtained in another trial on cantaloupe and paddy rice for 4 consecutive years.Various amounts(0, 4 ,8 ,16 , 32 and 64g) of used degradable PE films were seperately mixed with field soil. The mixed soil were used to grow paddy rice in clay pots. No difference was observed in plant height, length and weight of the spike, 1,000-seed weight and the kernel per spike among the treatments at harvesting.Six pieces (each 10cm□10cm)of Bioplastics, Bioflex and Green choice biodegradable films were buried in a 8-inch clay pot. Then head lettuce were planted in the pots. No difference was observed in head weight and qualities(vitamin C. total soluble solids and crude fiber)either among the treatments or the control. The weight losses for Bioflex, Bioplastics and Green choice were 58.4%,47.9% and 11.3%, respectively after 40 days.

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Introduction

Based on the estimates of the Taiwan plastic industry, the annual requirement for agricultural plastics in Taiwan is 13,000-13,500 tons. The most frequently used product is silver/black film for bed mulching . According to the Taiwan Agricultural Yearbook[6],the annual cultivation area of watermelons, sweetmelons and cantaloupes in Taiwan is about 31,214 hectares(Table 1) and the estimated mulching films is about 5,500 tons. Duė to the aging and man power shortage of agricultural workers, development of labor-saving production system such as mulching is increasing day by day. However, the problem of disposing of used plastic films which cause pollution is also increasing with time.[4,7] Some used plastic films were reused for mulching or covering the banks to prevent soil from erosion. Some films were dumped at will or were burned in the field which caused serious air pollution . Thus, coming up with the development of degradable films initiated in the last decades.The Tainan District Agricultural Improvement Station began in February, 1991 to conduct a series of experiments to evaluate the feasibility of using degradable plastic films in the production of horticultural crops in Taiwan[8-14]. The degradable films examined contained starch to assist biodegradation and transition metal compounds to accelerate photooxidation. Because of the concern about the effects of heavy metals on plant growth and quality[1,2,5],the plants were examined for the effects of plastics residues on metal content of grown plants and on rate of plant growth.Results are summarized as follows:

Table 1. Planted area of major mulching crops in Taiwan

Crop	Planted area(ha)
Watermelon	19,939
Muskmelon	2,836
Cantaloupe	8,349
Strawberry	400
Pineapple	7,499

Source: Taiwan Agricultural Yearbook (1997 edition)

Materials and Methods

The studies were conducted from 1991 in Southern Taiwan.Most of tested degradable PE films (Trademark : Ecolene) were produced and supplied by the Customer Service Laboratory, USI FAR EAST Corporation (The largest polyethylene comopany in Taiwan).

1. Study of the various mulching films on the yield and quality of melon crops

This trial was conducted at commercial growing area of watermelon and cantaloupe in

Husehchia, Tainan prefecture. Photo/bio-degradable PE mulching films incorporated with 5%, 10%, 15% and 20% starch were used and regular PE film film served as control. Photodegradable consist of benzophenone and transition metal ions, carbonyl and tertiary carbon polymers as promotors in low density polyethylene. Biodegradable consist of modify starch (10-60 %) , LDPE(20-60 %) and compatibilizer(10-20 %) . The starch has been treated on fluid bed, continous process to dry then, blending with LDPE and compatibilizer, processing by extrusion equipment.Masterbatch (treated starch + compatibilizer) is required if needed . All tested films were 1.8 m in width and 0.035 mm in thickness. A randomized complete block design with three replication was adopted in this trial. Each plot (12 m in length, 2.4 m in width) consisted of 12 plants in a single row with 45 cm between plants. Three fruits in each replication were randomly selected for analysis of total soluble solids by refractometer. One fruit from each replication for analysis of heavy metal content.

2. Study of the used degradable PE debris on the yield and quality of the following crops

   This trial was conducted at Tainan District Agricultural Improvement Station from January 1992 until now. Photo/bio-Degradable PE mulching films incorporated with 15-20 % starch was used and regular PE film served as control. All tested films were silver/black in colour, 1.5m in width and 0.035 mm in thickness. The tested films were mulched during the winter season . The regular PE film was removed after crop harvested and degradable PE film was plowed down to the soil. Then, the following crop was planted. Head lettuce and cabbage mustard were adopted, respectively in this experiment. Each plot(12 m in length, 1.3 m in width) in a double rows with 45 cm between plants and 50 cm between rows.

3. Study of various amount of used degradable PE debris on the growth, yield and heavy metal contents of rice plants

   This trial was conducted at Tainan DAIS. In each of the 8-inch clay pots, 0,4,8,16,32 or 64 grams of used degradable PE debris were throughly mixed with 6.5 kg of soil and the mixtures were then used to grow paddy rice. Seeds (cv.Taiken No. 2) were sowed on 13 January and transplanted on 9 March 1993. Each pot treatment was 3 mats and 5 plants per mat with four replications. The rice panicles were harvested on 21 July, 1993. The length , weight and grains of rice/panicle, 1,000- seed weight and percentage of fertile grains were recorded. Brown rice from each treatment was analysed for heavy metal contents.

4. Study of various amount of biodegradable films on the yield and heavy metal contents of head lettuce

   Six pieces (each 10cm□10cm)of Bioplastics(sample from Michigan state university; starch-polyester alloys) , Bioflex(product of Biotec, Germany ; starch-based blends)and Green choice (product of Zn Sang Co.,,Taiwan ; PE+starch).Biodegradable films were buried roughly at 6 and 12cm in depth, 3 pieces at each position,in a 8-inch clay pot. and the one without films served as control.Then head lettuce were planted in the pots on November, 1997 and harvested 40 days after planting on 17 December 1997.

5. Analysis of heavy metal contents

   All samples for analysis were cleaned with deionized water and then put in a forced-draft oven for 1 hour at followed by 48 hours at 70□ and then milled to powder and stored for analysis. Three grams of powder were weighed and burned in a muffle furnace at 560? for 10 hours. The ash was dissolved in 40 ml of hydrogen chloride solution (3N) in a 100 ml pyrex flask. Then 1 ml of 1 N HNO_3 was added until the solution was boiled off. After cooling the sample solution was filtered through Whatman No. 42 filter paper. The heavy metal contents for each sample were determined by Inductively Coupled Plasma Emission Spectroscopy(Model Jqbin-Yvon 24).

Results

1. Effect of the various mulching films on the yield and quality of melon crops

   No difference was observed in size, weight, yield, total soluble solids and heavy metal contents of the fruits of cantaloupe and watermelon grown on the beds mulched with various kinds of degradable PE films or traditional PE film(Table 2, 3, and 4).

Table 2. Effect of the various mulch films on yield & quality of cantaloupe fruits

PE films ***	Fruit size		Weight/ fruit	Yields/plot	Total soluble
	Length	Width	(kg)	($Kg/28.8m^2$)	solids
(cm)	(cm)				
Clear(P/B)**	11.3a *	14.1a	0.91a	34.5a	8.1a
White/Black(B)	11.0a	13.7a	0.88a	45.6a	9.1a
White/Black(P/B)	11.3a	13.9a	0.93	42.4a	9.8a
Silver//Black(P/B)	11.3a	13.7a	0.94a	39.6a	10.1a
Regular PE film	11.3a	13.5a	0.92a	35.0a	9.6a

** □Means within each column followed by the same letter are not significantly different at 5% level

* □ P/B=Photo/Bio-degradable ; B=Bio-degradable

Planting date : 29 Jan. 1992 ; Harvesting date : 27 April~May 1992

*** : PE films manufactured by blown film co-extrusion.

Table 3. Effect of the various mulch films on the growth & yield of watermelon fruits

Content of starch incorporated in film **	Fruit size		Weight/ fruit	Yield/plot	Total soluble
	Length (cm)	Width (cm)	(Kg)	(Kg/28.8m^2)	solids
5□	16.7b*	17.9a	3.06ab	87.4a	10.9a
10%	17.8b	18.3a	3.13ab	107.2a	10.9a
15%	18.1a b	18.3a	3.20a	112.6a	10.3a
20%	18.9a	18.3a	3.02ab	106.0a	9.8a
Regular PE	16.8b	17.6a	2.87b	107.1a	10.9a

*□Means within each column followed by the same letter are not significantly different at 5% level

Planting date : 6 Jan. 1993 ; Harvesting date : 15 April~May 1993

** : PE films manufactured by blown film single-extrusion.

Table 4. Effect of the various mulch films on the heavy metal content in watermelon fruits

Content of starch incorporated in film	Cu	Pb	Cd	Ni	Zn	Fe	Cr
	(ppm)						
5%	0.962a*	0.052ab	0.004a	0.286a	2.063a	2.797a	0.017a
10%	1.024a	0.056a	0.004a	0.264a	2.210a	2.950a	0.021a
15%	0.836a	0.039cd	0.003a	0.237a	2.057a	2.727a	0.015a
20%	0.874a	0.037d	0.003a	0.218a	1.820ab	2.787a	0.020a
Regular PE	0.878a	0.050abc	0.002a	0.228a	1.443a	2.950a	0.016a

*□Means within each column followed by the same letter are not significantly different at 5% level

2. Effect of used degradable PE debris on the yield and quality of the following crops

No difference was observed in yield(Table 5) as well as the heavy metal (Fe, Pb, Ni, Cu, Cd and Cr) contents in the edible part of the crops of cabbage mustard and head lettuce that were grown in the soil without or incorporated with debris of degradable PE films in 6 consecutive years(Table 6).The same results were also obtained in another trial on cantaloupe and paddy rice in 4 consecutive years (Table 7).The results also showed that the content of heavy metals from the plant (Cabbage mustard) were lower than that from the soil in 5 consecutive years (Table 8), therefore, it was presumed that the heavy metals did not transfer or uptake to the plants from soil.

3. Effect of various amounts of used degradable PE debris on the growth, yield and heavy metal contents of rice plants

Various amounts(0,4,8,16,32 and 64g) of used degradable PE films were seperately mixed with field soil. The mixed soil were used to grow paddy rice in clay pots. No difference was observed in plant height, length and weight of the treatments at harvesting(Table 9).There is also no difference in the content of heavy metals(except Cu and Zn) in brown rice among the treatments . Results also indicated that the content of heavy metals were not increased with the added amount of degradable PE pieces (Table 10) and were also less than the critical level of tolerance limits of foods[3]. Besides, the content of heavy metals of brown rice were lower than that of tested degradable film (Table 11).

Table 5. Yields of plants grown in the field incorporated in 6 consecutive years with used destructive PE debris

Planting sequence	Crop	Yields ($Kg/15.6m^2$) Without debris	With debris	Planting date
1st	Head lettuce	37.8a*	39.3a	Jan.1992
2nd	Cabbage mustard	37.6a	31.0a	Mar.1992
3rd	Cabbage mustard	35.4a	37.0a	Oct.1993
4th	Head lettuce	35.2a	38.2a	Jan.1994
5th	Cabbage mustard	Insects damaged seriously		Nov.1994
6th	Head lettuce	32.4a	34.5a	Feb.1995
7th	Cabbage mustard	41.6a	40.5a	Oct.1995
8th	Head lettuce	52.0a	55.4a	Dec.1995
9th	Head lettuce	32.5a	38.7a	Oct.1996
10th	Cabbage mustard	More plants flowering		Jan.1997
11th	Head lettuce	40.1a	40.5a	Oct. 1997
12th	Cabbage mustard	-	-	Dec.1997

*□Means within each line followed by the same letter are not significantly different at 5% level

Table 6. Heavy metal content of plants grown in field incorporated with used degradable PE debris

Planting sequence	Crop	Debris	Heavy metal content(ppm) Zn	Ni	Fe	Cr	Cu	Pb	Cd
1st	Head lett uce	with	2.0	0.08	3.3	0.02	0.76	-	0.08
		without	1.3	0.06	2.7	0.01	0.25	-	0.05
2nd	Cabbage mus tard	with	3.0	0.02	4.5	0.02	0.51	0.04	0.03
		without	2.9	0.04	7.6	0.17	0.58	0.06	0.03
3rd	Cabbage mus tard	With	-	-	-	-	-	-	-
		Without	-	-	-	-	-	-	-
4th	Head lett uce	With	1.8	0.03	4.0	0.05	0.33	0.07	0.03
		without	1.8	0.03	4.4	0.04	0.47	0	0.05
5th	Cabbage mus tard	with	4.7	0.05	8.3	0.05	0.77	-	-
		without	3.3	0.03	5.6	0.03	0.67	-	-
6th	Head lett uce	with	1.4	0.05	2.6	0.06	0.38	0.37	0.007
		without	1.2	0.03	4.2	0.04	0.33	0.007	0.007
7th	Cabbage mus tard	with	2.1	-	3.9	0.03	0.23	0.03	0.013
		without	1.5	-	2.7	0.03	0.13	0.017	0.017
8th	Head lett uce	with	1.4	0.03	3.0	0.02	0.23	0.01	0.013
		without	1.4	0.03	2.9	0.03	0.23	0.01	0.013
9th	Head lett uce	with	1.3	-	3.2	0.003	0.3	0.02	-
		without	1.3	-	2.4	0.027	0.3	0.03	-
10th	Cabbage mus tard	with	2.9	-	4.2	0.07	0.5	0.03	0.02
		Without	2.7	-	4.7	0.05	0.5	0.05	0.02
11th	Head lett uce	With	1.2	-	2.3	0.08	0.2	-	-
		Without	0.9	-	3.0	0.05	0.17	-	-

Table 7. Yields of plants grown in the field incorporated with used degradable PE debris in 4 consecutive years

Planting sequence	Planting date	Crop	Yields(kg/0.1ha)	
			With debris	Without debris
1st	May 1994	Rice	496*	507.6a
2nd	Oct. 1994	Cantaloupe	1,533a	1,464a
3rd	May 1995	Rice	588.3s	576.2a
4th	Oct. 1995	Cantaloupe	2,496s	2,299a
5th	June 1996	Rice	886.7a	726.2a
6th	Oct. 1996	Cantaloupe	2,584a	2,423a
7th	April 1997	Rice	333.2a	365.2a
8th	Nov. 1997	Cantaloupe	1,243a	1,405a

*□Means within each line followed by the same letter are not significantly different at 5% level

Table 8. Heavy metal content of Cabbage mustard grown in the field incorporated with used degradable PE debris in 5 consecutive years

Sample	Treatments	Zn	Pb	Ni	Fe	Cr	Cu
		(ppm)					
Plant	Without PE debris	1.3a*	0.03a	□	2.4a	0.027a	0.3a
	With PE debris	1.3a	0.02a	□	3.2a	0.003b	0.3a
Soil	Without PE debris	52.2a	20.2a	6.4a	7,236a	13.4a	12.4a
	With PE debris	49.5a	19.3b	4.3b	5,640a	11.6a	12.6a

*□Means within each column followed by the same letter are not significantly different at 5% level

Table 9. Investigation of rice plants grown in pots containing different amounts of used destructive PE pieces

Amount of Destructive PE pieces(g/pot)	Rice Length (cm)	Spike Weight (g)	Weight /1000 kernel (g)	Kernel /rice spike	% of fertile kernels (%)	Weight of brown rice /pot* (g)
0	14.9az	1.45a	24.2a	60.0a	85.3	20.5b
4	15.6a	1.50a	22.9a	64.1a	89.3	27.1a
8	15.2a	1.58a	24.1a	63.8a	91.2	23.1ab
16	13.8a	1.65a	24.7a	65.7a	89.8	25.9ab
32	16.3a	1.65a	23.7a	72.1a	86.3	25.6ab
64	16.9a	1.73a	23.6a	67.8a	90.1	24.4ab

* : 3mats/Pot, 5 plants/Mat,

z : Means within each column followed by the same letter are not significantly different at 5% level.

Table 10. Analysis of brown rice from plants grown in pots containing different amounts of used destructive PE pieces.

Amount of destructive PE pieces (g/pot)	Cu	Pb	Cd	Ni	Zn	Fe	Cr
	(ppm)						
0	4.1	0	0	0.2	35.0	15.7	0.4
4	3.5	0	0	0.1	33.0	15.4	0.2
8	2.8	0	0.01	0	28.0	13.8	0.3
16	2.3	0	0	0.04	27.7	14.6	0.3
32	3.0	0	0	0.05	29.5	14.7	0.5
64	2.9	0	0	0.2	31.3	14.7	0.2

Table 11. Analysis of heavy metal contents of degradable materials before testing

Materials	Cu	Pb	Cd	Ni	Zn	Fe	Cr	Al
	(ppm)							
Regular PE film*	1	1	N.D.	□	20	125	<1	4,200
Ecolene film**	2	□1	N.D.	□	35	80	□1	7,000

* : Silver/Black in colour

** : PE film incorporated with 20% starch, produced by USI Far East Corp.

4. Degradation rate at different mulching date

Macro-and micro-environmental changes in different seasons affected the degradation time of the tested degradable plastics films. The silver/black bio/photo-degradable PE films containing 20% starch from USI Far East Corporation degraded after 56, 83 ,38, and 33 days when they were mulched in fall(October 1991),winter(December 1991),spring(April 1992) and summer(August 1992), respectively(Table 12). The more starch incorporated, the faster the films degraded(Table 13).

Table 12. Days from mulching to degradation at different mulching date

Mulching Date		Days from mulching to degradation 5%*	10%	15%	20%
9 Oct.	1991	60	60	57	56
30 Dec.	1991	86	91	85	83
28 April	1992	49	45	38	38
3 Aug.	1992	44	32	32	33

* : PE film incorporated with 5% starch manufactured by blown film single-extrusion.

Table 13. Degradation rate of mulching films incorporated with different percentage of starch

Mulching date	% of degradation rate of mulching films 5%	10%	15%	20%	Date investigated
9 Oct. 1991	0.7	2.9	3.6	25.3	23Dec.1991
30Dec. 1991	4.6	3.1	15.7	20.7	25April 1992
8April 1992	20.9	24.8	17.1	26.6	24 July 1992
3Aug. 1992	19.3	47.5	78.7	56.4	20 Oct.1992

* : PE film incorporated with 5% starch manufactured by blown film single-extrusion.

5. Weight losses of bio degradable films in pot trial

Six pieces (each 10cm?10cm)of Bioplastics, Bioflex and Green choice biodegradable films were buried roughly at 6 and 12cm in depth, 3 pieces at each position,in a 8-inch clay pot. and the one without films served as control.Then head lettuce were planted in the pots on November, 1997 and harvested 40 days after planting on 17 December 1997. The heavy metal content of degradable films before testing were analyzed as Table 14. No difference was observed in head weight (Table 15)and quality (Table 16) either among the treatments or the control(Bare cultivation). Also,The heavy metal content(except Cu and Cd) in the culture media after crops harvested were not significant different among the treatments (Table 17).The weight losses for Bioflex, Bioplastics and Green choice were 58.4%,47.9% and 11.3%, respectively after 40 days(Table 15).

Table 14. Analysis of heavy metal contents of bio degradable film before testing

Degradable materials	Zn	Fe	Cu	Cd	Pb	Ni	Cr	Al
	(ppm)							
Bioplastics	□	□	□	□	□	□	□	□
Green choice	2.7	89	N.D.	N.D.	0.3	0.1	0.6	70
Bioflex	3.4	64	N.D.	N.D.	0.1	N.D.	0.5	42

Table15.Weight of head lettuce grown in pot with bio degradable pieces

Degradable materials	Weight/Plant (g)	Weight losses in film (%)	Remarks
Bioplastics	337.8a*	47.9a	From Michigan state university (PCL 50%+starch 20-30%)
Bioflex	341.3a	58.4a	From Biotec, Germany,(starch-based blends)
Green choice	320a	11.3b	From Zn Sang Co.,,Taiwan (PE+starch 40%)
Bare cultivation	351.3a	□	

Planting-harvesting : 6 Nov. 1997-17 Dec.1997

* : Means within each column followed by the same letter are not significantly different at 5% level

Table 16. Quality of head lettuce grown in pot containing bio degradable pieces

Degradable materials	Vit.C (mg/100g)	Total soluble solids (Brix □)	Crude fiber (%)	Nitrite (ppm)
Bioplastics	5.7a*	2.4a	0.54a	0.74a
Bioflex	6.2a	2.9a	0.58a	0.43a
Green choice	10.6a	2.9a	0.59a	0.43a
Bare cultivation	8.3a	2.9a	0.55a	0.39a

* : Means within column followed by the same letter are not significantly different at 5% □level

Table 17. Heavy metal content of culture media for head lettuce grown in pot containing bio degradable pieces after harvest

Degradable materials	Zn	Fe	Cu	Cd	Pb	Ni	Cr
	(ppm)						
Bioplastics	254a*	1,108a	8.8b	2.63a	13.8a	0.58a	3.9a
Bioflex	152a	1,007a	7.5b	2.3ab	15.1a	0a	3.1a
Green choice	134a	999a	14b	2.33ab	13.8a	0.18a	3.5a
Bare cultivation	144a	1,067a	37a	2.23b	15.8a	0.63a	3.3a

* : Means within each column followed by the same letter are not significantly different at 5% level

Conclusions

We began in 1991 the research and development of degradable plastic films for agriculture in Taiwan. Most of the research was focused on the use of bio- and photo-destructive films for the mulching in horticultural crops. Some data were very informative. The development of degradable materials updated quiet fast. The trend for the future research must focus on the development of much easily degradable materials containing high percentage of starch, complete or biodegradable materials, wasted-papers and fiber-rich agricultural wastes. The use of degradable materials is only one of the strategy to lessen the problem of agricultural wasted plastics. Other practices such as landfill, burning, reusing, and reduction must be used on different cases or situations. If composting is also feasible, the pollution of agricultural plastics can be reduced to a very low or acceptable level.

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