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# FIELD DEMONSTRATION OF BIODEGRADABLE MULCH FILMS IN SOUTH AFRICA

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# EXECUTIVE SUMMARY

The project aim was to demonstrate CSIR's formulated biodegradable mulch films (BDMs) in South Africa. For adoption of such relatively new technologies, it is imperative that demonstration in actual field to derisk it. The demonstration creates awareness and allows for identification of pitfalls that might hamper adoption.

Plastics application in the agricultural sector is on the rise. Plastic mulches for instance, have several advantages, including conservation of moisture, raising of soil temperature, suppression of weeds among others. These lead to crop earliness, less utilization of weedicides, low consumption of irrigation water and generally, higher crop yield. However, the conventional plastics have been shown to disintegrate into microplastics that have adverse ecological effect on soil, especially in the long-term. Even when designed for recycling, the process involves removal from the farm, at cost, and due to contamination with soil and plant debris, it becomes uneconomical to recycle. As an alternative, the BDMs are designed to fully biodegrade in soil, and don't have to be removed from farms at the end of crop season. This gives the benefits of conventional mulch, but with a favorable end-of-life scenario of full biodegradability. In this project, the CSIR demonstrated the technological readiness of the BDMs, through industrial process optimization and production of final products for downstream testing. Subsequently, the films were tested on actual farms, in Gauteng and in Eastern Cape, with several lessons being drawn.

A key finding is that the BDMs have similar performances as conventional plastic mulches, as revealed by outcomes of trials for short term crops in a greenhouse tunnel. Even though two product lines were developed for short- and long-term crops, both formulations have been shown to be suitable for short-term crops. For long-term crops such as pineapples, it was demonstrated that BDMs, just like conventional plastics mulches, encourage early growth, by raising the soil temperature to enhance plant vigour. Contrary to design expectations, the project has helped to clarify the value proposition for such 'long-term' BDMs, not for their longevity on farms, but for provision of the advantages of early crop establishment, when applied on pineapples. Having demonstrated manufacturability and performance in the actual field, these BDMs can be commercialized for targeted applications.

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# 1 Introduction

*Conventional Plastic Mulch films*

Agricultural plastic mulches present many benefits. These include conservation of moisture, raising the soil temperature, weed suppression, reduction of nutrients runoff and reduction of certain pests. Generally, these factors consequently lead to increased crop yield, crop earliness, expansion of growing season, reduction of fertilizer and weedicide usage and reduction of irrigation water. Due to these benefits, plastic mulching is on the rise
Despite the many benefits, several studies are beginning to show adverse effects associated with long-term usage of conventional plastics(Guo et al., 2020; Steinmetz et al., 2016; Wang, Wang, Adams, Sun, & Zhang, 2022; Xu et al., 2020). In its report, FAO (2021), identifies mulches as second only to polymer coated slow release fertilizer, as top priority product due to high risk profile. This is as result of ease of extent of its usage, potential for leakage into the environment, extent of direct contact with receptor environment, and potential to cause harm, particularly in its microplastic form. The conventional mulches could result in large quantities of plastics in the soil, if wrongly used and managed. They are hardly recycled, even when designed thick enough for recycling, due to contamination by soil and plant debris, thus rendering recycling uneconomical. At the end of the crop season, they are taken out of the farms and disposed of at cost, and in fact South Africa and Nigeria where we interacted with some farmers, they indicated that they burn the mulches on the field - exacerbating environmental pollution even further. As depicted in the Figure 1, the conventional mulches break down into large pieces and microplastics that have detrimental impact on the soil properties, harm soil microorganism and could also potentially enter the food chain(Salama & Geyer, 2023).

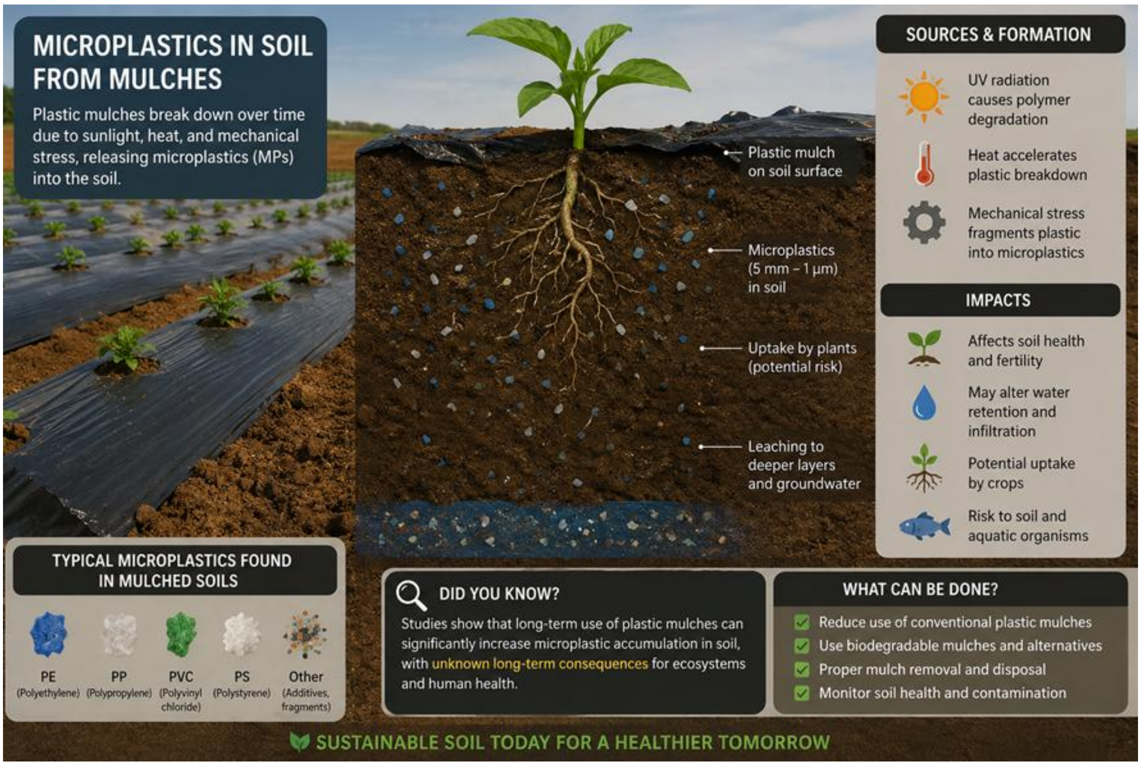


*Figure 1: ChatGPT generated depiction of microplastics formation from conventional plastic mulches and their impact on long-term soil health*

A comprehensive meta-analysis by Wan et al. (2023) indicate that microplastics substantial negative effect on soil fauna, reduction in bacterial diversity and some soil nutrients, with positive effects on fungal diversity and enzyme activity. This is still an active area of research as there are many contracting findings, partly due to non-standardized approaches and challenges in evaluating particles in complex matrices(Yang, Zhang, Kang, Wang, & Wu, 2021), among other factors.

*Biodegradable Mulch Films (BDMs)*

As an alternative to conventional plastic mulches, biodegradable mulch films are gaining traction in usage within the agricultural sector(FAO, 2021; Kasirajan & Ngouajio, 2012; Xiong et al., 2024). Unlike the conventional mulches, properly designed biodegradable mulches should be able to fully mineralize through the action of microbes into carbon dioxide and water, without leaving any toxic residue. BDMs do not contribute to the visible pollution often associated with used conventional plastic mulches, which tend to be discarded by the farm side, burnt on the farm, or landfilled. Any microplastic formed from BDMs is also eventually fully biodegraded, without leaving toxic residue. To this extent, the BDMs contribute in *designing out waste* from the conventional plastic mulches.

Even though biodegradable mulches now exist, they have not been adopted widely, partly due to the cost, and partly due to non-awareness among key stakeholders. Moreover, due to the differences in climatic conditions of different regions, it is imperative that tailored solutions that make use of as much local resources as possible is encouraged, for optimal performances. To this end, the CSIR developed biodegradable film formulations that are tailored for short - and long-term crops, and it is expected that these will biodegrade fully in soil into $CO_2$, water and biomass. The full biodegradability solves the microplastic issues and general pollution from the conventional mulch films. This technology was developed through funding from UK's Foreign, Commonwealth and Development Office – under the Sustainable Manufacturing and Environmental Pollution (SMEP) programme, and co-funding from the CSIR. However, for adoption, it was necessary that the technology be demonstrated, at least in South Africa, to test its utility for the different crops in this specific climatic condition. This current project funded by the DSTI through the Circular Economy Demonstration Fund sought to test industrial manufacturability of the formulated biodegradable pellets suitable for making mulches, suitability in terms of mechanical performance and biodegradability, and applicability for mulching short-term crops and long-term crop. This helps in derisking the technology, helps create awareness and gives confidence to potential users, hence promote adoption of the technology.

## 1.1 Objectives

The aim of the project was to demonstrate the BDMs in actual fields in South African farms, to help create awareness, derisk the technology, learn from shortfalls and encourage commercialization.

The specific study objectives were as follows:

1) To demonstrate the BDM manufacturability at industrial scale,

2) To demonstrate performance of the BDMs in actual field, for both long-term and short-term crops
3) To assess the preliminary techno-economic feasibility of commercializing the technology

# 2 Demonstration of Industrial Manufacturability of BDMs

## 2.1 CSIR BDM formulations

Two of the CSIR BDMs, CSIRP2006 and CSIRP20036, formulated for short- and long-term crops were produced at a pilot-scale facility at the CSIR, with a capacity of 200kg/hr. This closely mirrors industrial scale capacities, and therefore minimal optimizations are expected at full industrial production.

The technology relates to a series of formulations, incorporating up to 40wt% locally obtained natural materials, including thermoplastic starch and other ingredients (CSIRP2006, CSIRP20036), and process thereof, suitable for production of a short- and long-lasting mulch films, that can biodegrade fully to carbon dioxide, water and biomass, without leaving toxic residue, as prescribed in EN17033.

A typical a twin-screw extruder (refer to Figure 2) is used to produce the formulated pellets. Preferably, it should have an air-cooled line, to minimize the drying time for the pellets. The pellets should be dried to very low moisture content, preferably less than 0.15%, before packaging.

*Figure 2: Typical biopolymer compounding system*

The processing conditions were optimized for each formulation, with eventual production of ~500 kg of pellets for downstream conversion into films. Figure 3 illustrates the step-by-step BDM production process, from compounding the formulated pellets, to conversion into a finished product at the industry.

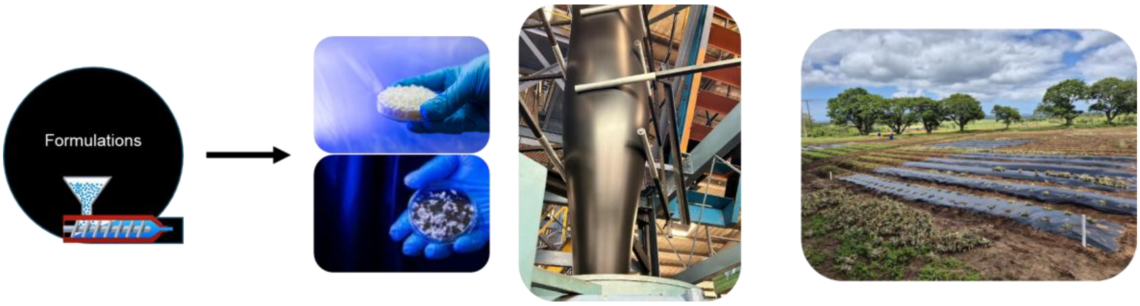


*Figure 3: Formulated pellets, Mulch film production process and Use case in pineapple mulching*

## 2.2 Industrial Production of BDM films

The Manufacturability of the two formulations was successfully demonstrated at two different industrial scale facilities. This shows the robustness of the formulations as they could be processed with film blowing equipment, typically used for conventional plastics.
Key parameters optimized included the profile temperature, draw-down rations, blow up ratios among others.


*Figure 4: Industrial-scale manufacture of CSIR BDMs (CSIRP20036)*

Key challenges noted

- The wastage at production stage is still notably high. Part of the reason for this was the changeover from conventional plastic material to the BDMS. With dedicated line for production of the BDMs, the wastage rate could be brought down.
- Drying of the pellets and packaging are essential for stable bubble formation. Due to the hygroscopic nature of key ingredients in the formulations, the formulated pellets absorb moisture, which contributes to chain scission during conversion process. This leads to high melt flow index (MFI) and collapse of the bubble.
- The MFI if the pellets ought to be tested as part of the quality assurance process. There is substantial deterioration of properties for some of the key ingredients, when kept long on the inbounds shelf. Internal MFI checks are necessary, regardless of the supplier's stated MFI ranges in the certificate of analysis

## 2.3 Performance and Technical Specification for the BDMs

The tensile testing of blown films in machine direction (MD) and transverse direction (TD) were analyzed according to ASTM D882 standard, using an Instron 5966 tensile tester (Instron Engineering Corporation, USA). The tests were conducted at a crosshead speed of 5mm/min. The data was recorded and processed using Bluehill software with average of five replicates. Density, MFI and other physical properties were also determined and the performance results summarized in the two technical data sheets for the products, CSIRP2006 and CSIRP20036, representing short- and long-term mulch formulations, respectively.

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## *Product data sheet*

### *General Description: Biodegradable mulch film material, Black (P20036)*

Features:

- *weather protection and pest control for young plants;*
- *maintenance of moisture in surface soils;*
- *creation of the most favourable microclimate;*
- *stimulation of beneficial plant growth-promoting bacteria;*
- *more abundant and early harvest;*
- *weed control;*
- *no constant weeding required;*
- *reduction of pesticides and herbicides use;*
- *keeping crops clean and undamaged due to no contact between them and the soil*
- *biodegradable and compostable as per ASTM D5338 and ASTM D5988 standards.*

<u>**Scope of Application:**</u> Agriculture and farming

***Specification:***

| Properties | | CSIR P20036 | Test method |
|---|---|---|---|
| Density (g/cm3) | | 1.26 | ISO 1183 |
| Colour | | Black | - |
| Width (cm) | | 120 | - |
| Relative light transmittance (%) | | 0.4 | Illuminance |
| Thickness (µm) | MD/machine direction | 45±5.0 | ASTM D6988 |
| | TD/transverse direction | 45±5.0 | |
| Tensile stress at break (MPa) | MD/machine direction | 20.4± 1.3 | ASTM D882 |
| | TD/transverse direction | 19.9± 1.8 | |
| Modulus (MPa) | MD/machine direction | 56.7±7.56 | ASTM D882 |
| | TD/transverse direction | 62.5± 6.8 | |
| Max tensile strain (%) | MD/machine direction | 1254.8± 72.6 | ASTM D882 |
| | TD/transverse direction | 1214.2± 116.1 | |

***Storage Requirements****: Biodegradable mulch film material shall be stored in its original packaging in a dry, clean and well-ventilated place, away from heating devices, and shall be protected from moisture, light and direct heat sources; the storage area shall be free from any acid, alkaline and other aggressive media.*

***Date of issue: 12 April 2024***

*Figure 5: Product Data Sheet for CSIRP20036*

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***Product data sheet***

*Home Compostable CSIR-P2006 formulated polymer resin*
*MFR: 4.25 g/10min at 150°C*

*Features*

- Processable by conventional methods
- 100% soil and compostable within 6 months compost (home & industrial) and soil conditions.
- Recyclable

*Applications*

- CSIR- P2006 is a formulated polymer resin compound that is soil biodegradable and compostable and designed for flexible packaging and agriculture mulch films.

*Material properties*

| Property* | Unit | Method | Value |
|---|---|---|---|
| Density | $gm/cm^3$ | ASTM D792 | 1.26 |
| Melt flow index at 150°C, 2.16 kg | gm/10min | ASTM D1238 | 4.25 |
| Maximum Tensile strength | MPa | ASTM D638 | 11.5 ± 1.2 |
| Tensile Modulus | MPa | ASTM D638 | 55.01±5.66 |
| Elongation at break | % | ASTM D638 | 890.38 ± 55.9 |
| Notched Charpy Impact at 23°C | (KJ/m2) | ASTM D256 | 250 ± 10.0 |
| Melting point | °C | DSC | 121.5 |
| Glass transition | °C | DSC | -25 |
| Crystallization temperature | °C | DSC | 95 |
| Processing temperature | °C | - | 125-145 |

*Packaging*

CSIR-P2006 is supplied in customized quantity.

*Storage*

Refrain from direct sun light. CSIR- P2006 is recommended to be stored in a cool and dry condition.

***Date of issue: Mar 2024***

* Specimens used for the testing of mechanical properties are injection moulded. The information provided in this document is of good faith. Properties might differ depending on the moulding technique and conditions.

*Figure 6: Product Data Sheet for CSIRP2006*

## 2.4 Biodegradability Profiles of the BDMs

*Industrial Composting of BDMs*

To determine the fate of the BDMs, a faster industrial compost method was used. This accelerated testing helps us know the eventual fate of the material in a quicker way, as opposed to soil biodegradation which will take a while. We will continue to monitor the fate of the BDMs in the field, post the project period, to ascertain the reality of biodegradation under real soil conditions.

ASTM D6400, EN13432 and ISO 17088 standard test methods were used to determine aerobic biodegradability of test samples under industrial composting conditions at 58 ± 2.0°C. Three months old organic rich compost was used for this compost biodegradation studies obtained from GardenMaster Compost, Pretoria, South Africa. The compost was sieved with a mesh of 8mm size to achieve a uniform particle compost for the biodegradation studies. Table 1 shows the physical-chemical properties of the compost. Activity of compost was measured based on volatile solids of compost. The compost produced 63.0 mg of carbon dioxide per gram of volatile solids over the first 10 days as per standard requirements.

*Table 1: Properties of controlled compost used in this study*

| Analysis | Obtained values for the Compost |
|---|---|
| Total dry solids, %[a] | 55 |
| Volatile solids, %[b] | 53 |
| pH of compost solution | 7.1 |
| Total organic carbon amount, %[c] | 10.6 |
| Total Nitrogen amount, %[c] | 0.9 |
| Carbon/nitrogen ratio, C/N[c] | 11.8 |

[a]The amount of solids obtained by taking a known mass of compost and drying at about 105ºC for 10 h; [b]The amount of solids obtained by subtracting the residue of a known mass of compost after incineration at about 550 ºC for 30 min; [c]Elemental analysis.

The ultimate biodegradability ($CO_2$ evolution) of test samples and microcrystalline cellulose (positive reference) were studied in three replicates under controlled composting conditions at 58-60 °C using Echo Automated closed respirometer system connected with $CO_2$/$CH_4$4/$O_2$ sensors. Two-liter capacity bioreactors were filled with mixtures of 300 g total dry solids of compost and 50 g dry solids of the test sample to obtain a ratio of about 6: 1. The vessels were incubated in the dark or in diffuse light at a constant temperature of 58°± 2°C. The total $CO_2$ emitted from each reactor during the test conditions was considered as the total degradation of test sample. The biodegradation of test sample was calculated based on the total organic carbon (Ct) present in the test samples as determined by elemental analysis. Equation 1 was used to calculate the theoretical $CO_2$ ($CO_2$(t)) in the total dry weight of plastic material.

$$CO_2\,(t) = M_t \times C_t \times \frac{44}{12} \qquad (1)$$

Where, $M_t$ is the total dry weight of plastic material added to the compost, and $C_t$ is the relative weight of the total organic carbon in the dry plastic material. The percentage biodegradation of the test sample's organic carbon mineralized as $CO_2$ was calculated according to the expression below (Equation. 2), where ($CO_2$)s is the carbon dioxide from the test sample (compost + specimen), ($CO_2$)c is the carbon dioxide from the blank compost and ($CO_2$)t is the total theoretical amount of carbon dioxide in the test material. A biodegradation curve was obtained by plotting percentage biodegradation versus incubation time.

$$Biodegradation(\%) = \frac{(CO_2)s-(CO_2)c}{(CO_2)t} \times 100 \qquad (2)$$

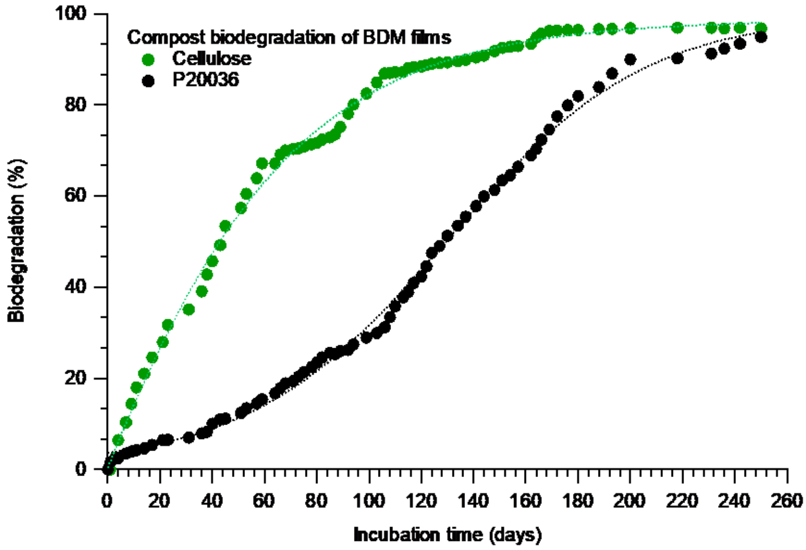


*Figure 7: Biodegradability Profile for CSIRP20036 under industrial compost conditions*

Figure 7 shows that the representative formulation, CSIRP20036, eventually biodegrades fully. Due to modification done to achieve longer period of performance as a mulch in the field, the film achieves ~ 83% mineralization by day 180,and therefore is not deemed industrially compostable as per EN 13432 standard. The standard requires at least 90% mineralization within 180 days, under specified conditions.

*Agricultural soil biodegradation testing*

Expectedly, the biodegradation under soil conditions is relatively slow for the BDMs. Abiotic QUV treated CSIR P20036 BDM films were tested biodegradation testing under agricultural soil conditions. The soil burial biodegradation test was carried out as per ASTM D5988 standard test methods. The $CO_2$ emission was measured by acid-base titration method by using phenolphthalein indicator. As the $CO_2$ emission was slow under mesophilic conditions, BDM films confirm the influence of synergistic effects of abiotic and biotic conditions for the mineralization process (Figure 8).

These lab results indicated that the BDMs ought to be able to remain functional as mulches, at least within 6 months.

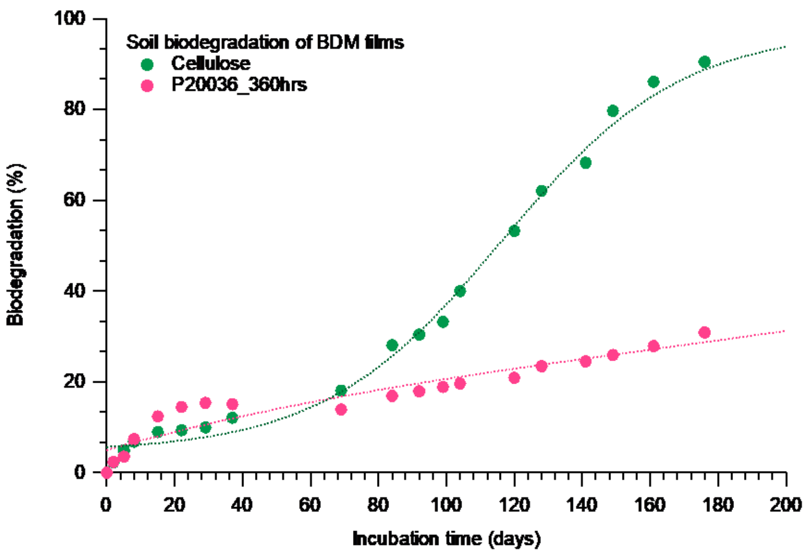

*Figure 8: $CO_2$ biodegradation results of BDM films under agricultural soil conditions*

# 3 Field Trials of BDMs

In the second phase of the project, the industrially produced BDMs were tested on actual farms to assess the following:

- Whether the mechanical strength was sufficient to allow for laying
- Whether a re-use model could be implemented, primarily to lower the total lifecycle cost of the BDMs
- How long the mulches as designed and tested in the lab could last on the farm before showing signs of disintegration
- To assess their performance as mulches, in comparison to conventional plastic films, in terms of growth rates, crop earliness, and for short-term crops, the overall yield

To answer these questions, three trials sites were secured, one in Gauteng and two in Eastern Cape. In Gauteng, an SMME renting greenhouse tunnel in Elandsfontein, Phutipoyana Pty Ltd., collaborated with project to test the re-use model on short term crops. The company does vegetable farming, and was deemed ideal to test a reuse model, under controlled environments in greenhouse.
For questions on the longevity of the mulches, pineapple was chosen as a model long-term crop for trials. Two distinct sites, one in Bathurst and the other in Peddie were approached to assist the project.

## 3.1 Assessing re-use Model for BDMs

### 3.1.1 Experimental Setup

In the re-use model, the idea was to test whether same mulch could be used for subsequent cropping season, and how such could be practically implemented. If successful, this could lower the overall cost of the solution and prolong the use of the product. Zhang et al. (2022) showed that overall cost of the conventional mulches could be lowered through re-use, which means, planting same crop on a previously mulched farm, without removing the mulches. The authors observed a significant increase in net revenue at 13.2% for faba bean system with re-

used mulches compared to one with new mulches. Productivity was also comparable. However, given the increased chance of production of microplastics from re-used mulch, the long-term effects remain unknown and is an area of active research. This led to the question: 'what if the re-used mulch was biodegradable, so that at the end of possible cycles, it would be buried into the soil and allowed to fully biodegrade?"
At the Elandsfontein greenhouse tunnel farm, CSIRP20036 was hand laid and green beans planted in February 2025. The mulches could easily be hand-laid using exiting contraptions that the farmer had for conventional plastic mulches. A parallel plot was planted with conventional white plastic mulches for comparative studies.

*Figure 9 Preliminary field trials at Phutipoyana Pty Ltd, and SMME running vegetable farming in Elandsfontein*

### *3.1.2 Observations*

The green beans harvesting started in April and ended in May 2025. Figure 10 shows the green beans plants mulched with CSIRP20036, at the start of the harvesting cycles.

*Figure 10: (a) Green beans under CSIR biodegradable mulch film at day 1 of harvesting in April 2025, at Phutipoyana Pty Ltd. Similar performance as those under conventional plastic mulches were noted; (b) early disintegration at certain sections of the mulches, in contact with Trichoderma, a fungal pretreatment under test at the site*

The following observations were made:

- The farmer noted that the growth rates and observable quality of the green beans were similar for the sections mulched with CSIRP20036 and those mulched with the white conventional plastic films
- The CSIRP20036 started to disintegrate earlier than anticipated, as shown in part (b) of Figure 10. This was mainly in areas that had received fungal pre-treatment, Trichoderma, which was also under trial. This accidental finding was further investigated in the lab
- Subsequent lab test reveals that indeed fungal pretreatment hastens the disintegration of the BDMs.
- Due to the disintegration of the BDMs at certain sections, it would not be possible to do attempt a re-use of the same. The BDMs have to be redesigned to have enough residual strength for subsequent handling post the first crop

### *3.1.3 Conclusions and recommendations*

Whereas the CSIRP20036 had similar performance as the conventional white plastic mulch, it was not deemed fit for a re-use model, with its current thickness.

- The thickness of the film tested for re-use model was 45μm. Thicker films could potentially retain sufficient mechanical strength to allow for handling in second cropping season. However, for single use in short term crop, the performance of the thinner BDM matches that of conventional white plastic film and could therefore be adopted for all short-term crops
- A critical problem that still lingers on is the transfer of pests from one crop season to the next, and how that is handled. The SMME currently re-uses the conventional plastic mulches, and typically has to remove and clean the mulches before re-laying.
- A window of opportunity was accidentally observed with the faster disintegration of the BDMs with the fungal pre-treatment. This implies, that a sprayable fungal treatment could be developed and applied on the BDMs after the cropping season, to hasten the disintegration and subsequent biodegradation of the films.

## 3.2 Long-term Crop Trials at Summer Hill Pineapple Farm and Peddie

### *3.2.1 Trial Site Set Up*

For long-term crop trials, pineapple farms in Peddie and Bathurst were chosen. The two represent pineapple growing regions. Due to time constraints, we limited the trials to only these sites. However, other potential site would have been in Kwa Zulu Natal, which represent a region with different climatic conditions.

At Peddie, the mulches were laid in July 2025, a second year run on trials, with thicker BDM samples (75 μm) as opposed to the previous one which were only 45 μm. This is the same batch of sample as 2$^{nd}$ year trials at Bathurst, with pineapples planted in October 2025, as shown in Figure 12. The Peddie site had two trial blocks, with an estimated area of about 60 m by 10m in total. In both Peddie and 2$^{nd}$ Bathurst trials, only the BDMs were not compared with conventional mulches, but rather un-mulched treatment. Currently the farmers do not use any form of mulch.


*Figure 11: Planting of pineapple heads after laying the CSIR Biodegradable mulch films at Peddie, Eastern Cape, in July 2025*

*Figure 12: CSIRP20036 mulches as $2^{nd}$ site at Summerhill farms, Bathurst, Eastern Cape*

Earlier in year 1 of trials, the first site in Bathurst had mulching done and pineapples planted between the $31^{st}$ October and $1^{st}$ of November 2024. These mulches were thinner, at 45 μm. A randomized experimental design having 3 treatments and a total of 16 trial blocks was used: (i) standard commercial practice without mulch; (ii) conventional plastic mulch with reduced herbicide application (50%); and (iii) CSIRP20036 biodegradable mulch with 50% herbicide application, as depicted in Figure 13. The actual planted block is as shown in part (a) of Figure 14. Part (b) of Figure 14 shows the zoomed image of the mulched field, with freshly planted pineapple head, at the Bathurst site 1.

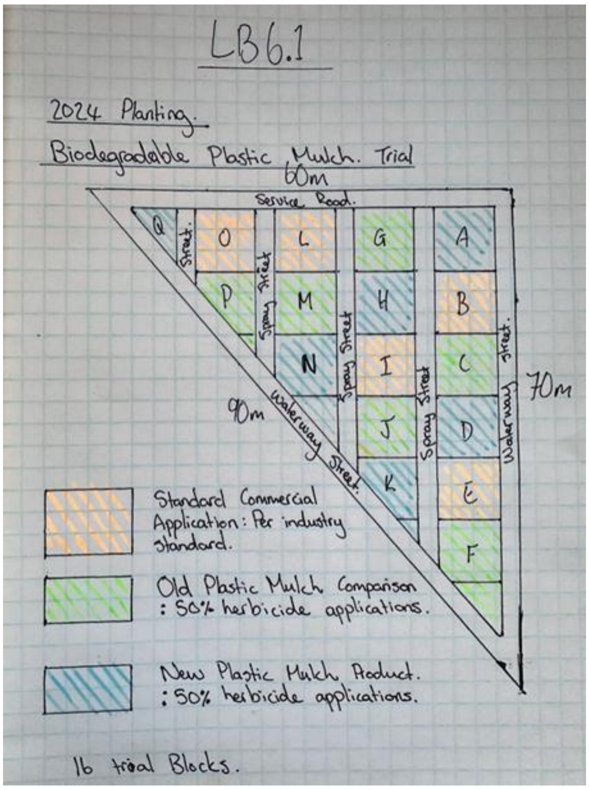


*Figure 13: Randomized experimental block design for the three treatments*

*Figure 14: (a) A drone image grab of pineapple farm, showing the different treatments: and (b) laid mulch with pineapple heads*

### 3.2.2 Observations

- In all three instances, the BDMs could be handled well through manual hand laying. It had enough strength for the laying. Interaction with farmers at Peddie revealed the need for mechanized laying of the mulches and also for punching of the holes. There farmers struggled to make neat holes and had to use their daily tools for poking. However, this created weak tear lines, and because of the winds often experienced in these two regions, there was significant tearing of the mulches, along the weak points created through poking.

- There was a challenge with covering the walkways with the mulches. This is critical because most of the weedicide tend to go to the walkways. An attempt to manually cover the walkways at Peddie site was not successful, since the width of the mulches was not sufficient. With the strong winds, most of these mulches were therefore blown off, as they could not be sufficiently tucked in. The trials at Peddie were then stopped.
- The trials, at site 2 Bathurst have not shown any significant difference between un-mulched and mulched areas. An observation was made on inconsistency in terms of the integrity of the mulches, with different rows of mulch showing different mechanical strengths. This can be traced back to the industrial production of the films. Since the industrial trial partners have to stop their production to accommodate production of the BDMs, the time period for initial optimization and sample production is not sufficient to stabilize the system. From experience, once requires at least 1 hr of operation to ensure process stability.
- At Bathurst site 1, interesting observations were made, especially within the first 3 months. It was established that mulches do enhance faster growth rate compared to bare land (during summer planting period); and an article has since been written on this in the CSIR science scope, vol 23, # 1 of 2025 – page 83 (https://indd.adobe.com/view/331ae416-bb7a-4f6e-8df1-022b650ebb6d ). As shown in Figure 15, there was distinct performance difference between blocks without mulching, compared to those with mulching- whether BDM or conventional plastic. At the time of mulching, there was rain, which later stopped. This observation is attributable to the soil temperature difference between the treatments. Whereas actual temperature was not measured in this instance, the feedback from the farm-in charge indicated that even by touch alone, the mulched sections had perceptibly higher temperatures compared to the bare land. They were able to make this observation during planting, as this happened a few days after the mulches were laid. Upon checking the root formation at month three, the mulched sections already had roots formed, whereas the un-mulched sections were still "dormant". Between the conventional mulch and the BDM, there were no observable differences in the early growth rates. Whereas the walkways were later infested with weeds, as the pineapples under mulches were still significantly better than those without mulches. This gave an interesting perspective in terms of tested value proposition for the BDMs. BDMs could be used targeting early-stage root formation, especially during winter growing season. The pineapples industry in South Africa have had trials several years ago with conventional mulches, and from discussions with staff at Summer Hill, the benefits were already proven, including crop earliness and enhanced yields. However, this idea was abandoned due to the lingering presence of plastic chunks, that stayed on the farms for long periods. The long-term effects of such pieces of plastic on the farm have been shown to be detrimental to soil health. It is therefore recommended that the as formulated CSIRP20036 be applied for the short-term benefit of early root formation in pineapples, and not necessary as a mulch cover to last more than 1 year.

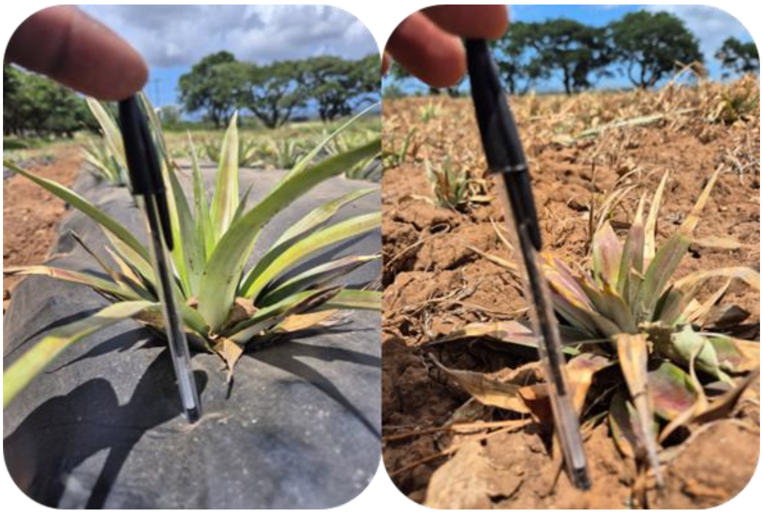

*Figure 15: Mulched treatments (both BDMs and Conventional Plastics films showing faster early growth compared to the un-mulched treatment*

### *3.2.3 Conclusions and recommendations*

- In both the greenhouse tunnel and open fields, the CSIRP20036 performs similar to the conventional plastic mulches. The overall yield will be ascertained upon harvesting.
- For long-term crops, and specifically the pineapple, the CSIRP20036 BDM could be used to enhance early root establishment and growth, leading to potential crop earliness. This has implication of reduced weedicide used in the formative stage, while the long crop cycle allows the BDMs to biodegrade, after conferring the benefit.
- In terms of the question on structural integrity of the BDMs and how long they would last before disintegration, the CSIRP20036 shows early disintegrations, which depends on the variability in the thickness of the films. They are suitable for short term crops as if, and for pineapples, could be used to target crop growth enhancements within the early stages, and not to be applied for periods longer than 4-6 months.
- On the question of whether the BDMs have sufficient mechanical properties to allow for laying, in all case studies, the films were hand laid easily. Further trials will need to be done with mechanized laying, upon commercialization of the technology. The punching rig can be customized by the farmer, due to variability in the number of crop per ridge for different regions. Alternatively, the punching can be done at the mulch production facility, for regions with known standardized crop density per ridge.
- In the study, a challenge observed was the lack of empirical data collections, as we relied on our implementation partner for feedback on performance. These observations tended to be qualitative in nature.

# 4 Preliminary Techno-Economics Analysis for BDMs

A comprehensive initial techno-economic analysis on the BDMs has been done and reported separately and may not be available publicly. This third phase of work was designed for life cycle sustainability assessment as well. However, at a project review meeting, this was dropped due to the inadequacy of the current models assessing sufficiently BDMs. There were no models to account for adverse effects of the microplastics generated by conventional plastic mulches, and yet this is one of the main differentiating aspects between the BDMs and conventional plastic mulches. Whereas the BDMs could also produce a burst of microplastics, they eventually biodegrade. On the other hand, microplastics from conventional plastic films linger extremely long periods, affecting the long-term health of soil. Such adverse effects are not currently built into the existing LCSA model. As such, the phase focused on comprehensive techno-economic assessment of the technology.

Briefly, in terms of technical readiness, technology is deemed feasible. Industrial manufacturability was demonstrated at two different converter's premises, underscoring robustness of the production process. It also implies that the formulated and compounded pellets can be manufactured with existing process vessels typically used for conventional plastics, without major changes. The process parameters have to be adjusted to accommodate the general sensitivity of bioplastics to temperature and shear. An area of concern is the level of wastages during production. With further industrial scale optimization, this can be brought down.

In terms of the markets, the project relied on projections based on a market study commissioned by the CSIR for African mulch applications. Assumptions are made in the share of market that CSIR technology can capture, and economic modelling is done based on such penetration assessment. For the economic modelling, it is assumed that a brownfields investment will be made in existing compounding facilities, to produce the formulated pellets. All key parameters show a sound investment, with positive net present values, good internal rate of return, short payback periods of less than 5 years, and healthy balance sheet within 5 years, and profitability from second year of operation. The assumptions, especially around share of addressable market size will have to be tested upon commercialization.

# 5 References


FAO. (2021). *Assessment of agricultural plastics and their sustainability – A call for action* Retrieved from Rome: https://doi.org/10.4060/cb7856en

Guo, J.-J., Huang, X.-P., Xiang, L., Wang, Y.-Z., Li, Y.-W., Li, H., . . . Wong, M.-H. (2020). Source, migration and toxicology of microplastics in soil. *Environment International, 137*, 105263. doi:https://doi.org/10.1016/j.envint.2019.105263

Kasirajan, S., & Ngouajio, M. (2012). Polyethylene and biodegradable mulches for agricultural applications: a review. *Agronomy for Sustainable Development, 32*(2), 501-529. doi:10.1007/s13593-011-0068-3

Salama, K., & Geyer, M. (2023). Plastic Mulch Films in Agriculture: Their Use, Environmental Problems, Recycling and Alternatives. *Environments, 10*(10), 179.

Steinmetz, Z., Wollmann, C., Schaefer, M., Buchmann, C., David, J., Tröger, J., . . . Schaumann, G. E. (2016). Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation? *Science of The Total Environment, 550*, 690-705. doi:https://doi.org/10.1016/j.scitotenv.2016.01.153

Wan, L., Cheng, H., Liu, Y., Shen, Y., Liu, G., & Su, X. (2023). Global meta-analysis reveals differential effects of microplastics on soil ecosystem. *Science of The Total Environment, 867*, 161403. doi:https://doi.org/10.1016/j.scitotenv.2023.161403

Wang, F., Wang, Q., Adams, C. A., Sun, Y., & Zhang, S. (2022). Effects of microplastics on soil properties: Current knowledge and future perspectives. *Journal of Hazardous Materials, 424*, 127531. doi:https://doi.org/10.1016/j.jhazmat.2021.127531

Xiong, L., Li, Z., Shah, F., Wang, P., Yuan, Q., & Wu, W. (2024). Biodegradable mulch film enhances the environmental sustainability compared with traditional polyethylene film from multidimensional perspectives. *Chemical Engineering Journal, 492*, 152219. doi:https://doi.org/10.1016/j.cej.2024.152219

Xu, B., Liu, F., Cryder, Z., Huang, D., Lu, Z., He, Y., . . . Xu, J. (2020). Microplastics in the soil environment: Occurrence, risks, interactions and fate – A review. *Critical Reviews in Environmental Science and Technology, 50*(21), 2175-2222. doi:10.1080/10643389.2019.1694822

Yang, L., Zhang, Y., Kang, S., Wang, Z., & Wu, C. (2021). Microplastics in soil: A review on methods, occurrence, sources, and potential risk. *Science of The Total Environment, 780*, 146546. doi:https://doi.org/10.1016/j.scitotenv.2021.146546

Zhang, X.-L., Zhao, Y.-Y., Zhang, X.-T., Shi, X.-P., Shi, X.-Y., & Li, F.-M. (2022). Re-used mulching of plastic film is more profitable and environmentally friendly than new mulching. *Soil and Tillage Research, 216*, 105256. doi:https://doi.org/10.1016/j.still.2021.105256