Supporting the adoption of biodegradable mulch technology in vegetable and perennial fruit enterprises

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South-West WA Drought Resilience Adoption and Innovation Hub

Table of contents

Key findings

- Within the parameters of this project, Sprayable Biodegradable Polymer Membrane (SBPM) showed potential to reduce moisture loss when compared to conventional practices in some circumstances.
- Soil type and ground preparation are significant factors that impact the performance of SBPM to conserve soil water and restrict weed growth.
- Soil temperature appears to be impacted by SBPM but whether this is detrimental will be based on the farming system and applied crop.
- Being not yet commercialised, the costs associated with the application of SBPM is unknown.
- Large scale application procedures and associated equipment requires development.
- The overall complexity of handling and applying SBPM is relatively low which is supportive to its adoption while acknowledging further work is required in its formulation.
- Overall, this project showed positive attributes from the SBPM demonstrations but also highlighted challenges which need to be addressed if the product is to progress to commercialisation.

Introduction

Due to climate change, the southwest of WA (SWWA) is experiencing declining rainfall, increasing temperature and greater frequency of extreme weather events. In horticultural farming systems, changes to agronomy can support adaption to these challenges especially through the adoption of innovative technologies. A novel, semi commercialised Sprayable Biodegradable Polymer Membrane (SBPM) developed by CSIRO promises potential to offer a sustainable solution to producers who are seeking opportunities to improve irrigation efficiencies, reduce herbicide and plastic use, and maintain healthy soils.

Important irrigated crops in SWWA include wine and table grapes, and vegetables. These crops are vulnerable to climate change and represent approximately $900m to WA’s economy. This study aims to apply the SBPM in multiple demonstration sites to evaluate its effectiveness in improving water efficiency, soil temperature and moisture, weed control, and crop yield and quality. The sites have been strategically installed in diverse horticultural farming systems across a number of different climatic regions.

The key outcome of this project is to support the profitability and sustainability of SWWA horticultural producers by demonstrating this innovative technology to growers across multiple crops to support potential adoption. More broadly this project sets to change the mindset of growers using traditional farming practices to one that is open to the adoption of new technologies to adapt to a drying and warming climate.

Materials and methods

Sprayable Biodegradable Polymer Membrane (SBPM)

Black in colour and with the viscosity of thick paint, the SBPM used in this study is a polyurethane emulsion in water (20% weight solid content). Its composition and synthesis described in the Material Safety Data Sheet included in Appendix 1).

The material used in this project was supplied in sealed 20 L plastic drums. SBPM specific gravity was tested at room temperature showing 1015 g/L (as shown in Image 1). After multiple manual inversions and then opening the drums, it was noted a ~3 cm thick sedimentary layer of the product formed at the bottom of the drum. A 18V cordless handheld drill fitted with a paint mixer was required to reincorporate the sediment via a 5 to 7 minute period of mixing.

A black film was also observed on the surface of the SBPM material in the drums and on equipment that was left with residue on their surfaces. This film was also observed on the internal walls of the spray units. The thickness of this film varied depending on time exposed to air as well as the concentration of SBPM material. This film was relatively easy to manually remove from the effected surfaces but was insoluble in water as well as in the SBPM solution.

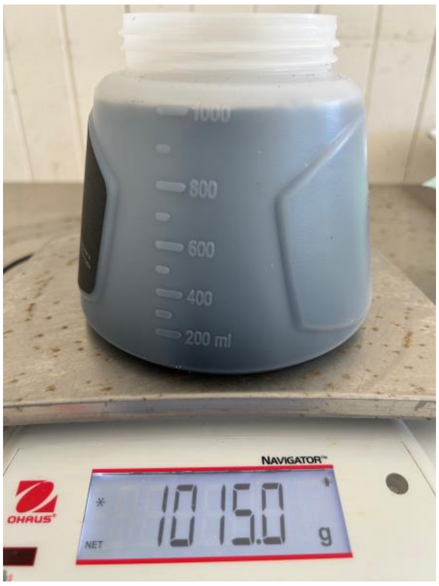

Image 1: SBPM special gravity test at room temperature

Considering the SBPM material in liquid form was close to a weight of 1 kilogram per litre, the application rates for this project are expressed as litres per square metre (L/m^2) instead of kilograms per square metre so to express applications in a unit of measurement familiar to growers.

Through consultation with Riverland Vine Improvement Corporation and DPIRD Research Scientist Dr Rushna Munir both of which had previously conducted independent field trials (not published) with the material, it was concluded that a rate of 1 L/m^2 was suitable for applications across all demonstrations sites.

In consultation with SBPM developers at CSIRO and researchers with previous experience trialling the product, three different application methods for evaluation were determined.

1. Silvan 8 L stainless steel hand sprayer with adjustable brass nozzle, easily adjusts from pencil stream to fine mist for a variety of applications. Its maximum pressure is 300 kPa (2.96 atm).
2. Ozito PXC 18V Outdoor Paint Spray Gun. This unit can be used for both oil and water-based solutions such as paint, lacquer, varnishes, and glazes with 360° adjustable spray pattern. The detachable spray head and included cleaning needle and brush made cleaning the unit after use quick and easy.
3. Garden watering can (9 L) with detachable spray head to make cleaning the unit quick and easy.

Prior to applying treatments at demonstration sites, a practice application was conducted on sandy soil at DPIRD's South Perth facility. Two weed free plots of 0.5 and 1.0 m^2 consisting of sandy soil were hand raked to remove debris and prepare the ground cover for application. Water was firstly applied at a rate of 1 L/m^2 to wet the soil surface and to reduce surface hydrophobicity. SBPM was then applied either in its original concentration or diluted with water on a 1:1 basic ratio to obtain sufficient coverage within the recommended SBPM application rate (see Image 2).

Lessons learnt from these practice applications aided the methodology development of the consequent demonstration sites.

Image 2: SBPM practice application at DPIRD's South Perth facility

Methods

The effects of SBPM application on crop growth parameters such as soil moisture, crop yield and quality and weed control were compared against growers' conventional practices as control treatments in the demonstrations listed in Table 1.

Table 1: List of demonstration sites with treatment details

No.	Crop	Region	SBPM rate l/sqm	Additional treatments to SBPM	Plots sizes (Sqm)	Number of replications
1	Wine grape	Margaret River	1	▪ Weed residue after herbicide application ▪ Bare soil after herbicide application	7.20	3
2	Wine grape	Frankland River	1	▪ Weed residue after herbicide application ▪ Bare soil after herbicide application	7.20	3
3	Table grape with driplines	Swan Valley	1	▪ Weed residue after herbicide application ▪ Bare soil after herbicide application	5.60	3
4	Table grape with sprinklers	Swan Valley	1	▪ Weed residue after herbicide application ▪ Bare soil after herbicide application	5.60	3
5	Butternut pumpkin	Carnarvon	1	▪ Normal Plastic film mulches ▪ Biodegradable plastic film mulch	6.40	3
6	Tomato	Carnarvon	1	▪ Plastic film mulches ▪ Biodegradable plastic film mulch	6.40	3

7	Carrot germination	Gingin	0.0; 0.1; 0.3 and 0.5	▪ Bare soil	0.12 (plastic tray)	4
8	Carrot seedlings	Myalup	0.5	▪ Grass cover crops ▪ Bare soil	4.50	3
9	Interrow soil workability	Carnarvon	1	▪ Plastic mulch	4.8	1

Image 2: SBPM demonstration in Swan Valley table grape vineyard

Image 3: SBPM demonstration in wine grape vineyard in Margaret River

Image 4: Carnarvon SBPM demonstration site in preparation for tomato crop

Image 5: Trial site assessing if sand blast damage on carrot seedlings can be mitigated with SBPM

Image 6: A piece of SBPM-soil debris film 4 months post application

For each of the demonstration sites, unique ground preparations were made in consideration to soil type and farming systems as summarised in Table 2.

Table 2: Ground preparation across various sites

Crop types	Ground preparation techniques
Wine and table grapes	The soil type ranged from gravel to sandy loam. A fast-acting broad spectrum, non-selective, contact herbicide was applied to treated plots in the demonstrations 5 weeks before SBPM application. Prior to treatment the ground was hand raked free of debris and wetted with 2 L/m^2 of water to overcome hydrophobicity. The topsoil was relatively fine with visible gravels (~2 cm in diameter).
Vegetables (pumpkins and tomatoes)	The soil type was alluvial loam. A 30cm deep rip was conducted followed with 2 rotary hoeing runs operated at 540rpm. The topsoil was rough with cracked soil fragments ranging between 4 to 5 cm in diameter. Prior to treatment the soil was wetted with 2 L/m^2 to overcome hydrophobicity.
Carrot	The carrot demonstration was conducted on sandy soil. Two runs of rotary hoeing were conducted. The soil between the tractor's wheel track formed the growing beds. After sowing carrot seeds and grass cover crop seeds, the soil surface was kept wet by regular watering using overhead sprinkler system.

Soil moisture and temperature

Wildeye® plug and play IoT hardware, cloud-based software and data hosting were utilised and installed for collection, hosting, presentation, and analysis of sensor data from the sites. These provided accessible soil tension graphs via the cloud https://www.mywildeye.com/soil-moisture-monitoring/.

The soil sensors were installed within the active root zone which were 35 cm for the perennial fruit crops and 25 cm for vegetable crops.

Time lap cameras were also installed around 25 cm above the ground directed toward a single replicate SBPM treatment so to visualise the emergence of weeds and breakdown of the mulch over time. A time lapse camera installed at the interrow soil workability site was directed toward the tractor wheel track next to the SBPM applied section so to monitor changes. The time lapse was set at 15 minutes for all cameras. Recordings were screened for changes in areas of interest (such as weed emergence, breakdown of SBPM film or mudding of the tractor wheel track soil.

Average daily soil moisture variations expressed in percentage of volumetric water content in soil (VWC%) were used to compare the effects of SBPM against control treatments in terms of average daily soil water loss. This parameter was obtained by subtracting the average daily maximum from the average daily minimum of volumetric soil water contents which were digitally recorded every 15 minutes.

Similarly, the average daily soil temperature variations expressed in degrees Celsius (°C) were calculated to reflect the influences of different mulching practices over soil temperature. This was obtained by calculating the difference between average daily maximum and average daily minimum of soil temperature.

Weather and climate data at the 5 locations (Carnarvon, Swan Valley, Myalup, Frankland River and Margaret River) of this study were collected via the online tool https://reg.bom.gov.au/climate to record the growing conditions and capture any extreme weather events that may have impacted the trials.

Weed control

Where measured, fresh weight of weeds (extracted by hand) in all plots were collected at 8 weeks after application to calculate mass weight and compare across treatments.

Timelapse cameras

Unfortunately, no emergence of weeds, film breakdown or mudding of the tractor wheel tracks were sufficiently captured within the positioned frames of the various cameras.

Yield and quality

Average fruit yield (kg per meter of trellis), percentage of marketable fruits, average berry weight, percentage of diseased fruit at post-harvest (expressed as marketable fruit) were recorded for table grapes.

Fruit quality in terms of berry weight, °Brix, pH and total acidity were recorded for both table grapes and wine grapes. Fruit yield and percentage of marketable fruits were recorded for pumpkin and tomato crops.

Cost analysis

As the SBPM product has not yet been commercialised, actual costs associated to its application could not be calculated with certainty. However, costs per hectare relative to applying conventional plastic mulch was investigated which services as a benchmarking reference.

These costs included the plastic mulch, labour for installation and removal, tractor fuel and plastic waste disposal at local land fill. Environmental impact of the expired plastic mulch was not calculated.

Protection from sand blasting

To assess the suitability of the SBPM for topsoil stabilization during the establishment of carrot seedlings cultivated in sandy soils. Nursery cover crop seeds were broadcasted a day after carrot seeds were sown. SBPM was diluted to 50% with water and applied at the rate of 0.4 L/m^2 two days after carrot seeds were sown.

Herbicide (Fusilade Forte, Syngenta®) was sprayed to kill the grass cover crop at 40 days after carrot seeds were sowed with seedlings around 7-10 cm tall.

Parameters recorded:

Survival: One metre of each treatment in each replication was randomly selected for survival plant counting. Total number of survival carrot seedlings per metre were recorded at 40 days after SBPM application when herbicide was also applied to the nursery crop.

Carrot seedlings height: the height of ten randomly selected seedlings of each treatment in each replication was recorded at 40 days after SBPM application.

Interrow soil workability

Refer to Appendix 2 for specific details regarding this activity.

Results

Application

As previously described, there were observations made of films forming on the surface of the product drums and equipment left with residue SBPM exposed to air. The formation of ‘flakes’ led to difficulties in maintaining clear spray nozzles and required significant adjustments to spray application procedures and equipment (see Image 7).

Image 7: a flake of solid SBPM not soluble in water

The Silvan 8 L stainless steel hand sprayer had an adjustable brass nozzle that could be easily adjusted from pencil stream to fine mist. Its maximum pressure was 300 kPa (3 bar). This equipment did not work at any nozzle adjustment due to the viscosity of the SBPM, even when the pressure was increased to the level that triggered the internal pressure release valve.

SBPM material flowed out inconsistently with bubbles. Moreover, heavy blockage of the intake tube, hose and nozzle occurred during the time when adjustments were made trying to get the sprayer work (see Image 8). Even diluting the SBPM to 50% with water was unsuccessful with this unit.

Image 8: Dried SBPM residue formed within a spray nozzle

The Ozito PXC 18V Outdoor Paint Spray Gun is designed to use for both oil and water-based solutions such as paint, lacquer, varnishes, and glazes with 360° adjustable spray pattern. However, there were difficulties to achieve sufficient coverage and produce a consistent film using this equipment. When the nozzle was positioned close to the ground, its high volume air flow disturbed the topsoil, breaking the SBPM into fragments and consequently was blown away. Wetting the soil with 2 L/m^2 helped reducing the topsoil flaking problem, but not completely. On the other hand, at a higher position the spray pattern was too broad and delivered the application outside of target area. Blockages occurred several times during each application.

Overall, this sprayer could help to effectively apply SBPM to achieve desirable coverage and to form a consistent film when certain conditions were achieved; being, the ground surface is prepared in the way so that the topsoil is relatively fine and compacted (not typical of conventional practices) and the topsoil is well watered to overcome hydrophobicity.

At first, the 9 L garden watering can did not work at all due to the high viscosity of the SBPM. However, it worked well when SBPM was diluted by 50% with water. The coverage was obtained when SBPM was applied in two passes and the ground was pre-wetted with 2 L/m^2 to overcome the hydrophobicity.

The detachable spray head made cleaning the unit after application quick and easy. This application technique did not form a physical film rather than a layer of SBPM-soil mix about 1-2 mm thick. From a practical perspective this was the most effective method for small scale SBPM application. Consequently, this approach was used for all demonstrations within this project.

Soil moisture

The below table summarises the average daily soil moisture loss expressed as VWC% across both wine and table grape sites.

Table 3: Average daily soil moisture loss across vineyard sites

Crops	Location	Average daily soil moisture loss (VWC%)		
		Bare soil	Conventional practice	SBPM
Table grapes on sprinklers	Swan Valley	1.31	1.10	0.49
Table grapes on drip line	Swan Valley	0.47	0.60	0.60
Wine grapes	Margaret River	0.31	0.30	0.14
Wine grapes	Frankland River	1.23	1.23	1.18

Table 4: Average daily soil moisture loss across vegetable sites

Crops	Location	Average daily soil moisture loss (VWC%)		
		Plastic mulch	Biodegradable plastic mulch	SBPM
Tomato	Carnarvon	0.80	0.41	0.75
Pumpkin	Carnarvon	0.64	0.70	1.21

Soil temperature

Table 5: Average daily soil temperature variation in different SBPM trial sites

Crops	Location	Average daily soil temperature variations (^{0}C)		
		Bare soil	Conventional practice	SBPM
Table grapes on sprinklers	Swan Valley	1.47	1.13	1.50
Table grapes on drip line	Swan Valley	1.48	1.14	1.42
Wine grapes on drip line	Margaret River	4.81	1.35	1.69
Wine grapes on drip line	Frankland River	3.61	3.34	4.15
Tomato	Carnarvon	1.48	2.62	1.16
Pumpkin	Carnarvon	2.78	2.52	2.83

Weed control

Table 6: Weed masses across different treatments in vineyard sites

Crops	Location	Fresh weed masses in different treatments (kg/m^2)		
		Bare soil	Conventional practice	SBPM
Table grapes on sprinklers	Swan Valley	0.38	0.40	0.37
Table grapes on drip line	Swan Valley	0.40	0.36	0.37
Wine grapes on drip line	Margaret River	0.24	0.24	0.27
Wine grapes on drip line	Frankland River	0.31	0.30	0.20

Image 9: Weed emergence under the drip line in the middle of SBPM treated bands at wine grape vineyard

Image 10: Weeds growing on residue mulch on herbicide treated plot at wine grape vineyard

Table 7: Fresh weight weed masses in different treatments on vegetable crops

Crops	Location	Average weed fresh weight (kg/m^2)		
		Plastic mulch	Biodegradable plastic mulch	SBPM
Tomato	Carnarvon	0.00	0.00	2.60
Pumpkin	Carnarvon	0.00	0.00	3.50


Image 11: Weeds within SBPM treated bed of pumpkin crop in Carnarvon


Image 12: Weeds within SBPM treated bed of tomatoes in Carnarvon

Crop yield and quality

The differences in growing conditions and growers' conventional harvesting practices on different crop types required different units of measurement to present the fruit weight data.

In the case of table grapes, while it was not possible to separate fruit from different vines on the same trellis row within a treatment plot, the yield data is expressed by kilogram per meter of row (kg/m) rather than kilogram per vine. Furthermore, one of the two table grapes growers in this study selectively harvested only marketable fruit, only marketable fruit yield data was obtained while the total yield data including both marketable and unmarketable yield was obtained from the other site.

In contrast, fruit yield data for the wine grapes trials were missed since the mechanical harvesting method made it impossible to separate fruit from the different treatments within the same row. Only indicative samples were collected from the different treatments for assessing quality parameters.

Crop yields were recorded as kg/plant in both tomato and pumpkin trials.

Table 8: Crop yields across the trial sites

Crops	Location	Units	Fruit yield		
			Bare soil	Conventional practice	SBPM
Table grapes on sprinklers	Swan Valley	Marketable yield (kg/m of row)	4.85	4.83	6.71
Table grapes on drip line	Swan Valley	Total yield (kg/m of row)	11.48	12.18	11.69
Pumpkin	Carnarvon	Kg/plant	14.0	14.21	14.0
Tomato	Carnarvon	Kg/plant	5.65	6.78	4.75

Table 9: Marketable fruit percentages

Crops	Location	Percentages of marketable fruit yield (%)		
		Bare soil	Conventional practice	SBPM
Table grapes on drip line	Swan Valley	82.3	84.3	88.3
Pumpkin	Carnarvon	81.0	82.0	81.0
Tomato	Carnarvon	75.9	69.8	74.1

The average rate of marketable fruit from SBPM treated plots (see Table 9) on the table grape site with drip line irrigation was 4 to 6% higher than that of weed residue mulch and bare soil. Because the total yield data on table grapes with sprinklers irrigation could not be collected, rate of marketable fruits was not obtained.

The difference in rates of marketable fruit in both tomato and pumpkin trials in this study were minor.

Table 10: Average berry weight from vineyard sites

Crops	Location	Average berry weight (g)		
		Bare soil	Conventional practice	SBPM
Table grapes on sprinklers	Swan Valley	7.08	6.74	7.66
Table grapes on drip line	Swan Valley	8.42	8.59	8.64
Wine grapes on drip line	Margaret River	1.55	1.56	1.58
Wine grapes on drip line	Frankland River	2.02	1.89	1.97

The average fruit weight of table grapes and wine grapes are presented in Table 10. The berry weights shown for SBPM treatments are slightly higher than that of the other treatments.
There are several factors influencing the fruit weight such as number of berries per bunch, grapevine pruning techniques, bud numbers, fertiliser application program, pest and disease factors. Considering these variables, these results are unlikely to be attributed solely to the SBPM treatment.

As °Brix is a measurement of the dissolved solids in a liquid and is commonly used to measure dissolved sugar content of an aqueous solution, it was used to measure berry sugar content in this study. Table 11 shows °Brix levels of different treatments in this study.

Table 11: Sugar content across vineyard sites

Crops	Location	Average sugar content (%Brix)		
		Bare soil	Conventional practice	SBPM
Table grapes on sprinklers	Swan Valley	20.87	20.20	20.43
Table grapes on drip line	Swan Valley	18.53	18.80	20.30
Wine grapes on drip line	Margaret River	21.60	21.30	21.70
Wine grapes on drip line	Frankland River	19.82	20.43	19.96

The sugar content of SBPM treated table grapes under drip irrigation was 7.4 to 7.8% higher than that of weed residue mulch and bare soil. However, there were only minor differences in fruit sugar content across treatments in the other trials.

Again, there are several factors that can influence fruit sugar content such as applied water stress techniques, maturity, fertiliser program; the observations in this study are not sufficient to be conclusive.

The total acidity of fruit sampled from SBPM treated plots in table grapes under drip irrigation was 17.3 to 18.3% lower than that of weed residue mulch and bare soil respectively. However, fruit acid contents in SBPM treatments in wine grapes were higher when compared to other treatments (see Table 12).

Table 12: Total acidity across treatments in vineyard sites

Crops	Location	Average total acidity contents (g/L)		
		Bare soil	Conventional practice	SBPM
Table grapes on sprinklers	Swan Valley	4.98	4.92	4.82
Table grapes on drip line	Swan Valley	4.01	3.94	3.28
Wine grapes on drip line	Margaret River	6.32	6.19	6.91
Wine grapes on drip line	Frankland River	5.84	6.02	6.24

Carrot germination

Preceding the assessment of SBPM suitability to protect carrot seedlings from sand blasting, it was first required to determine the appropriate SBPM application rate to topsoil's to achieve soil stability while not restricting seed germination.

Table 13: Average carrot germination as a percent sown

Bare soil (control)	SBPM 0.1 L/m^2	SBPM 0.2 L/m^2	SBPM 0.3 L/m^2	SBPM 0.4 L/m^2
82.5%	80.0%	85.0%	85.0%	83.8%

The results in Table 13 show the highest germination rate when SBPM was applied at 0.2 and 0.3 L/m^2. However, the difference in germination rates was minor across the different treatments including the control. Based on this, the highest rate of SBPM application was selected to apply in the trial to evaluate if SBPM can protect seedlings from sand blasting.

Protecting carrot seedlings from sand blasting

Table 14: Average number of seedlings present (plants/metre)

Treatments		
Bare topsoil	Nursery crop cover	SBPM (0.4 L/m^2)
84	83	88

Data presented in Table 14 showed that SBPM application at the rate of 0.4 L/m^2 increased the number of seedlings survived by 5% compared to that of bare topsoil control and the nursery crop cover control. There was no significant difference in terms of carrot seedling survival between the two control treatments.

Table 15: Average seedling growth across different treatments

Treatments		
Bare topsoil	Nursery crop cover	SBPM (0.4 L/m^2)
8.0cm	11.6cm	7.7cm

As presented in Table 15, the grower conventional practice of nursery cover cropping provided the best protection for carrot seedlings growth. Its average seedling was 11.6 cm tall which is 51.3% and 45.3% higher than that of SBPM treatment and bare topsoil respectively.

Discussion

Soil moisture

The SBPM treatments in both wine grape sites and the table grape site with sprinkler irrigation recorded the lowest soil moisture loss when compared to the two other treatments.

In the case of the Swan Valley table grape site with sprinkler irrigation, average daily soil moisture loss of the SBPM treatments were 44.5% and 37.4% lower than that of those treatments using weed residue mulch and bare soil after herbicide application respectively. In contrast, the volume of average daily soil moisture loss was not significantly different between SBPM and other treatments where drip irrigation was applied.

The average daily soil moisture loss in the SBPM treatments at the Margaret River wine grape site was 53.3% and 54.8% lower than that of other treatments. However, the SBPM application at the Frankland River site showed a lesser effect. The difference of average daily soil moisture loss between the SBPM and other treatments were as low as 4%.

In regard to the vegetable sites in Carnarvon, the data collected concerning soil moisture loss showed that SBPM was not as efficient as the comparable plastic and biodegradable mulches. Furthermore, the average daily soil moisture loss of SBPM treated plots was almost double to those of plastic mulches in the pumpkin trial.

This is mostly likely attributed due to the failure of the SBPM application forming an intact physical film on the soil surface. The reason for this was once the clay rich soil was irrigated it expanded and then contracted when it dried, forming cracks in the SBPM film (see Image 13).

The conventional soil preparation practice in Carnarvon, as described in Table 2, did not create an effective topsoil surface for a successful SBPM application. The topsoil was rough with cracked soil fragments ranging between 4 to 5 cm in diameter. That made it impossible to obtain a consistent physical film of SBPM.

Image 13: The cracking on the soil surface of a SBPM treated plot in Carnarvon

Therefore, SBPM application was shown in some cases to reduce soil moisture loss more than conventional practices but was not consistent across all sites and crops. It is reasonable to state that this innovation has the potential to save soil water.

Soil temperature

Data showed that daily soil temperature variation across the different treatments was relatively minor for all sites. The average daily soil temperature variation at the table grape sites were between 1.13°C to 1.50°C while those at the wine grape sites were 1.35°C to 4.81°C. Similarly, the average daily soil temperature variation in both pumpkin and tomato demonstrations in Carnarvon were moderate (from 1.16°C to 2.78°C). Since the soil temperature sensors were placed 25 cm below the soil surface in cases of the vegetable crops and 35 cm for the grape crops, there may have been an insulting effect on the data collected.

Weed control

On both wine grape and table grape demonstrations the SBPM application provided some level of weed control over the bare soil treatment in early stages of the trials (Image 9). However, the pre-treatment of a broad-spectrum herbicide did leave viable weeds in place of which re-emerged over time. Overall, there were similarities between all three treatments in terms of weed control.

In case of demonstrations on pumpkin and tomato in Carnarvon, SBPM mulch failed to control weeds (Images 11 and 12) when compared to both treatment types of plastic mulches due to the inability to maintain a consistent SBPM film over the soil and the occurrence of cracking allowing weeds to emerge and grow.

Crop yield and quality

Data collected showed SBPM treatment increased fruit yield when compared to conventional practice and bare soil treatments in the table grape site with sprinkler irrigation. However, SBPM treatment did not increase yield in the other table grape site that received drip irrigation. The different observations between the two table grape demonstrations may be attributed to different harvesting methods and grading standards or simply production variables such as bud numbers and vine nutrition, without consistency across both sites this impact is uncertain.

In the vegetable demonstrations, the average tomato fruit yield on SBPM treated plots was lower than that of plastic mulches while there was no difference in case of pumpkin yield. This may be explained because the large leaf size and the effective ground cover characteristic of the pumpkin plant's growth habit that compensated the low effective of SBPM mulch. Overall there was not a definitive benefit of the SBPM on improving crop yield and quality on the featured vegetable crops.

Carrot germination and soil stabilisation

The SBPM application at 0.4 L/m^2 was shown to stabilise the soil but not inhibit carrot seedling emergence. A modest 5% increase was observed in the number of seedlings emerging over the conventional nursery crop cover and bare topsoil controls.

However, the grower conventional practice provided better protection for carrot seedlings by measure of plant growth. On the average, these seedlings were 50% taller than that of SBPM application and bare topsoil grown carrots.

Cost analysis

A comprehensive cost analysis could not be investigated since the SBPM product has not yet been commercialised. However, costs relative to applying plastic mulch within this project was collected (see Table 16) for reference.

Table 16: Costs relative to applying plastic mulch

Items	Costs per hectare ($/ha)
Plastic mulch rolls: 4 x $200	800
Labor to layout and removing: 22hrs x $35	770
Fuel: 40L x $2	80
Waste management (land fill disposal of plastic mulch)	80
Total	$1730/ha

Considering anecdotal information, if the total costs of SBPM application achieves approximately $2,000/ha, the cost difference will be approximately $270/ha when compared to conventional plastic mulch use. It is expected that this difference would be acceptable to growers when accounting for the social license in term of environment care and affordability.

However, it is possible that the cost of plastic mulch can be diluted should its use be extended to a second crop such as pumpkin or watermelon after an initial tomato crop. Making the conventional plastic mulch costings significantly lower than that of the projected SBPM product.

Compatibility and adoptability

Compatibility is described as the degree to which this SBPM innovation is compatible to existing equipment, grower experiences and practices.

SBPM applied in these demonstrations revealed that SBPM's high viscosity makes it difficult to apply with typical boom sprayer equipment that are commonly used by growers for agri-chemical application. The practicality of applying SBPM at small scale was proved using either hand spray gun or garden watering can. However, these tools are not suitable for commercial scale.

Logistics around transport and storage presents challenges. For example, with a minimal application of 1 L/m^2, a small-scale commercial farm of 10 ha may need to receive and store up to one hundred tons of SBPM per year. Then considering local suppliers, they would need several thousand tons on stock to service potential orders.

The skills and knowledge in applying low viscosity materials such as liquid fertiliser and chemicals is not transferrable to SBPM application. Developing a small-scale application procedure by an experienced practitioner in this project was faced with several difficulties when modifying normal sprayers to apply the product.

Regarding ground preparation, it was also proved in this study that neither the ground cover with weed residue after herbicide application in vineyards nor the bed surface prepared for plastic mulch in vegetable industry are suitable for SBPM application to achieve a consistent physical SBPM. Moreover, working to destroy soil structure to achieve a compact and fine soil surface that is supportive to SBPM application is not recommended for general soil health.

The trialability and observability of an innovation is important as it allows growers to assess the net benefits for themselves under their unique conditions, making these attributes critical in supporting adoption.

It was proved in this study that a small-scale trial when specific equipment for effective SBPM application is not available, a simple tool such as garden watering can, can be used. The SBPM layer delivered by the watering can was able to achieve a desired mulch film. The impact of establishing a small-scale trial was also shown to have minimal disturbance to the general operations of the various farming systems.

It was also shown that the net benefits of SBPM in terms of soil water saving, improved crop yield and product quality were observable and measurable. Moreover, a potential for the SBPM application to have a negative impact of the workability of the interrow soil corridor in a vegetable farming system was not a factor.

Being a material-based innovation, SBPM can be simply trialled on a small-scale like plastic mulch. At this stage however, as SBPM has not been commercialised yet, the product is not available, thus the possibility for growers to try and to assess the net benefits themselves is not possible.

The complexity of SBPM can be considered as low when compared to a knowledge-based innovation which is conducive to ease of adoption. An informal survey of 6 growers showed that:

- although this SBPM innovation is new, its application is as simple as spraying paint.
- It can be tried on small scale which does not severely affect to the overall performance of a farming business.

Conclusion

This project has shown insights into understanding the potential of SBPM to assist farmers in a changing climate to improve irrigation efficiencies, reduce herbicide and plastic mulch use, while supporting healthy soils. This work has shown both benefits and challenges in adopting this innovative technology.

SBPM showed benefits in retaining soil moisture when compared to growers' conventional practices in light gravelly loamy and sandy soils for both table (sprinklers) and wine grapes. However, it failed to reduce soil water loss in vegetable crops when applied on heavy loamy alluvial soils due to the cracking of the SBPM film which consequently led to considerable weed emergence. SBPM did however show a promising feature when directly compared to plastic mulch in a tomato plot where there were no observed issue with horizontal movement of irrigation water into the tyre tracts.

It is then concluded that SBPM can help retain soil moisture and maintain weed control equivalent to conventional practices should the conditions favour the integrity of the mulch film.

Compared to conventional treatments soil temperature variation was generally seen to increase due to the application of the SBPM which may be desirable in certain farming systems and the contrary in others. Re-formulating the SBPM from a highly heat absorbent colour as black to one more reflective such as white may address this factor.

The influence of SBPM on crop yield and quality was less clear but likely not to have a negative impact. SBPM was shown to stabilise topsoil at a low rate of application while still allowing the emergence of carrot seedlings. However growth rates were out performed on those carrots grown in parallel with a sacrificial cover crop.

Future commercialisation of the SBPM requires a financial consideration to ensure purchasing and application costs are less than $2,000/ha to make it attractive as a plastic mulch alternative. Reviewing the formulation is suggested to address the logistical challenges and costs of transporting and storing a product with only 20% emulsion in water.

A procedure and suitable equipment to ensure trouble free application will be crucial for adoption. Adoption potential is favoured by ease of trialability and observability of impact for growers of all scale of operation.

With further refinement the technology has true potential to assist growers to be more water efficient, reduce reliance on herbicides and maintain and improve soil health.

Acknowledgements

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The authors thank DPIRD staff who contributed to this project and growers who hosted the demonstration sites.

Appendix 1

Material Safety Data Sheet

1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND THE COMPANY/UNDERTAKING

Product name: Polyurethane solution**.**

Use: Research Purpose.

Supplier:	Boron Pty Ltd
Street Address:	500 Princes Highway, Victoria
Telephone:	(03) 8558 8000

2. COMPOSITION/INFORMATION ON INGREDIENTS

CHEMICAL	ENTITY CAS NO.	PROPORTION
Polyurethane emulsion in water- 20 wt% solid content containing 4 wt% carbon		

3. HAZARDS IDENTIFICATION

Based on available information, this material is classified as hazardous according to criteria of NOHSC Australia.

It may be irritating to eyes, respiratory system and skin.

Not classified as Dangerous Goods by the criteria of the Australian Dangerous Goods Code (ADG Code) for transport by Road and Rail.

Poisons Schedule (Aust): Not applicable

4. FIRST AID MEASURES

If poisoning occurs, contact a doctor or Poisons Information Centre (Phone Australia 131 126; New Zealand 03 474 7000).

Inhalation: Remove victim from exposure - avoid becoming a casualty. Remove contaminated clothing and loosen remaining clothing. Allow patient to assume most comfortable position and keep warm. Keep at rest until fully recovered. Seek medical advice if effects persist.

Skin contact: Wash contaminated skin with plenty of soap and water. Remove contaminated clothing and wash before re-use. If irritation occurs seek medical advice. For skin burns, immediately flood burnt area with plenty of water and cover with a clean, dry dressing. Seek immediate medical advice.

Eye contact: Irrigate with copious quantities of water for 15 minutes. In all cases of eye contamination it is a sensible precaution to seek medical advice.

Ingestion: Rinse mouth with water. Give water to drink. Do NOT induce vomiting. Seek medical advice.

Notes to physician: Treat symptomatically.

5. FIRE-FIGHTING MEASURES

Specific hazards: N/A

Fire fighting further advice: On burning will emit toxic fumes including those of carbon oxides. Fire fighters to wear self-contained breathing apparatus if risk of exposure to vapour or products of combustion.

Suitable extinguishing media: Water fog (or if unavailable fine water spray), foam, dry agent (carbon dioxide, dry chemical powder). Do not use water jets.

6. ACCIDENTAL RELEASE MEASURES

SMALL SPILLS

Wear protective equipment to prevent skin and eye contamination. Cover with damp absorbent (inert material, sand or soil). Sweep or vacuum up, but avoid generating dust. Collect and seal in properly labeled containers or drums for disposal.

LARGE SPILLS

Wear protective equipment to prevent skin and eye contamination and the inhalation of dust. Work up wind or increase ventilation. Cover with damp absorbent (inert material, sand or soil). Sweep or vacuum up, but avoid generating dust. Collect and seal in properly labeled containers or drums for disposal.

7. HANDLING AND STORAGE

Handling: Avoid eye contact and repeated or prolonged skin contact. Do not breathe vapour.

Storage: Store in a cool, dry place and out of direct sunlight. Keep containers closed at all times - to prevent ingress of moisture. Check regularly for spills.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

National occupational exposure limits

No value assigned for this specific material by the National Occupational Health and Safety Commission (NOHSC Australia).

Engineering measures: Process in well ventilated areas. Keep containers closed when not in use.

Personal protection equipment: OVERALLS, SAFETY SHOES, SAFETY GLASSES, GLOVES (Short).

Avoid skin and eye contact. Do not breathe vapours. Wear overalls, safety glasses and impervious gloves. Always wash hands before smoking, eating, drinking or using the toilet.

If inhalation risk exists due to processing vapours wear organic vapour respirator meeting the requirements of AS/NZS 1715 and AS/NZS 1716.

9. PHYSICAL AND CHEMICAL PROPERTIES

Form / Colour / Odour: Liquid, Clear, Odourless.

Solubility: Soluble in many solvents: THF, DMF, DMA, chloroform, dichloromethane

Relative Vapour Density (air=1):	N App
Vapour Pressure (20 °C):	N App
Flash Point:	N App
Flammability Limits (%):	N App
Autoignition Temperature (°C):	N App
Melting Point (°C):	N Av
Decomposition Point (°C):	N Av
Sublimation Point (°C):	N Av

pH:	N App
Viscosity:	~6,000cP

(Typical values only - consult specification sheet)
N Av = Not available N App = Not applicable

10. STABILITY AND REACTIVITY

Stability: Stable according to available information.

11. TOXICOLOGICAL INFORMATION

No adverse health effects expected if the product is handled in accordance with this Safety Data Sheet and the product label. Symptoms or effects that may arise if the product is mishandled and overexposure occurs are:

Acute Effects

Inhalation: Processing vapours may be irritant to mucous membranes and respiratory tract.

Skin contact: Contact with skin may result in irritation. Exposure to hot material may cause deep skin burns. Molten material may adhere to skin.

Eye contact: May be an eye irritant. Exposure to the pellets/particles may cause discomfort due to particulate nature. May cause physical irritation of the eye.

Ingestion: No adverse effects expected, however large amounts may cause nausea and vomiting.

Long Term Effects: No information available for product.

Acute toxicity / Chronic toxicity
No LD50 data available for the product.

12. ECOLOGICAL INFORMATION

Avoid contaminating waterways.

ENVIRONMENTAL FATE, PERSISTENCE AND DEGRADATION
No information available.

AQUATIC TOXICITY
No information available.

TERRESTRIAL TOXICITY
No information available.

13. DISPOSAL CONSIDERATIONS

Refer to State/Territory Land Waste Management Authority. Normally suitable for disposal at approved land waste site.

14. TRANSPORT INFORMATION

Road and Rail Transport

Not classified as Dangerous Goods by the criteria of the Australian Dangerous Goods Code (ADG Code) for transport by Road and Rail.

Marine Transport

Not classified as Dangerous Goods by the criteria of the International Maritime Dangerous Goods Code (IMDG Code) for transport by sea.

Air Transport
Not classified as Dangerous Goods by the criteria of the International Air Transport Association (IATA)

15. REGULATORY INFORMATION

Irritant.
R-Phrases: 36/37/38 Irritating to eyes, respiratory system and

S-Phrases: 26-36/37 In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. Wear suitable clothing and gloves.

Caution: Substance not yet fully tested (EU).

Poisons Schedule (Aust): Not applicable

All the constituents of this material are listed on the Australian Inventory of Chemical Substances (AICS).

16. OTHER INFORMATION

For further information about this product;

Contact: Oliver Hutt

Telephone: (03) 8558 8000

Reason(s) For Issue: Revision.

Material Safety Data Sheets are updated frequently. Please ensure that you have a current copy.

This MSDS summarises at the date of issue our best knowledge of the health and safety hazard information of the product, and in particular how to safely handle and use the product in the workplace. Since Aortech Biomaterials cannot anticipate or control the conditions under which the product may be used, each user must, prior to usage, review this MSDS in the context of how the user intends to handle and use the product in the workplace.
If clarification or further information is needed to ensure that an appropriate assessment can be made, the user should contact this company.

Appendix 2

Impact of SBPM application on interrow soil workability

Introduction

Plastic mulch is a common practice by vegetable growers in Carnarvon, WA to preserve soil moisture and control weeds. Installation of plastic mulch is shown to prevent side leaching of irrigation water from the growing bed into the interrow, maintaining the soils workability to support tractor operations.

The SBPM innovation is designed, in principle, to be an alternative to plastic mulch. Once it is properly applied to a surface it dries to form a consistent physical film. This film is elastic and impermeable like a plastic film that helps to reduce soil water evaporation and to control weeds. However, grower feedback provided concern that the SBPM application only covers the topsoil, it may not be able to prevent irrigation water leaching into the interrow, thus reducing soil workability, especially in the loamy soils found in Carnarvon.

This study aims to investigate if SBPM application in a commercial tomato farm in Carnarvon will have a negative effect on interrow soil workability compared to the conventional plastic mulch.

Materials and methods.

The SBPM used in this study was a 20 wt% polymer solid content of polyurethane emulsion in water mixed with 4% carbon pigment. Its composition and synthesis have been reported by the supplier, Boron Pty Ltd, in the Material safety data sheet (Appendix 1). It was supplied in sealed 20 kg white plastic drum containers.

A plastic mulched tomato bed was used for the trial where one metre of the plastic mulch was replaced with a SBPM application at 1 L/m^2 (Image 1). A time lap camera was installed to capture the physical changes that appear on the tractor wheel track on the interrow soil at the SBPM applied section for 4 months. The results of the tractor wheel tract monitoring and the survey of the involved grower’s experience on the effects of the SBPM application on interrow soil workability were used to draw out the conclusion.

Image 1: SBPM application at 1 L/m^2 to replace plastic mulch

Results and conclusions

SBPM application did not show negative effects on the interrow soil workability of the tomato farm in this study.

The time lap camera did not capture wetting and mudding phenomena on the monitored tractor wheel track (Image 2 and 3). The involved grower noted that the tractor used for routine cultural practices like trellising, pruning, and picking could normally pass the interrow of the growing tomato bed in this study.

The involved grower revealed that the interrow soil beside the SBPM applied section supported the tractor operation as normal as the other part of the interrow. However, he wished to involve a further investigation in this matter where effects of SBPM application on the interrow soil workability could be in implemented on a larger scale.

Image 2: The monitored wheel track one month after plastic mulch was replaced by SBPM

Image 3: The tractor wheel tract beside the SBPM applied section at 3 months after SBPM application