Cut Slope Soil Erosion Control Trial

CAP Site 1: REPORT SUMMARY

EOS Ecology Report No. CHR01-20077-03 | November 2022

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SCIENCE + ENGAGEMENT

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Contents

Erosion and sediment generated from roadside cuttings in loess.

1 Project Overview

The Problem

The soils on the lower slopes of Christchurch's Port Hills and Banks Peninsula are prone to severe erosion when exposed as they are largely composed of silt-sized particles known as loess (pronounced low-iss). Bare loess erodes severely due to chemical and physical properties that cause dispersion of soil particles when wet. When vegetation and protective topsoil is removed from loess deposits, the underlying subsoil is subject to surface erosion (sheet-wash, rill erosion) and deep-seated erosion (slips and tunnel gullies). Once these tiny loess particles are in suspension they are difficult to remove via traditional stormwater treatment systems. As such this fine sediment ultimately ends up in our waterways and harbours, severely affecting the health of these ecosystems.

Exposed roadside cuttings of loess are an obvious source of silt-sized sediment (as per images on the previous page). During wet weather, sediment from eroded roadside loess cuttings enters water tables, that link to small streams or directly into the harbour. With little room within the road corridor the options for treatment of sediment-laden runoff are minimal. Thus, the onus must be on reducing sediment runoff at the source of the cut face.

The Project

Few replicated studies have been undertaken to characterise the nature of erosion from road-side cuttings in loess, let alone to test solutions to reduce erosion. Thus, best practice techniques to reduce such erosion in an efficient and cost-effective way are currently unknown. With support from the Banks Peninsula Zone Committee, the Christchurch City Council and Environment Canterbury commissioned EOS Ecology to design and implement a field study to determine the best way to reduce erosion from loess cut slopes.

With the requirement to develop cost-effective (i.e., low intervention) approaches to cut-slope erosion control that can be effectively implemented around the Peninsula's many roads, the focus of the programme has been on determining the best combination of 'soft' erosion control measures, incorporating products and vegetation over the long-term.

2 Aims & Benefits

Aim: Field test a mix of low-cost erosion control products and plants to determine which combination(s) best achieve a long-term natural solution to erosion control of predominantly loess cut faces.

Who Will Benefit:

- **Councils:** The findings will help Councils with roadside and track cut slope maintenance and design.
- **Private property owners:** The findings will help landowners better manage cut slopes on their land.
- **The environment:** Widespread implementation of the findings will help to reduce erosion of loess cut faces and so reduce sediment discharges into our waterways and harbours.

3 Approach

Site Location

The study has currently been implemented at one of four study sites. Located in the Christchurch Adventure Park (CAP), this first study site is a good example of a south facing cut loess slope typical of Port Hills and Banks Peninsula roads (Figure 1).

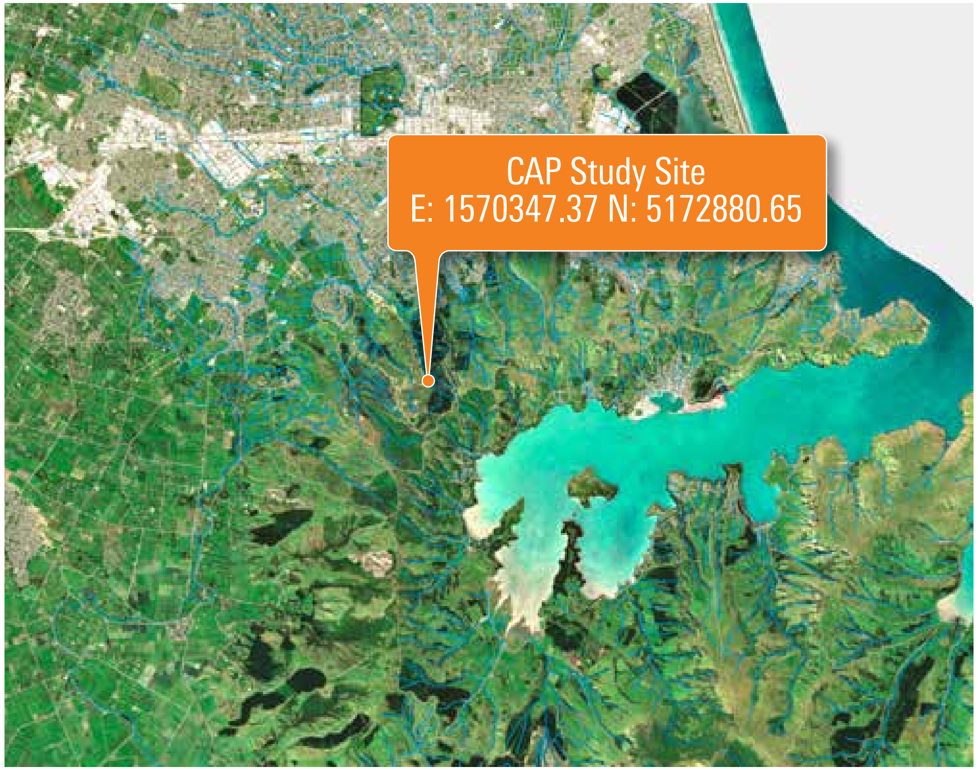

FIGURE 1: The location of the first cut slope soil erosion study site, located up Valley Road access track in the Christchurch Adventure Park. The individual test plots are numbered. Photo taken shortly after completion of the site setup, in June 2019.

Site Setup

Site-wide interventions (Figure 2):

- **Slope above the cut face:** Runoff intercepted and prevented from flowing over the face of the batter via use of diversion flumes. Planting to cover the slope above the cut face to help intercept any smaller overland flow and provide colonist sources for the cut face.
- **Cut face:** A battered cut face formed to expose the underlying loess subsoil on which to implement the cut face experiments. The experiment incorporates five erosion control products and six species of plants applied to the battered face along with a control (i.e., where the face is prepared but left untreated) for comparison.
- **Rock toe at the base of the cut face:** The toe of the cut face is buttressed using locally sourced volcanic rock, backfilled with in-situ (i.e., on-site) soil and second-grade topsoil, and planted. The rock toe helps to stabilise the cut face and prevents under-cutting and destabilisation, whilst the plants help to trap sediment that may run off the cut face before it can reach the water table.
- **Water table:** A bidim®-lined[1] rock channel at the base of the rock toe forms a stable water table for track-side runoff and allows for observations of sediment sourced from the study area.

The products and plants being tested on the cut face (Table 1, Figure 3):

- Rather than selecting and testing plant species that would readily germinate but not necessarily remain viable, this study is about achieving a long-term natural solution to erosion control. As such, erosion control products were selected based on their ability to provide initial cover of the exposed soil whilst vegetation was becoming established, and to assist with vegetation establishment through increasing the amount of water available for plant growth and increasing available nutrient supply. The plants chosen for the trial were ones that are more able to cope with the harsh conditions of loess soil, including low macro-nutrient levels but high sodium content, and would be more likely to continue to grow and spread across the cut face. Not surprisingly most are native species.
- Erosion control products applied to the cut face consist of two rolled products, two hydraulically applied mulch/erosion control products with grass seed, and one rolled/mulch combination (Table 1).
- The six native plant species plug-planted into the cut face were the New Zealand ice plant (*Disphyma austral*, later replaced with the grass *Carex comans*), Banks Peninsula fescue (*Festuca actae*), cutty grass (*Carex geminata*), silver tussock (*Poa cita*), pig fern (*Hypolepis ambigua*), and bracken fern (*Pteridium esculentum*) (Figure 3). The New Zealand ice plant was replaced because of its extreme palatability to possums and possibly also to rabbits/hares.
- Kidney herb (*Dichondra repens*), NZ linen flax (*Linum monogynum*), and plume grass (*Dichelachne crinita*) – species not readily available via native plant nurseries – were also planted into a single trial plot to see if they would grow to a level that they could be suitable for use in future studies.

[1] bidim® is a geotextile.

FIGURE 2: Key features of the study site.

TABLE 1: Products applied to the cut face experimental plots.

SPRAYED		ROLLED		COMBO
Hydromulch + seed mix ('hydromulch mixed')	Hydromulch on organic base + seed mix ('hydromulch & base')	Coir fibre blanket ('rolled – jute')	Wool blanket ('rolled – wool')	Coir fibre blanket with Hydromulch + seed mix ('combo hydromulch & jute')
				
VE Gro-Matt & Vital polykelp mixed together	**Flexterra HP-FGM with Proganics (top layer)** **Proganics BSM & Trichoflow Pro WP mixed together (base layer)**	**Geofabrics JuteMat 650**	**Terra Mulch**	**Geofabrics CJ450 + ProMatrix EFM**
Wood fibres mixed with nutrient-infused stabilising biodegradable polymers and applied via spray.	Two organic bio stimulants applied first followed by a wood fibre mulch applied via spray.	A 'heavy weight' (650g/m^2) natural jute fibre blanket applied in rolls and secured with pins.	5 mm thick wool fibre blanket applied in rolls and secured with pins.	Promatrix Engineered Fibre Matrix (EFM) applied via spray, with coconut fibre blanket applied over top in rolls and secured with pins.
Applied with cover crop seed mixed in: Creeping red fescue, browntop, Poa, red clover.	Applied with cover crop seed mixed in: Creeping red fescue, browntop, Poa, red clover.	n/a	n/a	EFM applied with cover crop seed mixed in: Creeping red fescue, browntop, Poa, red clover.


Disphyma australe (NZ ice plant) (left)
Creeping rhizomes, dry/sun tolerant. Later replaced with *Carex comans* (right) relatively dry tolerant, spreads well from seed.

Festuca actae (Banks Peninsula fescue)
Hardy evergreen, dry tolerant, spreads well from seed.

Carex geminata (cutty grass)
Deciduous, creeping rhizomes, dry tolerant. Dies back in winter but rhizomes remain.

Poa cita (silver tussock)
Evergreen, dry tolerant, speads from seed.

Hypolepis ambigua (pig fern)
Creeping rhizomes, dry/sun tolerant. Dies back in winter but rhizomes remain.

Pteridium esculentum (bracken fern/rahurahu)
Creeping rhizomes, dry tolerant, sun loving. Dies back in winter but rhizomes remain.

FIGURE 3: Plants applied to the cut face experimental plots.

Study Design

- Each erosion control product was applied to three replicate plots. There were also three control plots where no interventions occurred (Figure 4). All products were arranged in a randomised block design, to take into account the gradient of environmental conditions across the site.
- The six plant species were applied to each of the treatment plots (excluding control plots) in a randomised block design with four replicates of each plant per plot.

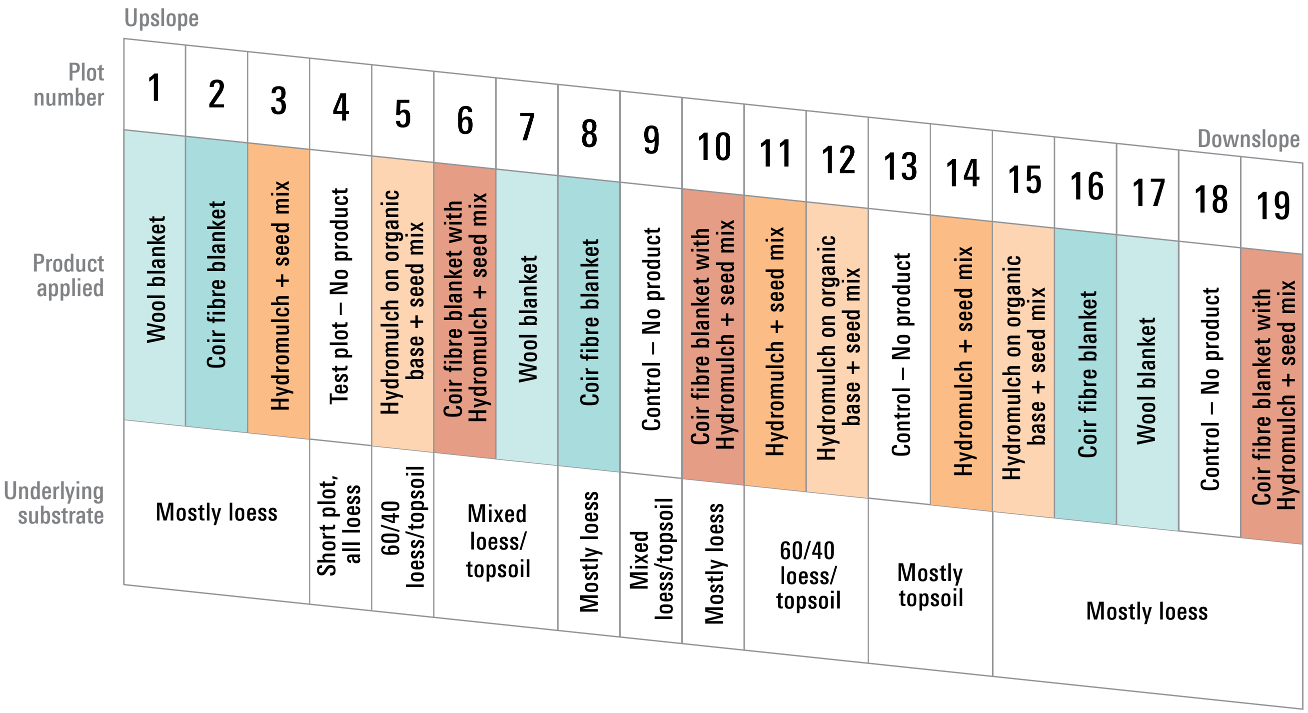

FIGURE 4: Site layout for the cut face experiment.

4 Work Programme

Pilot Study (completed 2016)

- Using a combination of desktop study and field investigations, scientists from EOS Ecology first undertook a pilot study to summarise the existing knowledge of erosion around the Harbour, define the characteristics of road-side cuttings around Te Whakaraupō, and identify possible locations for undertaking field trials of erosion control methods.
- Report citation: Adamson, T. & McMurtrie, S. 2016. Erosion and sediment control pilot project on Lyttelton Harbour/ Whakaraupō road-side cuttings. EOS Ecology report No. ENV01-16116. EOS Ecology, Christchurch. 42 p.
- Funding provided by Environment Canterbury.

Methodology Development (completed 2018)

- Scientists from EOS Ecology and Manaaki Whenua/ Landcare Research undertook more detailed site investigations of short-listed potential field trial sites, and developed an appropriate construction design and experimental setup.
- Report citation: McMurtrie, S., Keay, W., Lynn, I., Simcock, R. & Meurk, C. 2018. Whakaraupō roadside cuttings: Methods for testing treatment options. EOS Ecology, Christchurch. EOS Ecology Report No. ENV01-16164-01. 81 p.
- Funded by Environment Canterbury.

Implementation of Study at the CAP Valley Road Site (2019–2022)

- Site setup implemented in May–June 2019 (Figure 5).
- The science team completed 2.5 years of monitoring (June 2019–December 2022) including detailed monitoring of the cut face (for erosion features and product/plant condition and coverage), checking of plant condition in the rock toe and slope above the cut face, undertaking site inspections, and implementing site maintenance when needed (Table 2). A summary of the study's findings is presented here in this summary report.
- Report citation: McMurtrie, S., James, A., Lyn, I., Meurk, C. & Simcock, R. 2022. Cut slope soil erosion control trial CAP Site 1: Year 3 monitoring report. EOS Ecology Report No. CHR01-20077-02. 84 p.
- Funded by Christchurch City Council.


Fulton Hogan creating the cut face under the oversight of the science team.


The cut face with horizontal 'scarifying' and the rock toe prior to backfilling. The plastic sheeting is a temporary flume prior to the installation of the diversion flumes.


One of the product suppliers applying their hydromulch product.


Waiora and the science team planting into the cut face.

FIGURE 5: Site setup implemented in May–June 2019.

TABLE 2: The monitoring programme timeline for the CAP Valley Road site.

		COMPLETED							TO COME
		Year 0 (installation)	**Year 1 (1 July 2019–30 June 2020)**		**Year 2 (1 July 2020–30 June 2021)**		**Year 3* (1 July 2021–30 June 2022)**		**Year 4 onwards**
			Monitoring date	Months since site setup	Monitoring date	Months since site setup	Monitoring date	Months since site setup	
Site setup		20 May–20 June 2019							
Monitoring	Cut face – plants and products		FOUR ROUNDS		ONE ROUND		ONE ROUND		TBC
			Aug 2019	2	Dec 2020	18	Dec 2021	30	
			Nov 2019	5					
			Feb 2020	8					
			May 2020	11					
	Cut face – erosion	ONE ROUND May 2019: before products applied	TWO ROUNDS		ONE ROUND		ONE ROUND		TBC
			Aug 2019	2	Dec 2020:	18	Dec 2021	30	
			May 2020	11					
	Above/below slope – plant condition		THREE ROUNDS				ONE ROUND		TBC
			Aug 2019	2			Dec 2021	30	
			Mar 2020	9					
			May 2020	11					
Inspections & maintenance	Site inspections		SIX ROUNDS (Jul/Aug/Sep/Oct 2019, Jan/June 2020)		FIVE ROUNDS (Aug/Oct 2020, Feb/Apr/Jun 2021)		TWO ROUNDS (Aug/Oct 2021)		TBC
	Maintenance – replacement planting of some plants		ONE ROUND (June 2020)						
	Maintenance – weeding/spraying above slope		THREE ROUNDS (Nov 2019, Jan/June 2020)		ONE ROUND (Mar 2021)		ONE ROUND (Oct–Nov 2021)		TBC
Reporting					Programme overview: June 2021		Final report: Aug 2022 (McMurtrie *et al*., 2022).		TBC

* Rather than being a full 'year three' monitoring programme, this was created by delaying the last of the 'year two' monitoring until year three. This was partly due to funding limitations and partly due to particularly dry growing seasons meaning that some plants had not grown much between monitoring rounds.

5 Methods

Monitoring Setup

The setup for each plot consisted of an approximate 1.5 m wide by 4.5 m high area demarcated for monitoring, and with a 0.8–0.9 m buffer between plots. Slope of the cut bank ranged between 30–48 degrees. Monitoring was undertaken with the use of a 3 (across) x 9 (up) gridded metal frame, with the internal dimensions of each grid approximately 0.5 m x 0.5 m (Figure 6). The bottom row of the grid was excluded from monitoring, leaving a total of 24 grids used for plot monitoring. The grided frame was placed on the cut face against permanent location marker pegs set along the bottom edge and spray marks to denote the edge of the plot (which were refreshed on each subsequent monitoring round) to ensure correct placement of the grid on each subsequent monitoring. To reduce damage to the cut face an aluminium extendable ladder was lowered on top of, or adjacent to, the grid and used to access the cut face (Figure 6).

What was Monitored

The focus of monitoring was on the cut face, with treatment performance and success measured in terms of four components that were measured for each 0.5x0.5m grid in each monitoring plot:

» **Visual evidence of erosion:** initial classification of the soil material type, the presence/absence, number, and % cover class (<1%, 1–10%, 10–20%, 20–40%, 40–60%, >60%) of different erosion features (Figure 7). Undertaken five times: before the products were applied to the cut face (to classify underlying soil type), two rounds in Year 1 (2 and 11 months after site setup), and one round each in Year 2 (18 months) and Year 3 (30 months) (Table 2). Undertaken to classify the soil type in each grid of plot prior to application of any products or plants, and to determine if there was increasing stability/instability of the faces by comparing over time between treatment types and interpreted based on baseline conditions within each plot.

» **Visual measures of vegetation cover:** % cover class (<1% cover, 1–5%, 5–25%, 25–50%, 50–75%, 75–100%) of different vegetation types (broadleaf weeds, clover, creepers, ferns, grasses, sedges, woody vegetation) and of all vegetation (including plug plants) - assessed based on aerial coverage of the grid, not what was rooted in the grid itself. Undertaken six times: four rounds (every three months) in Year 1, and one round each in Year 2 (18 months) and Year 3 (30 months) (Table 2). As greater vegetation cover will reduce sediment runoff/erosion, measuring vegetation cover is a good corollary for stabilisation of the cut face.

» **Visual measures of plug plants:** % cover of each plug plant as per the % cover classes specified above (assessed based on aerial coverage of the grid, not what was rooted in the grid itself) and plant vigour category (dead, alive just, alive static, alive vigorous, alive rampant). Undertaken at the same time as other vegetation cover monitoring.

FIGURE 6: The science team using the monitoring grid and ladder to quantify conditions within 24 replicate grids for each plot in the cut face experiment.

FIGURE 7: Different erosion features recorded during the Cut Slope Soil Erosion Control Trial at the Christchurch Adventure Park.

Undertaken to determine which plug plants grow the best in the challenging loess conditions.

- **Visual measures of product condition and cover:** % cover of product (if a rolled or sprayed product present) – assessed based on looking under any overhanging vegetation. Undertaken at the same time as the vegetation monitoring. Undertaken to determine when applied products started to degrade.
- This type of monitoring was appropriate given the focus of the study was to determine the most successful approach to achieve revegetation of the cut faces, and due to the prohibitive cost and practical limitations of employing methods of sediment runoff quantification. The high and steep slopes of the study sites meant that only pragmatic and simple techniques could be applied to monitor and evaluate treatment performance. By necessity they were restricted to visual assessments as the installation of any permanent monitoring equipment into the cut slope would invariably encourage the establishment and expansion of erosion features. All analysis was undertaken by comparing the change in the proportion of each of the monitored cover class categories, both between treatments and over time compared to the control plots.
- Checks of plant condition in the slope above the face and the rock toe were also undertaken, as were site-wide inspections during the intervening months between monitoring rounds.

Classification of the Soil Material Type

Because of a natural variation in soil type throughout the cut face, classification of the soil material type in each grid of each plot was undertaken before products and plants were applied, so as to identify whether grids were dominated by loess topsoil[2] (A horizon) or loess subsoil[3] (S, C or P layer after Hughes 1970) (Figure 8). Subsequent analysis to compare treatment types and plug plant performance was undertaken on the 'mainly loess subsoil' grids only. As this study relates to the development of 'soft' (or biological) erosion control methods it was necessary to first classify the surface soil conditions, as they influence both erosion features and plant growth (i.e., topsoil is more conducive to plant growth and more resistant to erosion than loess). Grids that were assessed as having 50% or more of topsoil were classified as being dominated by soil ('mainly loess topsoil'), whilst grids that had more than 50% coverage of subsoil loess were classified as being dominated by loess ('mainly loess subsoil'). The number of grids classified as either 'mainly loess subsoil' or 'mainly loess topsoil' is shown in Table 3. Subsequent analysis to compare treatment types and plug plant performance was undertaken on the 'mainly loess subsoil' grids only.

[2] Topsoil: a general term for the upper part of a soil (A horizon) with dark coloured organic matter accumulation

[3] Subsoil: a general term for the lower horizons of a soil; usually B horizons and below.

TABLE 3: Dominant soil material type in each grid. Only grids that were classified as 'mainly loess subsoil' were used in subsequent data analysis.

Product Type	Treatment Type	Dominant soil type in each grid	
		Mainly loess SUBSOIL	Mainly loess TOPSOIL
Control	No product	85%	15%
Combo	Combo Hydromulch & Jute	57%	43%
Rolled	Jute	81%	19%
	Wool	49%	51%
Sprayed	Hydromulch & base	68%	32%
	Hydromulch mixed	67%	33%
Rare Plug Plants (no product)		100%	0%
OVERALL AVERAGE		68%	32%

'Mainly loess subsoil'

'Mainly loess topsoil'

FIGURE 8: Photos showing grids dominated by loess topsoil vs loess subsoil

6 Summary of Findings

Performance – Vegetative Cover & Erosion Reduction

In terms of overall product-type performance for providing vegetation cover and limiting erosion features, the study rated the treatments in the following order of performance (Table 4):

1. MOST SUCCESSFUL

SPRAYED – Hydromulch on organic base + seed mix ('hydromulch & base')


2 months after site setup
30 months (2.5 years) after site setup

The sprayed 'hydromulch & base' treatment performed the best, achieving the highest vegetation cover and lowest erosion cover categories of all the treatment types (Table 4).

- By the final monitoring round 91% of 'mainly loess subsoil' grids supported >50% total vegetation cover (67% of grids with 75–100% vegetation cover and 24% with 50–75% cover) (Figure 9).
- The only treatment to support (and retain) >50% vegetation cover in more than a quarter of 'mainly loess subsoil' grids by the second monitoring round (5 months after site setup) (Figure 9).
- Product cover retained throughout the 30 month monitoring period (93% of 'mainly loess subsoil' grids with 75–100% product cover at the final monitoring round).
- No erosion features (sheetwash, rills, pipes/tunnels, slips) present by the final monitoring round (Figure 10).
- Very little bare soil at the end of the monitoring period (91% of 'mainly loess subsoil' grids with <1% bare soil, and 9% of grids with 1–5% bare soil). Presence of bare soil limited to areas where product had been disturbed to plant the plug plants.

2. SECOND BEST

ROLLED – Wool blanket ('rolled – wool')

2 months after site setup | 30 months (2.5 years) after site setup

The rolled 'wool' treatment performed second-best overall, scoring second on the two vegetation-cover attributes, but retaining a first equal score for all the erosion attributes (Table 4).

- By the final monitoring round 71% of 'mainly loess subsoil' grids supported >75% total vegetation cover (26% of grids with 75–100% vegetation cover and 24% with 50–75% cover) (Figure 9).
- Only achieved >50% vegetation cover in more than a quarter of 'mainly loess subsoil' grids by the final monitoring round (30 months after site setup) (Figure 9).
- Product cover retained throughout the 30 month monitoring period (97% of 'mainly loess subsoil' grids with 75–100% product cover at the final monitoring round). However, signs that the wool fibers in the rolled product were starting to degrade.
- No erosion features (sheetwash, rills, pipes/tunnels, slips) present by the final monitoring round (Figure 10).
- Very little bare soil at the end of the monitoring period (100% of 'mainly loess subsoil' grids with <1% bare soil). Presence of bare soil limited to areas where product had been disturbed to plant the plug plants.

3. INTERMEDIATE

COMBO – Coir fibre blanket with Hydromulch + seed mix ('combo hydromulch & jute')

2 months after site setup | 30 months (2.5 years) after site setup

The combination 'combo hydromulch & jute' treatment scored third overall, with a first equal score for all the erosion attributes but coming third and last equal for the two vegetation cover attributes.

- By the final monitoring round 34% of 'mainly loess subsoil' grids supported >50% total vegetation cover (5% of grids with 75–100% vegetation cover and 29% with 50–75% cover) (Figure 9).
- Only achieved >50% vegetation cover in more than a quarter of 'mainly loess subsoil' grids by the final monitoring round (30 months after site setup) (Figure 9).
- Product cover mostly retained throughout the 30 month monitoring period (93% of 'mainly loess subsoil' grids with 75–100% product cover at the final monitoring round). Although evidence of degradation of the rolled jute product, the underlying hydromulch retained integrity throughout the monitoring period.
- Very few erosion features (sheetwash, rills, pipes/tunnels, slips) present by the final monitoring round (2% of 'mainly loess subsoil' grids with erosion cover categories 'present to 1%' or '1–10%') (Figure 10). This consisted of sheet wash.
- Only small amounts of bare soil at the end of the monitoring period (83% of 'mainly loess subsoil' grids with <1% bare soil, 10% of grids with 1–5% bare soil, 7% with 5–50% bare soil).

4. SECOND WORST

ROLLED – Coir fibre blanket ('rolled – jute')

2 months after site setup

30 months (2.5 years) after site setup

The 'jute' treatment performed similarly to the control (i.e., plots with no treatments or plug plants applied) in relation to the vegetation cover attributes, but performed better than the control in relation to reducing erosion features - where it scored second on all five erosion attributes.

- By the final monitoring round 19% of 'mainly loess subsoil' grids supported >50% total vegetation cover (7% of grids with 75–100% vegetation cover and 12% with 50–75% cover). This was little different to the control plots which had 21% of 'mainly loess subsoil' grids with >50% total vegetation cover (Figure 9).
- Did not achieve >50% vegetation cover in more than a quarter of 'mainly loess subsoil' grids at any time in the study (Figure 9).
- Product cover diminished by the final monitoring round (30 months after site setup) (only 64% of 'mainly loess subsoil' grids with 75–100% product cover). Some product degradation began in the fifth monitoring round, 18 months after site setup.
- Four types of erosion features (sheetwash, rills, pipes/tunnels, slips) present by the final monitoring round (5% of 'mainly loess subsoil' grids with erosion cover categories 'present to 1%' or '1-10%', 6% of grids with erosion cover of 10-40%, and 0.3% with erosion cover of >40%) (Figure 10). For sheetwash 5% of 'mainly loess subsoil' grids had 10-40% cover. For rills 5% of grids had 10–20% cover, and for pipes/tunnels 2% of grids had 10–20% cover. For slips 3% of grids had 20–60% cover, however this was a result of a slip in an adjacent control plot.
- Moderate amounts of bare soil at the end of the monitoring period (29% of 'mainly loess subsoil' grids with <1% bare soil, 26% of grids with 1–5% bare soil, 41% with 5–50% bare soil, and 3% with 50–75% bare soil).

5. WORST

SPRAYED – Hydromulch + seed mix ('hydromulch mixed')

2 months after site setup

30 months (2.5 years) after site setup

The sprayed 'hydromulch mixed' treatment scored lowest equal with the control for all vegetation and erosion cover attributes; and as such was little different to the control plots that had no treatments or plug plants applied.

- By the final monitoring round 18% of 'mainly loess subsoil' grids supported >50% total vegetation cover (8% of grids with 75–100% vegetation cover and 10% with 50–75% cover). This was little different to the control plots which had 21% of 'mainly loess subsoil' grids with >50% total vegetation cover. (Figure 9).
- Did not achieve >50% vegetation cover in more than a quarter of 'mainly loess subsoil' grids at any time in the study (Figure 9).
- Product cover greatly diminished by the final monitoring round (30 months after site setup) (only 21% of 'mainly loess subsoil' grids with 75–100% product cover). Product degradation increased from the fifth monitoring round (18 months after site setup), with most degradation occurring at the final monitoring round (30 months after site setup).
- Two types of erosion features (sheetwash, rills) present by the final monitoring round. The greatest overall coverage of erosion features of the tested treatments (6% of 'mainly loess subsoil' grids with erosion cover categories 'present to 1%' or '1–10%', 4% of grids with erosion cover of 10–40%, and 10% with erosion cover of >40%) (Figure 10). For sheetwash 35% of 'mainly loess subsoil' grids had >40% cover and 6% had 10–40% cover. For rills 13% of grids had >40% cover and 15% had 10–40% cover. The only product to have erosion features in the '>60%' cover category by the final monitoring round (23% of 'mainly loess subsoil' grids). Cover of erosion features similar to the control plots.
- Large amounts of bare soil at the end of the monitoring period (only 6% of 'mainly loess subsoil' grids with <1% bare soil, with 17% of grids with 1–5% bare soil, 38% with 5–50% bare soil, and 23% with 50–75% bare soil, and 17% with >75% bare soil). The only treatment to have bare soil in the >75% cover category.

TABLE 4: Summary of results for performance of the five different treatments compared to the control ('no product'). Data for 'mainly loess subsoil' grids only. Performance of each individual treatment is ranked using ☐ = best, ☐ = second best, ☐ = second worst, ☐ = worst (colours apply to data within the dark blue border).

	SPRAYED		ROLLED		COMBO	CONTROL
	Hydromulch + seed mix ('hydromulch mixed')	Hydromulch on organic base + seed mix ('hydromulch & base')	Coir fibre blanket ('rolled – jute')	Wool blanket ('rolled – wool')	Coir fibre blanket with Hydromulch + seed mix ('combo hydromulch & jute')	No product
Total Veg Cover (final round)	19% of grids with >50% vegetation cover	91% of grids with >50% vegetation cover	19% of grids with >50% vegetation cover	71% of grids with >50% vegetation cover	34% of grids with >50% vegetation cover	21% of grids with >50% vegetation cover
Total vegetation cover (over time)	# rounds when 50–100% cover class present in >25% of grids: none	# rounds when 50–100% cover class present in >25% of grids: five	# rounds when 50–100% cover class present in >25% of grids: none	# rounds when 50–100% cover class present in >25% of grids: one	# rounds when 50–100% cover class present in >25% of grids: one	# rounds when 50–100% cover class present in >25% of grids: none
Product cover (final round)	30% of grids with >50% product cover*	100% of grids with >50% product cover*	88% of grids with >50% product cover	100% of grids with >50% product cover	100% of grids with >50% product cover*	N/A
All erosion features (final round)	10% of grids with >40% erosion, 4% of grids with 10–40% erosion	0% of grids with >40% erosion, 0% of grids with 10–40% erosion	0% of grids with >40% erosion, 3% of grids with 10–40% erosion	0% of grids with >40% erosion, 0% of grids with 10–40% erosion	0% of grids with >40% erosion, 0% of grids with 10–40% erosion	11% of grids with >40% erosion, 10% of grids with 10–40% erosion
Sheetwash erosion (final round)	35% of grids with >40% cover, 6% with10–40% cover	0% of grids with >40% cover, 0% with10–40% cover	0% of grids with >40% cover, 5% with10–40% cover	0% of grids with >40% cover, 0% with10–40% cover	0% of grids with >40% cover, 0% with10–40% cover	36% of grids with >40% cover, 18% with10–40% cover
Rills erosion (final round)	13% of grids with >40% cover, 15% with10–40% cover	0% of grids with >40% cover, 0% with10–40% cover	0% of grids with >40% cover, 5% with10–40% cover	0% of grids with >40% cover, 0% with10–40% cover	0% of grids with >40% cover, 0% with10–40% cove	10% of grids with >40% cover, 33% with10–40% cover
Bare Soil (final round)	40% of grids with >50% bare soil	0% of grids with >50% bare soil	4% of grids with >50% bare soil	0% of grids with >50% bare soil	0% of grids with >50% bare soil	67% of grids with >50% bare soil
OVERALL RANK	**WORST little different from control**	**BEST**	**SECOND WORST**	**SECOND BEST**	**INTERMEDIATE**	**N/A**

* Includes N/A cover categories where coverage of vegetation was >75% making it difficult to ascertain coverage of the sprayed product.

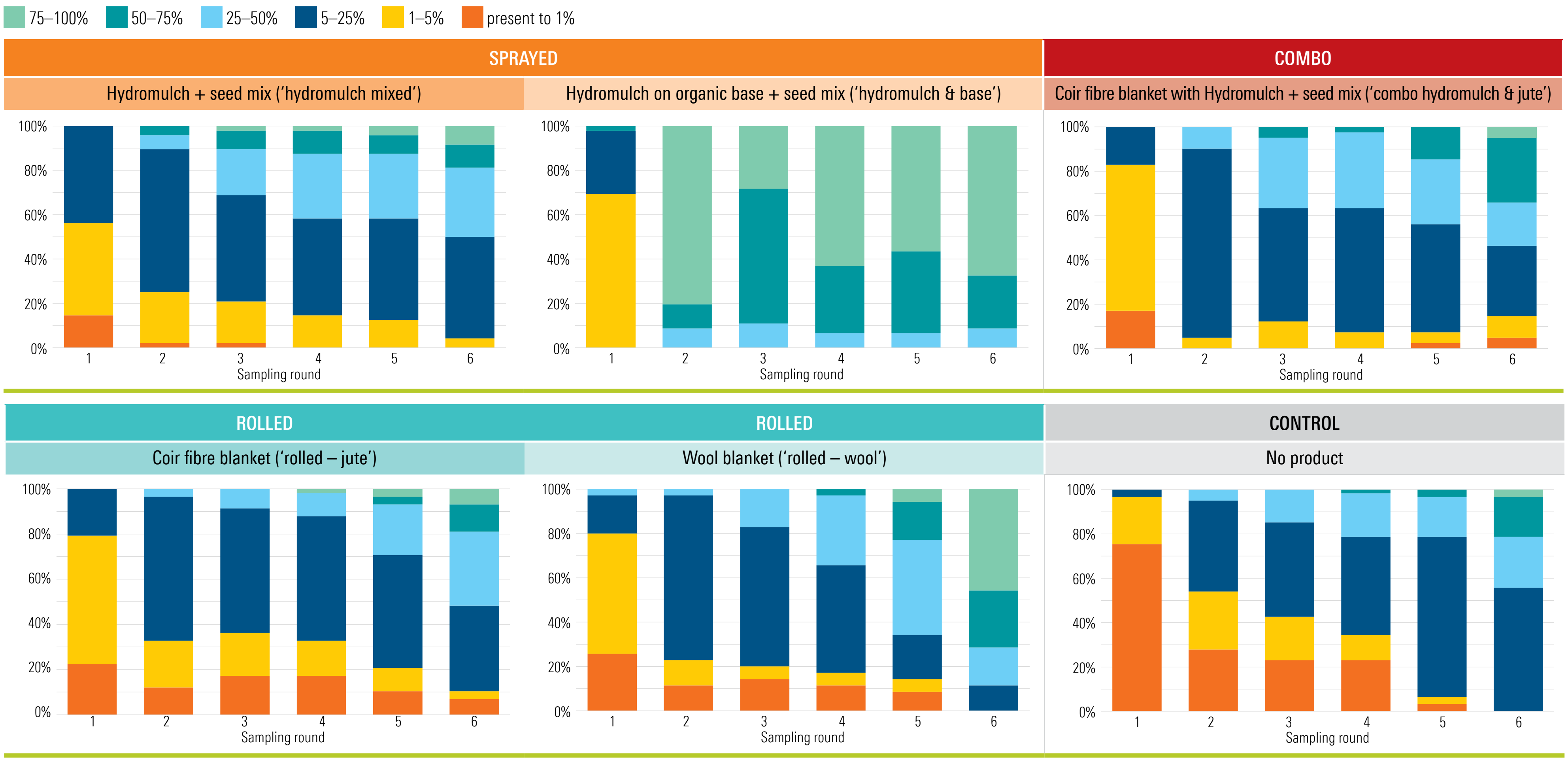

FIGURE 9: Stacked bar graphs showing the PERCENTAGE COVER OF ALL VEGETATION IN GRIDS across five different treatments and control ('no product'), for grids that were classified as 'mainly loess subsoil'. Data is based on the proportion of grids that were classified as one of six cover categories, and is presented for each monitoring round, undertaken approximately 2, 5, 8, 11, 18 (1.5 years) and 30 months (2.5 years) after site setup.

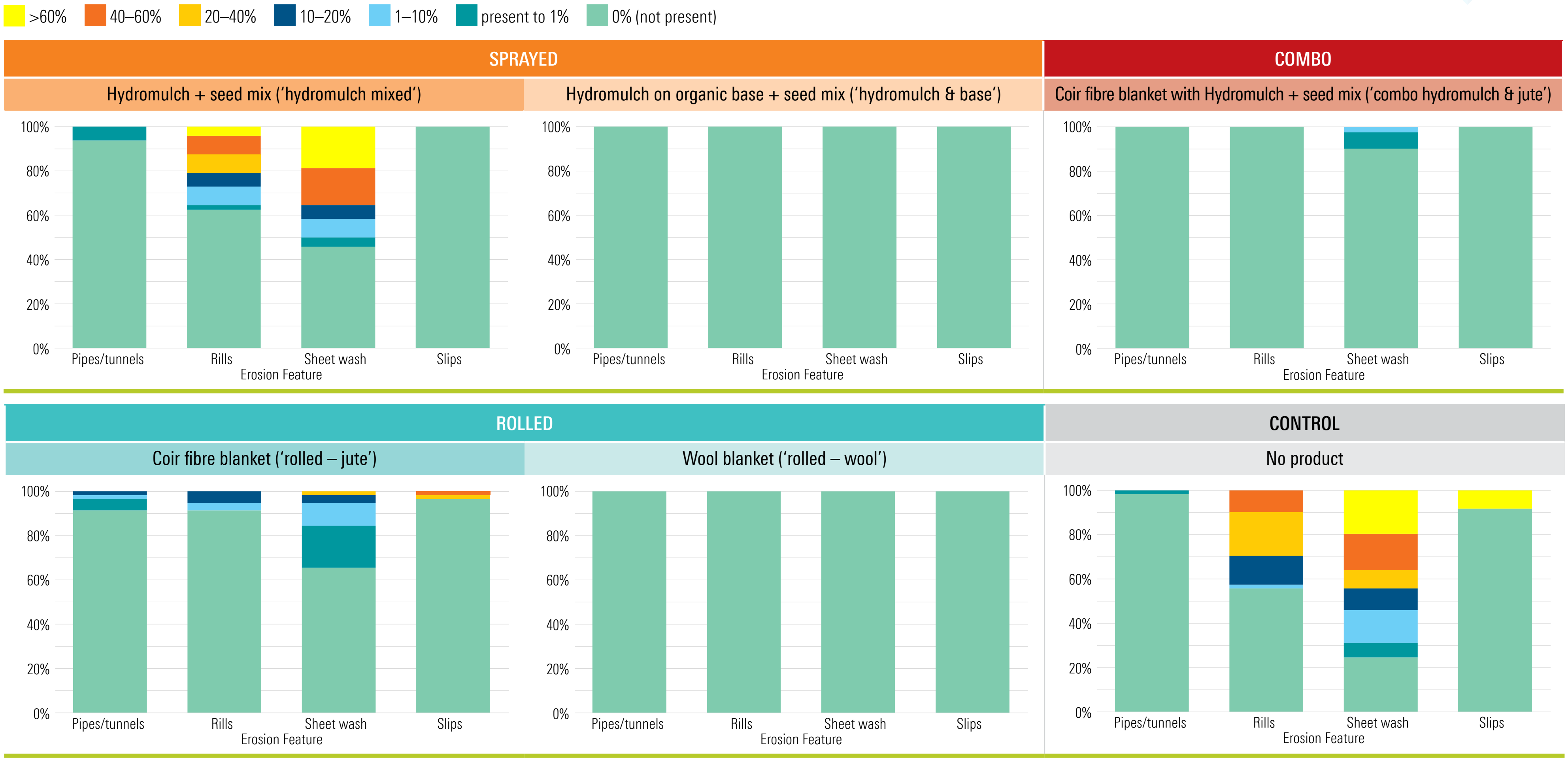

FIGURE 10: Graph showing the PROPORTION OF THE DIFFERENT TYPES OF EROSION FEATURES in grids across the five different treatments and control ('no product'), for grids that were classified as 'mainly loess subsoil'. Data for the % cover categories is based on the proportion of grids that were classified as one of six cover categories. Data is presented for the last round of monitoring only, undertaken approximately 30 months (2.5 years) after site setup.

Products that provide a thick cover of the cut slope (i.e., the 'hydromulch & base' and 'wool' treatments) appear to provide the best erosion control as they help to retain moisture for plant growth, as well as prevent erosion by rainsplash or runoff.

» **The 'hydromulch & base' treatment:**

- appeared to provide the most beneficial environment for plant growth (especially for grasses) and also prevented erosion throughout the 2.5 year monitoring period.
- The thick interlaced fibrous product stuck well to the cut surface, and once it was fully dried, became fused to the surface. Even after 2.5 years the thick fibrous sprayed product was still evident on the cut face, and there were few areas of bare earth evident on any of the grids .
- The majority of grids were covered with thick vegetation growth, consisting mainly of grass species, from five months after site setup. This grass cover remained throughout the 2.5 year monitoring period, and even when there were times of grass dieback there still remained a high level of vegetative cover (Figure 9).
- Hydromulch products such as this which are hydraulically applied need to have time to dry (and thus become bonded to the surface) before a large rain event to ensure they remain on the cut face. This was illustrated when there was an especially heavy rainfall the day after application of the sprayed products during installation. The sprayed products were reapplied following this event.

» **The 5 mm thick 'wool' treatment:**

- acted to provide an effective barrier to the establishment of most adventive plant species, but did seem to facilitate the growth of at least some of the plug plant species.
- However, whilst the rolled 'wool' treatment had not yet started to break down, when this eventually occurs the underlying soil will be exposed to rainfall and erosion without the added plant seed available for subsequent germination, as in the hydromulch treatments. As the wool treatment was effective in controlling the growth of adventive species, when the product degrades it is likely that, excluding the plug plants that have been able to establish, any remaining areas of bare soil will become sources for erosion. Alternatively, if the wool continues degrading slowly, plant colonisation will keep pace. Thus, it will be important to continue this monitoring to plot the changes that occur with the degradation of the rolled product.

Combination approaches (such as the 'combo hydromulch & jute') do not always provide a synergistic solution:

- The rolled product prevented the effective germination of the grass seed in the underlying hydromulch.
- As the rolled product started to degrade the underlying hydromulch remained evident and continued to protect the face from erosion. Thus, it is possible that as the rolled product degrades further the underlying hydromulch may continue to provide erosion protection and a growing substrate for the contained seed (should it still be viable) and adventive vegetation.
- However, given that the cost of applying both a hydromulch and rolled product is effectively double that of the individual treatments, and the combination performs worse that the individual treatments, it is unlikely to be a viable option.

The **thinner rolled and thinner hydromulch** products performed the worst of all the treatments.

- The lighter weight of the rolled 'jute' treatment is likely responsible for the faster breakdown of the product, thereby exposing the underlying soil to rain and erosion. This was exacerbated by the tracking of possums down the cut face to access the NZ ice plants in the early stages of the trial, which is unlikely to be repeated in areas where there are not excessive possum numbers or where the NZ ice plant is not used. That said, it does illustrate the greater rapidity of product breakdown in thinner rolled materials and thus the greater chance of erosion once the product degrades and before vegetative cover can establish. This seemed to be the case for this treatment at the 2.5 year conclusion to the current trial.
- The thinner nature of the sprayed 'hydromulch mixed' treatment meant that whilst the cut face was initially covered with hydromulch there was not a substantial thickness to provide beneficial growing conditions for vegetation and to continue to provide cover of the cut face. Whilst the product remained on the cut face it did provide some erosion protection, but it soon became eroded from the surface, with the proportion of erosion features similar to the control plots by the end of the monitoring period. Thus, whilst at the end of the monitoring period there were small pockets where the product remained, evidence of erosion was evident around them. The product also did not appear to provide beneficial growing conditions for the grass seed in the hydromulch, with vegetation cover being comparable to that of the control plots.
    - Hydromulch products such as this which are hydraulically applied need to have time to dry (and thus become bonded to the surface) before a large rain event to ensure they remain on the cut face. This was illustrated when there was an especially heavy rainfall the day after application of the sprayed products during installation. The sprayed products were reapplied following this event.

Performance – Plug Plants

In terms of overall growth/vigour and aerial coverage provided by the trialled plug plants, the study rated the plug plants in the following order of performance (Table 5):

1. MOST SUCCESSFUL
Silver tussock (*Poa cita*)

The plug plant that appeared the most successful in the loess-dominated cut face over the 2.5-year monitoring period was the native grass silver tussock (*Poa cita*).

» This large grass performed the best on all cover and vigour attributes. Despite this the results were variable with only 30% of the 'mainly loess subsoil' grids achieving >50% cover by the end of the 2.5-year monitoring period.

» We would recommend this as a plug plant to use in helping to stabilise loess cut slopes but would need to be planted more densely than what was done in this study to provide more continuous cover, or alternatively consider turf grasses as an inter-tussock sward.

2. SECOND-MOST SUCCESSFUL
Banks Peninsula fescue (*Festuca actae*)

Banks Peninsula fescue was the only other plug plant that performed reasonably well, second only to silver tussock.

» However, this grass is a smaller stature species and as such only 5% of 'mainly loess subsoil' grids achieved >50% cover by the end of the 2.5 year monitoring period.

» If this plant is to be used in loess cut faces it would need to be planted more closely than larger stature plants such as Poa cita, and/or consider the combined application of turf grasses as an inter-tussock sward.

3. LESS SUCCESSFUL
Cutty grass (*Carex geminata*)

The cutty grass (Carex geminata) sedge had variable performance, with some specimens of cutty grass surviving and spreading but cover still only reaching 25–50% cover category in 3% of 'mainly loess subsoil' grids.

» Whilst this cutty grass is not a successful plant for providing coverage of a cut loess face on its own, it may be worthy of including in a species mix to plant; if it survives it will be able to spread via rhizomes over time. It would likely benefit from being planted in the late spring/early summer in wetter sites (toe slopes) so that photosynthetic activity is winding up and thus the plant is better able to feed root growth, thereby enabling establishment.

4. UNSUCCESSFUL
Sedge (*Carex comans*)

The sedge *Carex comans* had the same level of coverage at the end of the monitoring period as the cutty grass, but the plants were less vigorous, and it is uncertain if they will continue to survive in the long-term.

- As this species had only been planted 12 months into the programme it has not had as long to establish on the face, but its current development indicates that it may not be successful in the long-term. There is, however, no good reason why it shouldn't perform well on dry slopes like this, other than establishment problems.
- It needs to be clarified that failure in this trial doesn't necessarily mean the species should be abandoned, but rather better establishment techniques are required, or a longer monitoring period to plot ongoing establishment.

5. UNSUCCESSFUL
Bracken fern (*Pteridium esculentum*) & Pig fern (*Hypolepis ambigua*)

The two ferns – bracken fern (*Pteridium esculentum*) and pig fern (*Hypolepis ambigua*) – were not successful in the 'mainly loess subsoil' grids.

- Most were dead by the end of the monitoring period and what little cover remained was in the 5–25% cover category.
- Both species die back in winter, and it is possible that the especially dry month following Round 3, combined with a natural winter dieback of live vegetation, may have negatively affected plant survival. However, even with all dead specimens being replaced after 12 months there was a similar level of mortality in the subsequent period.
- Thus, while these plants should theoretically provide good erosion control if they can become established, it may be difficult to establish them on loess cut faces.
- It may be relevant to try an alternative approach to planting, which would be the inclusion of spores in any sprayed hydromulch product. Some initial trials using fern gametophytes in a hydroseeding mix showed that the viability of gametophytes of NZ native ferns (specifically *Blechnum novae-zelandiae*, *Cyathea medullaris* and *Dicksonia squarrosa*) was retained during the macerating process of hydroseeding (Denton-Giles, 2006). However, large scale in vitro propagation of fern gametophytes would be needed to first optimise survival prior to being used in commercial hydroseeding (Denton-Giles, 2006). This will be very species-dependent as well as being dependent on the rainfall and/or soil moisture environment.

6. UNSUCCESSFUL NZ ice plant (*Disphyma australe*)

UNSUCESSFUL, BUT LIKLEY TO WORK IN THE ABSENCE OF GRAZING PESTS: The NZ ice plant (*Disphyma australe*) grew well in the initial months following planting but due to the persistent grazing by possums they were dead by the second monitoring round.

- Due to the unusually high numbers of possums in the CAP area and a lack of a concerted possum control programme in the park it was deemed unviable to replace the dead plants with new specimens. However, in areas where the possum population is under better control there is the potential for this plant to provide good coverage of a loess cut slope.
- To provide a more definitive answer however would require inclusion of this plant in another cut slope erosion control trial location.

Caught on camera! Evidence of the source of the ice plant killer being possums.

TABLE 5: Summary of results for performance of the plug plants. Data for 'mainly loess subsoil' grids only. Performance of each treatment is ranked for each column using ■ = best, ■ = second best, ■ = second worst, ■ = worst (colours apply to data within the dark blue border).

		GRASS		SEDGE		FERN		CREEPER
		Banks Peninsula fescue (*Festuca actae*)	Silver tussock (*Poa cita*)	Cutty grass (*Carex geminata*)	*Carex comans*	Bracken fern (*Pteridium esculentum*)	Pig fern (*Hypolepis ambigua*)	NZ ice plant (*Disphyma austral*)
% Cover	Final Round	5% of grids with >50% vegetation cover	30% of grids with >50% vegetation cover	3% of grids with 25–50% vegetation cover	3% of grids with 25–50% vegetation cover	3% of grids with 5–25% vegetation cover	5% of grids with 5–25% vegetation cover	100% dead after round 2
% Cover	Over Time	# rounds when 25–100% cover class present in >20% of grids: 1	# rounds when 25–100% cover class present in >20% of grids: 3	# rounds when 25–100% cover class present in >20% of grids: 0	# rounds when 25–100% cover class present in >20% of grids: 0	# rounds when 25–100% cover class present in >20% of grids: 0	# rounds when 25–100% cover class present in >20% of grids: 0	100% dead after round 2
Plant Vigour	Final Round	10% of grids with 'vigorous', & 49% 'active'	11% of grids with 'alive–rampant, 11% 'vigorous', & 65% 'active'	44% of grids with 'active'	3% of grids with 'alive-vigorous' & 6% 'active'	0% of grids with 'active' or greater	14% of grids with 'active' growth	100% dead after round 2
Plant Vigour	Over Time	# rounds with 'vigorous' growth: 4	# rounds with 'rampant growth: 2 # rounds with 'vigorous' growth: 5	# rounds with 'vigorous' growth: 2	# rounds with 'vigorous' growth: 1	# rounds with 'vigorous' growth: 0	# rounds with 'vigorous' growth: 3	100% dead after round 2
OVERALL RANK		SECOND–MOST SUCCESSFUL	MOST SUCCESSFUL	LESS SUCCESSFUL	UNSUCCESSFUL	UNSUCCESSFUL	UNSUCCESSFUL	UNSUCCESSFUL but could work in the absence of grazing pests

FIGURE 11: Stacked bar graph showing the PERCENTAGE COVER AND PLANT VIGOUR of each plug plant for grids that were classified as 'mainly loess subsoil'. Data is based on the proportion of grids that were classified as one of six cover or vigour categories, and is presented for each monitoring round, undertaken approximately 2, 5, 8, 11, 18 (1.5 years) and 30 months (2.5 years) after site setup. Note that *Carex comans* was planted to replace the dead ice plant (*Disphyma australe*) and dead specimens of *Carex geminata* and the two ferns replaced with new plants between the fourth and fifth monitoring rounds.

FIGURE 11: Continued.

Performance – Different Treatments for Facilitating Plug Plant Growth

In general, the three products containing rolled material ('wool', 'jute' and 'combo hydromulch & jute') seemed to provide somewhat better growing conditions for the growth of silver tussock and Banks Peninsula fescue, and to a lesser extent the 'wool' and 'jute' products seemed to provide marginally better conditions for cutty grass (Table 6). This is most likely due to the rolled products suppressing the growth of other plants and so reducing competition for the plug plants. However, it is possible that as the rolled products degrade and adventive species appear, that the increased competition may influence future growth of these plug plant species in those treatments. Alternatively, the size of the plug plants may now be sufficient in some of the grids to dominate over any adventive species that would appear with the degradation of the rolled products. This would most likely apply to the silver tussocks, which were considerably larger and shaded out much of the grid where their growth was greatest.

It is also evident that some time is required before plug plants begin to achieve any reasonable coverage, with a minimum of 18 to 30 months required before any significant change in growth occurs. This is not surprising given the harsh conditions of loess cut slopes, where plant growth would be limited by the lack of water and macro-nutrients and high sodium content. This also highlights the importance of longevity in monitoring programmes and in the vegetative approaches taken to stabilise loess cut faces.

TABLE 6: Summary of results for performance of the treatment types in terms of facilitating the growth of the plug plant species. Note that only the two most successful plug plant species are included in this table. Data is presented only for the 'mainly loess subsoil' grids. Performance of each treatment is ranked for each column using ☐ = best, ☐ = second best, ☐ = second worst, ☐ = worst (colours apply to data within the dark blue border).

	SPRAYED		ROLLED		COMBO
	Hydromulch + seed mix ('hydromulch mixed')	Hydromulch on organic base + seed mix ('hydromulch & base')	Coir fibre blanket ('rolled – jute')	Wool blanket ('rolled – wool')	Coir fibre blanket with Hydromulch + seed mix ('combo hydromulch & jute')
Total plug plant cover (final round)	0% of grids with >50% cover	2% of grids with >50% cover	7% of grids with >50% cover	14% of grids with >50% cover	7% of grids with >50% cover
Total plug plant vigour (final round)	0% of grids with 'vigorous' or 'rampant' growth	2% of grids with 'vigorous' or 'rampant' growth	7% of grids with 'vigorous' or 'rampant' growth	23% of grids with 'vigorous' or 'rampant' growth	0% of grids with 'vigorous' or 'rampant' growth
Silver tussock (*Poa cita*) – % cover (final round)	0% of grids with >50% cover	11% of grids with >50% cover	33% of grids with >50% cover	80% of grids with >50% cover	43% of grids with >50% cover
Silver tussock (*Poa cita*) – vigour (final round)	0% of grids with 'vigorous' or 'rampant' growth	0% of grids with 'vigorous' or 'rampant' growth	33% of grids with 'vigorous' or 'rampant' growth	80% of grids with 'vigorous' or 'rampant' growth	0% of grids with 'vigorous' or 'rampant' growth
Banks Peninsula fescue (*Festuca actae*) – % cover (final round)	0% of grids with >50% cover	0% of grids with >50% cover	10% of grids with >50% cover	17% of grids with >50% cover	0% of grids with >50% cover
Banks Peninsula fescue (*Festuca actae*) – vigour (final round)	0% of grids with 'vigorous' or 'rampant' growth	0% of grids with 'vigorous' or 'rampant' growth	10% of grids with 'vigorous' growth	50% of grids with 'vigorous' growth	0% of grids with 'vigorous' or 'rampant' growth
OVERALL RANK	**4**	**3**	**2**	**1**	**3**

7 Conclusion

Performance of treatments & plug plants

» The sprayed 'hydromulch & base' treatment provided the best erosion control both in terms of providing the greatest level of total vegetative cover and absence of erosion features by the end of the 2.5 year monitoring period, and in terms of establishing a high level of vegetation early in the monitoring period and maintaining this over time. The features that make this product suitable for establishing vegetation cover (particularly the applied grass seed species) and effective as an erosion control measure include the following:

  — A spray-on base layer consisting of a phyto-sanitised engineered soil medium, combined with a bio-stimulant and seed mix. This application is designed as a surrogate for topsoil - to accelerate the development of depleted substrates as vegetation establishes.

  — A spray-on phyto-sanitised flexible and pervious growth medium as the top layer consisting of 100% recycled and thermally refined wood fibres, with cross-linked biopolymers creating a biodegradable, erosion resistant matrix that allows for rapid germination and accelerated plant growth. The structure is a thick fibrous matrix of interlocking fibres that increases water and nutrient retention.

  — A high viscosity product that sticks to steep cut slopes during application, especially once dried.

  — A long-lasting product that retained physical coverage of the cut face for the duration of the 2.5 year monitoring period with little sign of loss of material integrity over that time.

» The use of grass seed in the 'hydromulch & base' product proved successful. Thus, the mix of species used in this study is recommended for use in mulch applications. Most species used are standard exotic sward grasses and one clover which would be expected to begin fixing nitrogen in a very nitrogen poor substrate. The one indigenous species in this mix is *Poa imbecilla*, which forms a fine turf that would be expected to provide a useful erosion control function in conjunction with the other species. Given the stressed nature of the environment it will persist without the extreme competition from a more benign substrate. Some further attention should be given to the potential of this native grass. In addition, if it was possible to propagate seed for the native plume grass (*Dichelachne crinita*) this could be a potential additional candidate for seed for cover crop mixes.

» Because the 'hydromulch & base' treatment was so successful in supporting growth of the seed mix and other adventive species, there was increased competition for the plug plant species used. Thus, if plug plant species were to be used it would be best to limit this to larger stature grasses such as the native grass silver tussock. We note that the current duration of the monitoring programme (i.e., 2.5 years) is not sufficient to confidently determine if the grass seed cover alone is enough to provide longer term erosion control of the cut face, or whether it is worth also applying plug plant species to increase substantial vegetative cover in the medium-long term.

» The rolled product 'wool' provided the next best erosion control in terms of an absence of erosion features by the end of the 2.5 year monitoring period, and in terms of providing better growing conditions for plug plant species. However, it was less successful in providing full vegetative cover due to the inherent weed suppressant capabilities of a rolled product. The features that make this product suitable for providing better growing conditions for plug plants and in retaining coverage of the cut face include the following:
    - A thick (500 gsm weight, approximately 5 mm thick) rolled fabric that can absorb up to three times its weight in water, and thus retain moisture.
    - A sufficiently thick and interwoven product that is not susceptible to ripping from the tracking of animals down the cut face.
    - A product made of natural wool fibres that can take up to 36 months before degrading.

» Whilst the rolled 'wool' product had not substantially degraded by the end of the 2.5 year (30 month) monitoring period there were signs of initial product degradation. Thus, the performance of this rolled product in providing longer term erosion control is in question. Further monitoring would be required.

» Use of a rolled product on cut faces is only worth considering if the face is also planted with plug plant species – to provide vegetative coverage of the face to replace the rolled product once it has degraded.

» This study has shown that plug plant species most able to grow in loess cut faces include the native grass silver tussock, and the Banks Peninsula fescue. The NZ ice plant also showed promising results but would only be suitable to use in areas where there are not high numbers of possums present that would otherwise graze the ice plant to death.
    - Failure of individual plant species in the trial should not be taken to mean that they may not still have some potential, but rather that the establishment technique may need to be revised. In particular, species that are summer green or have special requirements of soil moisture must be planted in a very specific seasonal window. Since the establishment of this trial was time constrained it was not possible to necessarily plant individual species at their optimum season.

Other Features Required to Stabilise Cut Faces

A key conclusion of this study is that is it vital to have a spatially integrated approach to the management of loess cut slopes that also includes overarching features to incorporate above, below, and on the cut face (Figure 12). Without an integrated approach to help stabilise the cut face and redirect water flow away from the cut face, the implementation of any interventions on the cut face itself are unlikely to be as successful. Throughout the monitoring period there was evidence of significant erosion and destabilisation of cut faces outside of the study site, whilst the cut face of the study site itself had very little sediment runoff into the water table (Figure 13). This demonstrates that the general sitewide interventions (horizontal 'scarifying' of the cut face, diversion pipes to stop overland flow down the cut faces, rock toe to stabilise slope, planting above cut faces and in the rock toe, as well as the products and plants that are being trialled on the cut face itself), all worked to reduce sediment runoff. It shows how critically important it is to also incorporate these sitewide features into any roadside cutting.

These features shown in Figure 12, including:

1. Horizontal 'scarifying' of the cut face prior to the application of any products or planting, to help interrupt the surface flow of water on the cut face.
2. Inclusion of a planted rock toe (or other form of hard buttress) as it provides multiple benefits, from stabilising the cut face through the formation of a buttressed toe, providing a bench where sediment that may come from the cut face can be trapped, and providing a hard edge to prevent over-excavation of the base of the cut slope.
   - The rock toe not only serves to help stabilise the cut face and reduce the chance of maintenance crews cutting into the toe of the slope (and thereby increasing the angle of the cut face) but also serves to retain sediment during rain events as well as during collapse of a cut face (Figure 14). Such rock toe features thereby also give maintenance crews the time needed to get to site to remove accumulated sediment before it has a chance to enter the water table and nearby receiving environments.
   - This study has shown that species suitable for planting in the rock toe include the rushes *Juncus sarophorus* and *Juncus edgareae*, and the sedges *Ficinia nodosa* and *Carex virgata.* It is likely that cutty grass *Carex geminata* would also work well here if planted in late spring/early summer when young leaf growth was flushing.
3. Inclusion of cut off drains/diversion channels and planting above the cut face to redirect as much surface flow as possible away from the cut face. Any water that can form concentrated flows down a loess cut face will contribute significantly to destabilisation of the cut face.
   - This study has shown that species suitable for planting in the slope above the cut face include the native shrubs *Coprosma crassifolia*, *C. propinqua* and *C. virescens*, NZ flax (*Phormium tenax*), toetoe (*Austroderia richardii*) and cabbage tree (*Cordyline australis*). However, the latter two (and indeed most plants) are susceptible to some (broad spectrum) sprays and so this needs to be considered during maintenance in the establishment phase.
   - The scrambling *Muehlenbeckia complexa* is also a suitable species to plant just above the cut face to gradually trail down over the face. The NZ ice plant (*Disphyma australe*) is another species that could be used in this fashion, although only in areas where possum numbers are not high. Other small browsing mammals may also pose a threat to such revegetation projects.
4. Control of browsing pests such as possums in the wider area that could impact on the survival of plants used on or around the cut face. This will have other significant biodiversity benefits.
5. Wider catchment management to control and prevent further deep erosion features (i.e., tunnel gullies and slips that originate above any cut face), which are not able to be controlled through any measures applied on the cut face.

FIGURE 12: For a spatially integrated approach to the management of loess cut slopes, these are the other key features (in addition to the cut face treatments) that are needed to stabalise a cut face.

Sediment in the water table for the study site that has come from the diversion flume that takes water from a cut face above the study site.

Evidence of erosion and loess runoff from cut faces and track above the study site.

The water table for the study site upgradient of the diversion flume pictured above, showing that little sediment sourced from the study site itself has made it to the water table.

Figure 13: Photos illustrating sediment runoff from other cut faces near the Cut Slope Soil Erosion Control Trial site at the Christchurch Adventure Park, compared to minimal signs of sediment runoff from the experimental plots. Much of the sediment runoff that did come from the trial site was trapped behind the rock toe slope and thus was kept out of the water table, as illustrated in Figure 14.

The rock toe in January 2021 showing the established vegetation that is also helping to trap any sediment that does come off the cut face.

The rock toe in August 2019 showing sediment runoff from Plot 9 (control/no product) being trapped on the rock toe.

Plot 9 in July 2020 following a slip, showing how the sediment from the slip was retained on the rock toe and kept out of the water table until the material was able to be removed.

Figure 14: Photos illustrating the benefit of having a short flat slope and rock toe at the base of a cut face, as it acts to trap sediment before it can reach the water table.

Monitoring soil erosion onsite before planting.

8 Recommendations

The following are key recommendations for the next phase of this programme:

- This study was originally intended to run for five years to determine the best strategies for meaningful erosion control (McMurtrie *et al.*, 2018). The shorter (2.5 year) duration of the current study has not provided sufficient time to track the degradation of the applied products or the growth and survival of vegetation on the cut face. We strongly recommend that the original intention of the monitoring programme be realised to make the most of the investment of the site setup, and to gain as much data and knowledge as possible, thereby gaining valuable and currently unknown insight into erosion control. Based on how long it is taking for some of the plug plants to grow in stature we would recommend that the cut face continue to be monitored annually for 2022, 2023 and 2025 and then again in 2030. Site inspections should be undertaken in intervening times, including after storm events.
- This study was originally intended to be undertaken at four sites around Christchurch and Banks Peninsula on cut slopes. One of the dangers with relying on just this one site is that the results are specific to the environmental conditions at this site. The trial site is only representative of relatively shady, moist, lower footslopes. Ideally all major aspects, or at least a contrasting sunny, dry northerly aspect site, should also be trialled. Having the study implemented at other locations will increase the breadth of environmental conditions covered and thus increase the relevance of the findings to a much wider sphere. Learnings from this current study can also be implemented to streamline the monitoring programme; given the time it takes for vegetation to become established we would recommend that monitoring be undertaken at 2 months, and then every 12 months thereafter. A monitoring round prior to the application of products will also be required to characterise the underlying soil characteristics.
- Implementing this programme at other sites will also provide for the ability to refine the products and plants to be tested. We would recommend that other forms of hydromulch be tested, including compost applied by pneumatic blower. This was originally intended to be included in this current study, but the product supplier was unable to access the site with their machinery. We would also recommend that the NZ ice plant is trialled at another site where possum numbers as not as high as they are in the Christchurch Adventure Park. The potential for adding fern gametophytes in a hydroseeding mix could also be investigated.

9 Further Reading

The full findings of this study can be found in McMurtrie *et al*. (2022).

» McMurtrie, S., James, A., Lyn, I., Meurk, C. & Simcock, R. 2022. Cut slope soil erosion control trial CAP Site 1: Year 3 monitoring report. EOS Ecology Report No. CHR01-20077-02. 84 p.

10 References

Adamson, T. & McMurtrie, S. 2016. Erosion and sediment control pilot project on Lyttelton Harbour/Whakaraupō road-side cuttings. EOS Ecology report No. ENV01-16116. EOS Ecology, Christchurch. 42 p.

Denton-Giles, M. 2006. Reproduction in selected New Zealand native ferns and their suitability for revegetation. Unpublished MSc thesis, Massey University. 125 p.

Hughes P. 1970. Tunnel gully erosion in loess of Banks Peninsula. MSc Thesis, University of Canterbury.

McMurtrie, S., Keay, W., Lynn, I., Simcock, R. & Meurk, C. 2018. Whakaraupō roadside cuttings: Methods for testing treatment options. EOS Ecology, Christchurch. EOS Ecology Report No. ENV01-16164-01. 81 p.

McMurtrie, S., James, A., Lyn, I., Meurk, C. & Simcock, R. 2022. Cut slope soil erosion control trial CAP Site 1: Year 3 monitoring report. EOS Ecology Report No. CHR01-20077-02. 84 p.

11 Appendices

APPENDIX I: Product Information

TABLE 7: Details of the products applied to the cut face of the Cut Slope Soil Erosion Control Trial site at the Christchurch Adventure Park.

	SPRAYED	
	Hydromulch + seed mix ('hydromulch mixed')	Hydromulch on organic base + seed mix ('hydromulch & base')
Product Type	Hydromulch mixed– bonded wood fibre matrix pre-mixed with nutrient-infused stabilising polymer	Hydromulch & base – wood fibres applied over a base of organic material
Product Name	VE Gro-Matt & Vital Polykelp	Top layer: Flexterra® HP-FGM with Proganics; Base layer: Proganics BSM & Trichoflow Pro WP mixed together
Key Features	100% recycled heat-treated wood fibres pre-mixed with seed and a nutrient-infused stabilising polymer to form a bonded fibre matrix (BFM). Has a flexible surface allowing for vegetation growth, and which holds up to 15 times its weight in water. Contains a rainfast biodegradable polymer mix that is proven to effectively stabilise soil. Provides water diversion and rain impact erosion from surface and will not remobilise. Non-hazardous to the environment (certified) and bio-contaminant free. Is applied with seed pre-mixed in it. Seed includes: *Poa imbecilla*, *Festuca rubra* var. *rubra*, *Agrostis capillaris*, *Trifolium pratense*.	Mulch (FGM – Flexible Growth Medium) and Organic Material (BSM – Biotic Soil Media) with a bio-stimulant incorporated. The FGM is 100% biodegradable. However, the biochar component of the BSM product is resistant to decomposing meaning the BSM is not 100% biodegradable. The bio-stimulant is a biological formulation that contains strains of Trichoderma Atroviride shown to support fast establishment of seed. Mulch/FGM made up of 80% thermally processed wood fibres (heated under pressure for 5mins), 10% wetting agents, 5% biodegradable interlocking fibres and 5% micro-pore granules to increase water and nutrient retention. Organic material/BSM made up of 89% thermally processed organic fibres, 11% blend of high viscosity nutrient media. Spray on products used had been tested for biodegradability (Test method: ASTM D5338) and ecotoxicity (Test Method: EPA 2021.0). Long lasting, up to 18 months (functional longevity). Improves vegetation establishment by up to 800%, with the FGM having 1700% and the BSM having 900% water holding capacity. The FGM is designed to limit erosion and performs well on steep slopes. Is applied with seed pre-mixed in it. Seed includes: *Poa imbecilla*, *Festuca rubra* var. *rubra*, *Agrostis capillaris*, *Trifolium pratense*.
Additional information	This is a combination of two different products that are pre-mixed and applied with seed. One product (Vital Polykelp) is designed to stabilise the soil with a polymer and add organic mass, while the other (VE Gro-Matt) is used to assist with stabilisation whilst creating and maintaining good growing conditions to support long-term vegetation growth. This combination is cost-effective and is applied to surfaces hydraulically. Over time the wood fibre naturally breaks down to further increase the organic soil content promoting sustained growth.	The BSM is applied as an alternative to topsoil, and the FGM is applied as hydraulically applied erosion control. 1) a spray on organic layer with the bio-stimulant mixed into the slurry prior to application 2) a wood-fibre based surface product (also sprayed on). This will be embedded with seed.
Product supplier for use in this study	Vital Industries	PGG Wrightson Turf

TABLE 7: Continued.

	ROLLED		COMBO
	Coir fibre blanket ('rolled – jute')	Wool blanket ('rolled – wool')	Coir fibre blanket with Hydromulch + seed mix ('combo hydromulch & jute')
Product Type	Coir fibre blanket - biodegradable blanket (450 gsm)	Wool Blanket - Rolled wool-based blanket (500 gsm)	Combination hydromulch base with Coconut fibre blanket
Product Name	Geofabrics JuteMat 650 and metal ground staples that are 230 mm in length with a 2 mm diameter between the two legs.	Terra Mulch and metal ground staples that are 230 mm in length with a 2 mm diameter between the two legs.	Base layer: ProMatrix / Top layer: Biomac CJ450
Key Features	A heavy weight (650g/m^2) natural jute fibre blanket that is a medium term (2 to 3 years) method for controlling soil erosion and aiding plant establishment. The product is a dense but flexible mat of needle punched natural jute fibres which have high tensile strength and low extensibility. The mat provides protection against weather extremes (rain, wind and sun) for the surface whilst holding moisture and preventing water run off form the surface. Provides insulation for soil and roots of planted out vegetation while inhibiting weeds and protecting the soil between plants.	A rolled product made of natural wool fibres, needle-punched to a weight of 500 gsm (approx. 5 mm thick), with or without a 100 gsm jute reinforcing. The product is pinned to the surface using 100% biodegradable sugar-based resin pins of 150 mm length. Capable of absorbing and holding up to 3 times its weight in water. The product ensures an approximate 50% reduction in weed growth. Fully natural product that will biodegrade in 18–36 months, depending on ground conditions.	Base layer: ProMatrix is an Engineered Fibre Matrix (EFM) that is 100% biodegradable. Made up of 100% recycled thermally refined wood fibres, crimped interlocking biodegradable fibres, mineral activators and wetting agents (including high-viscosity colloidal polysaccharides, cross-linked biopolymers and water absorbents. The base layer is applied with seed pre-mixed in it. Seed includes: *Poa imbecilla, Festuca rubra* var. *rubra*, *Agrostis capillaris, Trifolium pratense*. Top layer: Biomac CJ450 is a fully biodegradable coir erosion control blanket reinforced with fully biodegradable jute mesh containing no plastic. Provides initial erosion protection to seed and young plants from the extremes of rain, wind and sun during the critical germination and development stage.
Additional information	Product comes in 2.4 m wide rolls that are 25 m long. The product is then secured to the face with ground staples. For steep slopes (over 45 deg or 1:2), a frequent pinning regime is required (every 1 m vertically and 1 m horizontally) to ensure the product does not overstretch and lose functionality.	Comes in 1.8 m wide rolls that are 30 m long. Rolled product is secured to the face with ground staples that are pinned at 0.5 m centres along joins and outer perimeter and at 1 m spacings in the middle.	Base layer: When cured forms an intimate bond with the soil surface to create a continuous, porous, absorbent and flexible erosion resistant blanket that allows for rapid germination and accelerated plant growth. Performs as a Bonded Fibre Matrix (BFM) product and may require 4–24 hour curing period for maximum performance. Top layer: Biomac CJ450 is laid on prepared slopes which are normally pre seeded. Biomac CJ can also be used on slopes which are planted out. Steel staples or Biopegs are used to hold down Biomac CJ and maintain good intimate contact with the soil.
Product supplier for use in this study	Geofabrics New Zealand Ltd	Terra Lana Products Ltd	Geofabrics New Zealand Ltd

APPENDIX 2: Plot Photographs

TABLE 8: Plot photographs – ROUND 1 (2 months after site setup) and Round 6 (30 months or 2.5 years after site setup).

CONTROL No product					
ROUND 1: TWO MONTHS AFTER SITE SETUP			**ROUND 6:** 30 MONTHS (2.5 YEARS) AFTER SITE SETUP		
					
Plot 9 (92% loess grids, 8% soil grids) Plot is dominated by loess	**Plot 13** (75% loess grids, 25% soil grids) Plot is dominated by loess	**Plot 18** (87.5% loess grids, 12.5% soil grids) Plot is dominated by loess	**Plot 9** (92% loess grids, 8% soil grids) Plot is dominated by loess	**Plot 13** (75% loess grids, 25% soil grids) Plot is dominated by loess	**Plot 18** (87.5% loess grids, 12.5% soil grids) Plot is dominated by loess

TABLE 8: Continued...

SPRAYED					
Hydromulch + seed mix ('hydromulch mixed')					
ROUND 1: TWO MONTHS AFTER SITE SETUP			**ROUND 6:** 30 MONTHS (2.5 YEARS) AFTER SITE SETUP		
					
Plot 3 (79% loess grids, 21% soil grids) Plot is dominated by loess	**Plot 11** (71% loess grids, 29% soil grids) Plot is dominated by loess	**Plot 14** (50% loess grids, 50% soil grids) Plot is 50/50 loess & soil	**Plot 3** (79% loess grids, 21% soil grids) Plot is dominated by loess	**Plot 11** (71% loess grids, 29% soil grids) Plot is dominated by loess	**Plot 14** (50% loess grids, 50% soil grids) Plot is 50/50 loess & soil

TABLE 8: Continued...

SPRAYED					
Hydromulch on organic base + seed mix ('hydromulch & base')					
ROUND 1: TWO MONTHS AFTER SITE SETUP			**ROUND 6:** 30 MONTHS (2.5 YEARS) AFTER SITE SETUP		
					
Plot 5 (54% loess grids, 46% soil grids) Plot is close to 50/50 loess & soil	**Plot 12** (79% loess grids, 21% soil grids) Plot is dominated by loess	**Plot 15** (71% loess grids, 29% soil grids) Plot is dominated by loess	**Plot 5** (54% loess grids, 46% soil grids) Plot is close to 50/50 loess & soil	**Plot 12** (79% loess grids, 21% soil grids) Plot is dominated by loess	**Plot 15** (71% loess grids, 29% soil grids) Plot is dominated by loess

TABLE 8: Continued...

ROLLED					
Coir fibre blanket ('rolled – jute')					
ROUND 1: TWO MONTHS AFTER SITE SETUP			**ROUND 6:** 30 MONTHS (2.5 YEARS) AFTER SITE SETUP		
					
Plot 2 87.5% loess grids, 12.5% soil grids) Plot is dominated by loess	**Plot 8** (79% loess grids, 21% soil grids) Plot is dominated by loess	**Plot 16** (75% loess grids, 25% soil grids) Plot is dominated by loess	**Plot 2** (87.5% loess grids, 12.5% soil grids) Plot is dominated by loess	**Plot 8** (79% loess grids, 21% soil grids) Plot is dominated by loess	**Plot 16** (75% loess grids, 25% soil grids) Plot is dominated by loess

TABLE 8: Continued...

ROLLED					
Wool blanket ('rolled – wool')					
ROUND 1: TWO MONTHS AFTER SITE SETUP			**ROUND 6:** 30 MONTHS (2.5 YEARS) AFTER SITE SETUP		
					
Plot 1 (75% loess grids, 25% soil grids) Plot is dominated by loess	**Plot 7** (4% loess grids, 96% soil grids) Plot is dominated by soil	**Plot 17** (67% loess grids, 33% soil grids) Plot is dominated by loess	**Plot 1** (75% loess grids, 25% soil grids) Plot is dominated by loess	**Plot 7** (4% loess grids, 96% soil grids) Plot is dominated by soil	**Plot 17** (67% loess grids, 33% soil grids) Plot is dominated by loess

TABLE 8: Continued...

COMBO					
Coir fibre blanket with Hydromulch + seed mix ('combo hydromulch & jute')					
ROUND 1: TWO MONTHS AFTER SITE SETUP			**ROUND 6:** 30 MONTHS (2.5 YEARS) AFTER SITE SETUP		
					
Plot 6 (29% loess grids, 71% soil grids) Plot is dominated by soil	**Plot 10** (87.5% loess grids, 12.5% soil grids) Plot is dominated by loess	**Plot 19** (54% loess grids, 46% soil grids) Plot is close to 50/50 loess & soil	**Plot 6** (29% loess grids, 71% soil grids) Plot is dominated by soil	**Plot 10** (87.5% loess grids, 12.5% soil grids) Plot is dominated by loess	**Plot 19** (54% loess grids, 46% soil grids) Plot is close to 50/50 loess & soil

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