EVALUATION OF THE PHSICO-CHEMICAL STABILISATION OF THE BERM & BATTER SLOPES OF A CHANNEL IN NORTHERN VICTORIA.

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Abstract

Road authorities throughout Australia are responsible for maintaining the stability of relatively steep embankments and cuttings in earth. The process of stabilisation is easier during construction but much more difficult on existing degraded long and wide banks where access is difficult and safe working practice can be compromised. Similar problems are encountered by water authorities seeking to stabilise degraded channel banks and earthen dam embankments, particularly if the exposed earth is dispersive, the surface irregular and rilling is pronounced. Conventional approaches for remediation of such sites include reconstruction, the placement of earthen patches and the reduction of batter slopes. Geosynthetic shrouds, wire reinforcement and revegetation as well as the spreading of organic matter and hydro-mulching are also used for slope protection with varying rates of success. Mined gypsum can be applied to batters and berms to render dispersive soil non-dispersive if the slope can be safely accessed to facilitate spreading and soil incorporation. This method of soil improvement is commonly used in agriculture for soil improvement and revegetation but it is not common in engineering practice where hydrated lime is the preferred ameliorant. Unfortunately hydrated lime stabilised soil is not ideal as plant growth media.

An alternate technique for soil stabilisation using soil physical and chemical amelioration has been carried out on a section of earthen channel formed in dispersive soil. This channel is maintained by Goulburn Murray Water. The channel is 1.5 kilometres in length and is incised into a dark grey Sodosol soil. The berm and batter slope lengths are 5 and 10 metres respectively and both sides of the channel were subject to treatment. The berms and batters had suffered from rill erosion and tunnelling was evident in parts of slope below the berm where imperfect drainage has led to surface ponding. Some sections of the channel evincing tunnelling had been subject to patch repairs using an excavator and the incorporation of mined gypsum with placed soil.

This project sought to control rilling along the full length of the channel batter and to stabilise the section of berm adjoining the batter. Stabilisation was also needed to promote the growth of plants as a means of protecting the exposed soil surface. Investigations confirmed that the soils were dispersive, with Emerson dispersion class 1 and 2 and Exchangeable Sodium Percentages of up to 12 recorded on exposed surfaces. The remediation process included physical disturbance using custom built harrows able to work on the slope and chemical amelioration using liquid gypsum. Harrowing was found to create a scabbled surface on the berm and batter, with nooks and crannies created at right angles to the slope. This assisted the lodgement and covering of seed and created a tortuous surface to disperse water flowing down the slope. Liquid gypsum application created a flocculated surface, exhibiting a high level of crazing. The level of dispersion on the soil surface was significantly reduced or eliminated as a result of the treatment. Laboratory soil tests show that the conductivity level of the soils had increased after treatment whilst the ESP level of soil samples from the berm had decreased to 4 rendering the soil surface non-sodic and non-dispersive. The soil had become soft under foot as a result of the treatment.

The effect of the treatment was found to be shallow to a depth of 20-50mm. This is the effective root depth of many grass species on similar soil. This process has been effective at achieving soil stability and improving plant growth media at a relatively low cost. Plant colonisation, root development and decomposition of organic matter will provide slope protection and these processes are taking effect. In order to take advantage of a window of opportunity Goulburn Murray Water hydro mulched the surface rather than wait for a plant response in spring from rainfall under natural conditions.

EVALUATION OF THE PHYSIO-CHEMICAL STABILISATION OF THE BERM & BATTER SLOPES OF A CHANNEL IN NORTHERN VICTORIA.

Wrigley & Bannan.

1. Introduction

The behaviour of sodic and dispersive soils limits their utility for earthen structures and particularly for embankment construction. Because these types of soil are commonly encountered in engineering practice and the risk of structural failure associated with their employment is high (Moore, Wrigley and Styles, 1985) prospects for improving the soil properties needs to be understood. Remediation can involve physical, chemical and biological amendment (Ingles and Metcalf, 1972; Lee, 1974 and Hausman, 1990). Conventional practice for embankment construction is to rely on soil densification by mechanical compaction (Hausman, 1990) and to employ surface and subsurface drainage systems for moisture control. Geosynthetic systems are also commonly used for filtration, drainage and seepage control (Koerner, 1986) and like compaction the risk of failure is reduced.

Admixtures can be mixed with soil to improve physico-chemical characteristics for embankment construction. Mixing agents include cement, agricultural lime, hydrated lime, calcium chloride, fly ash, bitumen, gypsum and polyacrylamide (Burrow, Hughes, Surapaneni and Wrigley, 2002). These agents are generally intended to improve geotechnical properties but they have limited value for improving agronomic characteristics. Admixtures which yield this outcome are generally restricted to agricultural lime and gypsum.

Biological amendment of soil is very common to improve agronomic properties but not geotechnical properties. Techniques of soil reinforcement which use mulches, trees, grasses, understory plants and ground cover are in widespread use for geotechnical stabilisation but they are restricted to surface protection of earthen structures. Organic amendments can be incorporated with soil to assist this reinforcement role as well as to enhance agronomic properties. Typical additives include garden mulch, pine bark, manure and bio-solids. Even enzymes are claimed to improve soil cohesion and sealing but they are mainly used on dirt roads.

Soil amendment is much easier when applied to the construction of new earthen structures and the remediation of existing structures is limited by their dimensions and configuration, accessibility, safety concerns and the need to disturb a settled surface which could exacerbate the risk of failure. Given the existence of many old and deteriorated banks formed with sodic and dispersive soil which need stabilisation, this paper presents a practical solution to improve bank stability and remediation of dispersive and sodic soil using established agronomic methods.

2. Project Background

The site is the old Mokoan outlet channel located 10 kilometres north of Benalla in north-east Victoria. The channel once passed spillway flows from Lake Mokoan and into the Broken River via the Stockyard Creek. Since the decommissioning of Lake Mokoan in 2009 water is supplied to irrigators by sending a backflow up the channel from the Broken River to the spillway wall. Construction of the lake and outlet channel was completed in 1971.

The outlet channel has a batter length of approximately 10 metres incised into natural ground with a slope grade of 3:1. The total length of the section of amended channel is 1.6 kilometres. This section of channel suffers from rill and tunnel erosion as a result of raindrop impact, rainfall runoff, drainage outfalls and channel water level surges which dislodged sodic and dispersive soil which is gravity assisted to move downslope. Large cavities caused by tunnelling on the berm created occupational health and safety issues for Goulburn Murray Water (GMW), the water authority managing the infrastructure. Rilling has also caused soil deposition and silting on the floor of the channel. Some sections of marked tunnel erosion were amended by excavating soil from the eroded section, mixing gypsum into the soil, wetting and compacting using the boom on an excavator.

This project sought to address the rill erosion along both sides of the channel. Site investigations revealed that most of the rills varied in depth from 50-300mm. It was also proposed based in investigations that the use of harrows in conjunction with a soil stabilising agent would provide nooks and crannies to slow the flow of water, spread seed and allow seed lodgement while maintaining soil stability. This avoided excessive cultivation, ripping or mixing which may lead to mass soil loss and risk of failure upon heavy rainfall.

Investigations into the use of prilled gypsum were initially conducted for remediation of the soils. Comprehensive agronomic soil testing revealed high levels of exchangeable sodium (sodic) and high exchangeable magnesium (magnesic) indicating that the soils should be gypsum responsive. Gypsum computations revealed that rates of 7-15 t/ha were required to raise calcium levels and displace sodium and magnesium assuming that 100mm of soil is treated. After discussions surrounding safety issues with application of mined gypsum on the batter, the need for machinery to access the batter, the need to mix gypsum into the soil to improve soil flocculation and the need to modify spreading equipment, it was agreed that an alternate option which avoids trafficking the slope must be explored. The use of liquid gypsum and harrows was developed by the investigators based on experience with other agronomic and geotechnical applications to provide a shallow but uniform soil treatment and eliminate the need to traverse the batter using machinery.

3. Soil Sodicity

Sodic soils are defined in Australia as having an Exchangeable Sodium Percentage (ESP) of 6 or greater and/or their sodium adsorption ratio (SAR) in the 1:5 soil:water extract is >3. Sodic soils contain a high amount of sodium adsorbed to clay particles in relation to other cations including calcium, magnesium and potassium. Sodium is a single charged cation which is adsorbed to one negatively charged exchange site on a single clay particle. Sodic soils swell and disperse upon wetting due to a lack of cohesion caused by instability from excess sodium. Upon drying, detached particles block soil pores and cause clogging, better observed as surface crusting. Sodicity symptoms include poor water infiltration and drainage (resulting in water-logging and increased runoff), poor water holding capacity, surface sealing, poor emergence of crops and pastures, problems with cultivation and erosion. Where sodic or dispersive soils occur on sloping sites rill erosion is a threat because water moves down the slope and conveys soil particles and peds as well as assisting the dislodgement of large soil chunks which are moved downslope by gravity.

In Victoria two types of sodicity occur;

1. **Inherent sodicity.** This results from leaching of salts from saline soils or soils that have inflated sodium levels. This is naturally occurring and follows a pattern coinciding with soil type and landform.

2. **Induced sodicity.** This results from the use of high sodium irrigation water (wastewater and groundwater), application of products high in sodium or as a result of sodic subsoil clay being brought to the surface by water table rise from over irrigation, or subsoil clay exposure from topsoil stripping, land forming, over exuberant ploughing and poor soil restoration following earthworks.

Induced sodicity develops when salts (exchangeable NaCl) in a saline soil are leached through the exchange complex over a long period (up to 100 years). As salt is naturally leached through the soil it leaves sodium ions, displacing cations such as calcium and magnesium creating a rise in exchangeable sodium in the upper profile. Induced sodicity can occur when wastewater or ground water with high levels of sodium is applied to land on soils with low leaching fractions, causing sodium to accumulate in the upper profile or when water tables rise or water-logging causes suspended sodium to remain in the upper profile after evaporation or transpiration loss has occurred.

Emerson (1967) developed the aggregate test to identify the presence of a dispersive soil. Although there is not a perfect correlation between the presence of a dispersive soil and a sodic soil, most soils which record Emerson class 1 or 2 (dispersive samples) show sodic or inflated levels of sodium, equivalent or greater than a sodic soil ESP of 6% or greater).

Dispersive and sodic soils are commonly assessed and treated in agricultural practice however these issues are rarely benchmarked in geotechnical practice. Most soils which are tested as sodic on agricultural lands are treated with varying levels of gypsum (CaSO4) to provide an abundance of calcium in relation to other cations. The double charged calcium ion is adsorbed onto negatively charged clay exchange sites and causes displacement of other cations including sodium and magnesium.

Amelioration of soils for geotechnical use using gypsum or other calcium ameliorants works in the same fashion as treatment for agricultural practice. If soils are mechanically compacted for geotechnical use but remain dispersive due to reactivity with fresh water, the soil has a likely chance of structural failure at some point of time. The level of failure can be minor (surface related) to significant where the integrity of a structure is compromised. There are risks associated with use of dispersive and sodic soils when used for the construction of embankments for dams, reservoirs and channel embankments as well as roads. Where road cuttings exist there is a risk of poor surface stability, surface soil loss, rill and tunnel erosion and landslip where dispersive soil layers exist throughout the soil profile in the road cutting.

4. Dispersion

Soil dispersion relates to the suspension of clay particles in water upon wetting. Dispersive soils are identified using the Emerson Aggregate Test (Emerson, 1967; Charman and Murphy, 2000). Emerson class 1 (complete dispersion) and class 2 (some dispersion) usually correspond with sodic conditions. Emerson class 3 soils do not disperse after initial wetting of dry aggregates but show dispersion after remoulding under moist conditions. The methodology used for determination of a dispersive soil is outlined in Figure 1.

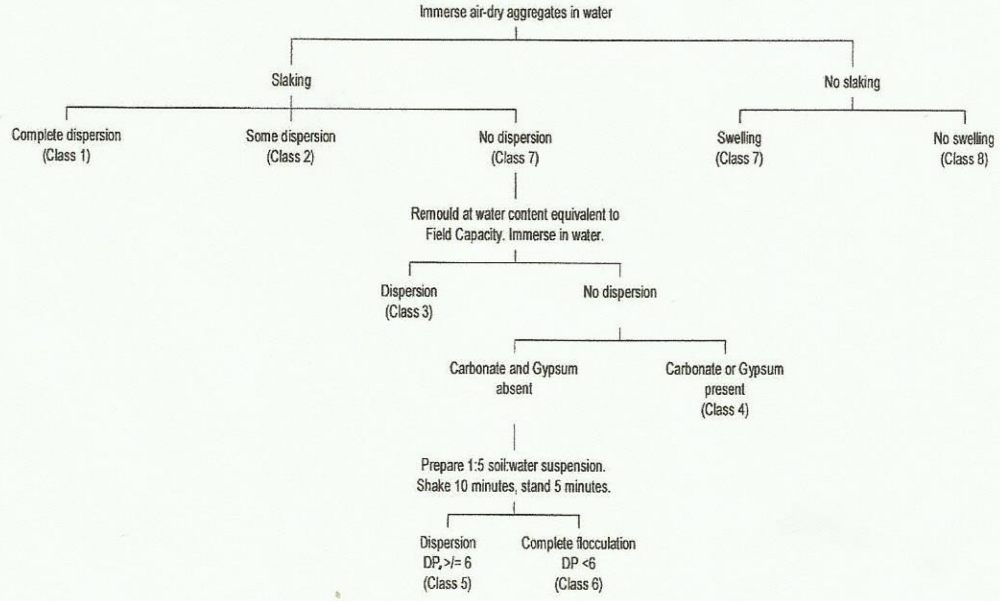

Figure 1. Emerson Aggregate Test (Emerson, 1967).

Emerson class 1, 2 and 3 soils are important to identify for geotechnical use. Wetting soils to a level of moisture slightly above the optimal moisture content enhances the soils ability to disperse during construction and promotes clogging and sealing. Under adequate levels of compaction these soils can be used successfully for geotechnical purposes. Where dispersive and sodic soils lack compaction or become exposed without vegetative cover, clay dispersion results in rill and tunnel erosion. Sherard and Decker (1977) provides information on the significance of dispersive soils in the performance of earthen structures.

A state of dispersion creates poor soil physical conditions including:

1. **Low hydraulic conductivity** in clay dominant soils, due to blockage of pores by dispersed colloids. This results in the formation of a shallow subsurface pan, limiting root development and drainage;

2. **Unfavourable soil consistency**. Soils are hard when dry and plastic-sticky when moist. Such soils are difficult to work and provide low resistance to slaking, which contributes to the formation of surface crusts. Soil infiltration is reduced and the mechanical strength of crusted soil is likely to hinder seed germination and plant growth;

3. **Waterlogging**, resulting from the presence of a shallow clay pan and the general deterioration of soil drainage characteristics. Care should be taken in relating poor drainage to high ESP only, as poorly drained soils may also exhibit soil salinity problems.

4. **High erodibility potential** exacerbated by lack of surface protection by vegetation and slope.

Dispersion is also aided by the low salinity level of rainfall and runoff. The presence of elevated electrolyte levels in some surface waters, groundwater and wastewater will limit soil dispersion.

5. Techniques for Stabilisation of Sodic or Dispersive Soils.

Soil stabilisation techniques commonly used in engineering practice include:

1. **Mechanical stabilisation.** This is achieved by compaction to the maximum density possible at optimal moisture content. This process reduces soil permeability and assists in maintaining constant soil moisture levels. Mechanical compaction does not provide surface protection upon wetting or protection from soil dispersion. The exposed surface of a mechanically compacted soil will erode if dispersive particularly when there is a lack of vegetative cover. Compacted soils also provide aggressive soil conditions which are not conducive to plant growth.

2. **Biological stabilisation.** Use of organic matter and other organic products to provide a physical buffer on the soil surface. This protects the soil from rainfall impact and the physio-chemical interaction between organic matter and dispersive soil can limit the level of dispersion. Hydro-mulching is a common form of biological stabilisation which has varying degrees of success depending on a soils dispersive character and condition before and after the application.

3. **Chemical stabilisation.** Use of polyacrylamides, agricultural lime, hydrated lime, gypsum, cement, enzymes, sulphate lignin conditioners, sulphuric acid or elemental sulphur.

Conventional geotechnical practice favours physical amendment by mechanical compaction as well as use of some biological stabilisation. Chemical stabilisation methods are less common but sometimes used to correct dispersive and sodic soil. This is possibly due to a lack of understanding of the agronomic properties of soil, a lack of confidence in soil chemistry or issues with site access and ameliorant application. To provide adequate soil chemical stabilisation soil testing for agronomic purposes, including testing for exchangeable cations needs to be determined to calculate ameliorant rates and render a soil from sodic to non-sodic, or dispersive to non-dispersive (Rengasamy, 1984).

Techniques commonly used for remediation of sodic and dispersive soils in agriculture include application of prilled gypsum or use of fine grade agricultural lime in conjunction with deep ripping or shallow cultivation (Ellington, 1985; Nadler & Magaritz, 1986). There is little published data on the use of gypsum for geotechnical use on existing earthen structures, steep banks and slopes in Australia. Gypsum should be mixed into the soil to be most effective.

6. Gypsum Amendment and Calculation of Application Rate

When an accumulation of sodium ions occurs in the soil exchange complex, soil management techniques are used to decrease soil ESP levels and render soils stable. Gypsum is the most common amendment for reclaiming sodic soils. Reduced ESP and an increasing soil electrolyte level are the main benefits from gypsum application. The reduced ESP, the associated cation exchange effect and change in soil electrolyte level can increase soil permeability. The electrolyte effect is beneficial at low application rates and injurious at high application rates.

Gypsum effectiveness is influenced by dissolution properties. The factors that affect this include the volume of water in contact with gypsum, the surface area of gypsum particles, purity and solubility. There are differing gypsum sources which can be used as amendments for remediating dispersive and sodic soil, including mined (prilled), liquefied and industrial. These sources differ in measured properties and the difference in the rate of dissolution between gypsum types affects the efficiency as an ameliorant.

The amount of rainfall or applied water to dissolve gypsum is variable dependent on type. It is not unusual for the process of dissolution to require two seasons of rainfall in Victoria for even relatively small application rates of 3 tonne/ha. For irrigation systems dissolution is quicker unless salty or turbid water is applied.

Where ameliorants are used on steep slopes and risks of soil loss from rainfall is high, products with a high level of solubility and dissolution are preferred in order to achieve stability within 10-50mm of the soil surface. Products higher in solubility require less water in comparison to gypsum which is of lower solubility to become suspended in solution and displace sodium. Mined and prilled gypsum is effective on flat to slightly undulating lands but not as suitable for dispersive soils on steep slopes that require rapid stabilisation.

Calculating gypsum application rates for dispersive and sodic soils is dependent on the soils ESP, with additional consideration of soil magnesium and potassium levels. The application rate depends on soil depth which can be used to determine the soil volume and therefore define the gypsum requirement.

7. Methodology

Following an investigation of soil constraints options for remediation, a methodology for trial was proposed. This sought to achieve biological stabilisation on the slope by providing better conditions for plant growth. Physical soil disturbance along with chemical stabilisation using liquid gypsum were intended to provide a flocculated surface after rainfall contact, slow down the movement of water on the slope, allow rainfall and seed to be spread and lodge in harrowed and scabbled sections and encourage plant germination. Aggressive ripping would have led to the destruction of rills and associated downslope movement of dislodged chunks. It was resolved to try and maintain the existing vegetation.

Harrowing.

The channel batter was initially harrowed using a 4.0 metre wide custom built stump jump harrows. The harrows were constructed with anchor points to attach chains of varying lengths. This allowed the harrows to be towed with an excavator and maintain their position on the batter. A staff member of GMW walked behind the harrows and acted as a spotter for overhead cables and other unforseen objects such as rocks and large cavities. The excavator manoeuvred on the berm to adjust the position of the harrows and provided the ability to lift the harrows over cavities as well as raise the harrows to drop trash. One side of the 1.6 kilometre channel was treated with the harrows in approximately 1 hour. Figure 2 shows the harrows in action.

Figure 2. Excavator towing custom made harrows along the channel batter. The untreated area of channel can be observed in front of the harrows.

Harrowing as opposed to cultivation allowed for existing vegetation and organic matter to be maintained on the batter. Phalaris (Phalaris aquatica) was the dominant species. Phalaris and other grass and weed seed was spread over bare patches by the harrows. Dry organic matter resting on the soil surface also passed through the harrows. The technique of applying granular gypsum and cultivation would have resulted in the loss of all organic matter and vegetation. Figure 3 shows the finished surface after harrowing.

Figure 3. Harrowed channel batter showing remnant swards of grass.

Chemical Stabilisation.

The site was treated with liquid gypsum at 200 litres per hectare, with specifications including 35% calcium and 25% sulphur. This equates to an equivalent of 70 kilograms of calcium and 50 kilograms of sulphur per hectare. The product is a milled suspension with a particle size of 5 micron. The investigators sought to stabilise the harrowed surface using the product in conjunction with natural rainfall. As the volume of calcium in liquid gypsum is less than that of bulk gypsum, our intended depth of stabilisation was shallow. The technique of stabilising the soil surface only and using plant growth as a medium for achieving soil anchorage was compatible with the shallow treatment. Figure 4 shows the extended single sided boom spray in action.

Figure 4. Boom spray emitting liquid gypsum on the harrowed channel batter.

The use of liquid gypsum was selected for other practical reasons:

- Adaptation of equipment to spread prilled or mined gypsum on one side of a spreader truck required machinery modification.
- Contractors were reluctant to work on such a steep slope.
- Granular gypsum requires mixing using tillage to be most effective. Tillage is not preferred on steep slopes with dispersive soil conditions.
- Liquid gypsum can be applied much more uniformly in comparison to spread gypsum.
- As a liquid it can be applied by aerial application or boom spray.

Biological Stabilisation.

Biological stabilisation was the ultimate goal of the exercise, by providing improved growth conditions on the batter and berm. The maintenance and improvement of vegetation was important to provide minimal disturbance to plant root systems and to enhance prospects for further germination.

After the establishment of vegetation, it is expected that the surface will be protected from wind and water erosion and water runoff will be impeded by the presence of divots. Plant roots will provide anchorage and allow the soil to maintain a reasonably dry state, which is desired given that saturated conditions are likely to cause the batters to fail.

8. Response to Treatment

Visual Response.

The site was inspected May 2012, approximately five months after the treatment. During this time the site had received 125mm of rain, with the largest event being 31mm on the 28th of February. Visual observation showed evidence of a crazed and aggregated soil surface which show nil dispersion on the upper batter (grey cracking clay soil) and limited dispersion on the lower batter (light grey sandy clay). There was no evidence of rill erosion as a result of the February event or from the total rainfall received during this period. Harrowing had scabbled the surface enough to allow for the penetration of liquid gypsum as well as providing an effective seedbed for plant establishment. Figure 5 shows the surface after remediation.

Figure 5. Crazed soil surface from liquid gypsum application. Aggregation is also evident.

The soil was soft under foot as opposed to the original conditions which were hard and dense. Tyre tracks were obvious along the berm from water authority vehicles, providing evidence of flocculated soil. The effective depth of penetration from the treatment was measured at 40-50mm in thickness.

Plant establishment was also limited by warm and hot daytime temperatures over summer. These conditions when combined with the lack of rainfall limited germination. It is likely that seed may have been removed by insects, birds and other animals. There was some establishment of grasses and weeds and the soil recorded slight moisture conditions at the time of inspection and the investigators observed the seedbed to be biologically healthy in May 2013, five months after the treatment.

Chemical Response.
Soil chemical analysis was undertaken for the project. In June 2012 prior to undertaking works representative soil samples from the berm were collected for comprehensive analysis to provide background data on soil chemistry and calculate gypsum requirements. Samples were also collected from the berm only in May 2013 to provide comparison and contrast.

The data collected shows increases in levels of exchangeable calcium, electrical conductivity and sulphur as a result of the treatment. There were other positive soil changes including a decrease in exchangeable magnesium and sodium which is also favoured for improving soil stability. The data in Figures 6 and 7 contrasts the change in nutrient levels as a result of the treatments. The data is not statistically validated but provides an indication of the change that has taken place since the time of the treatment. These observations correspond with similar soil changes that occur in agricultural situations where mined gypsum is spread and incorporated.

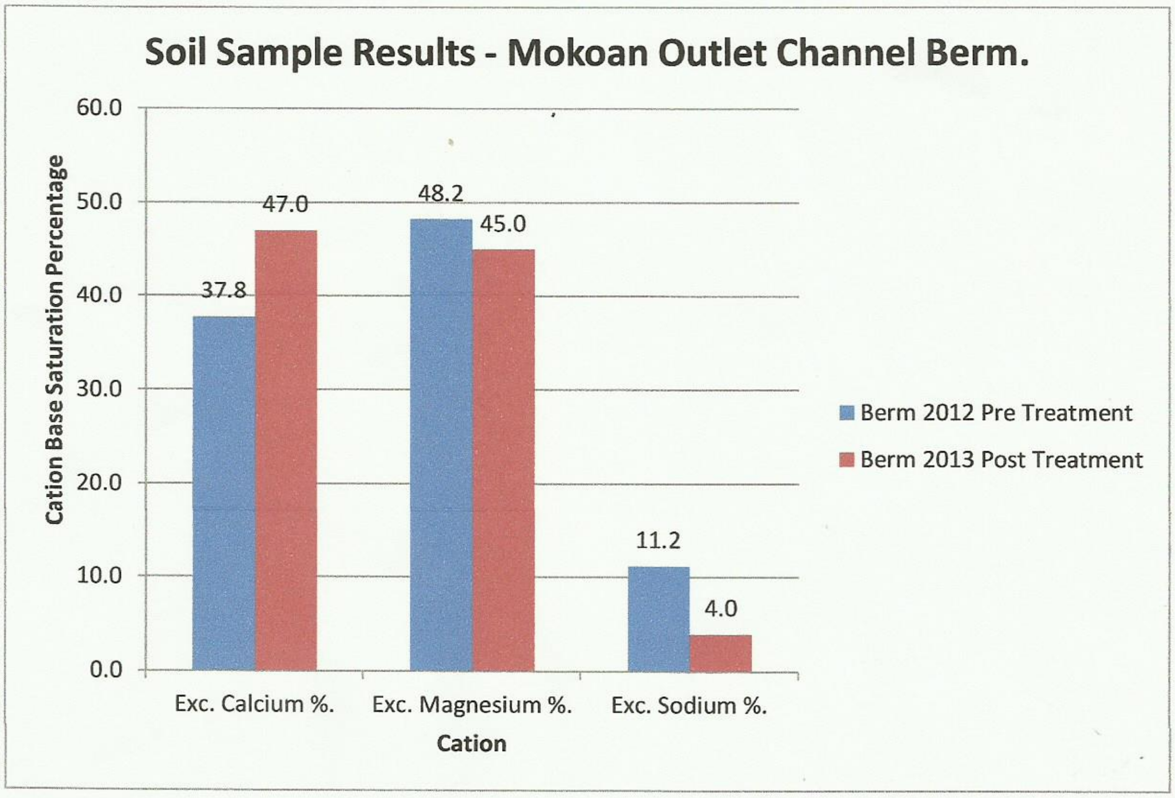

Figure 6. Changes in Exchangeable Cation levels after applying the treatment to the berm.

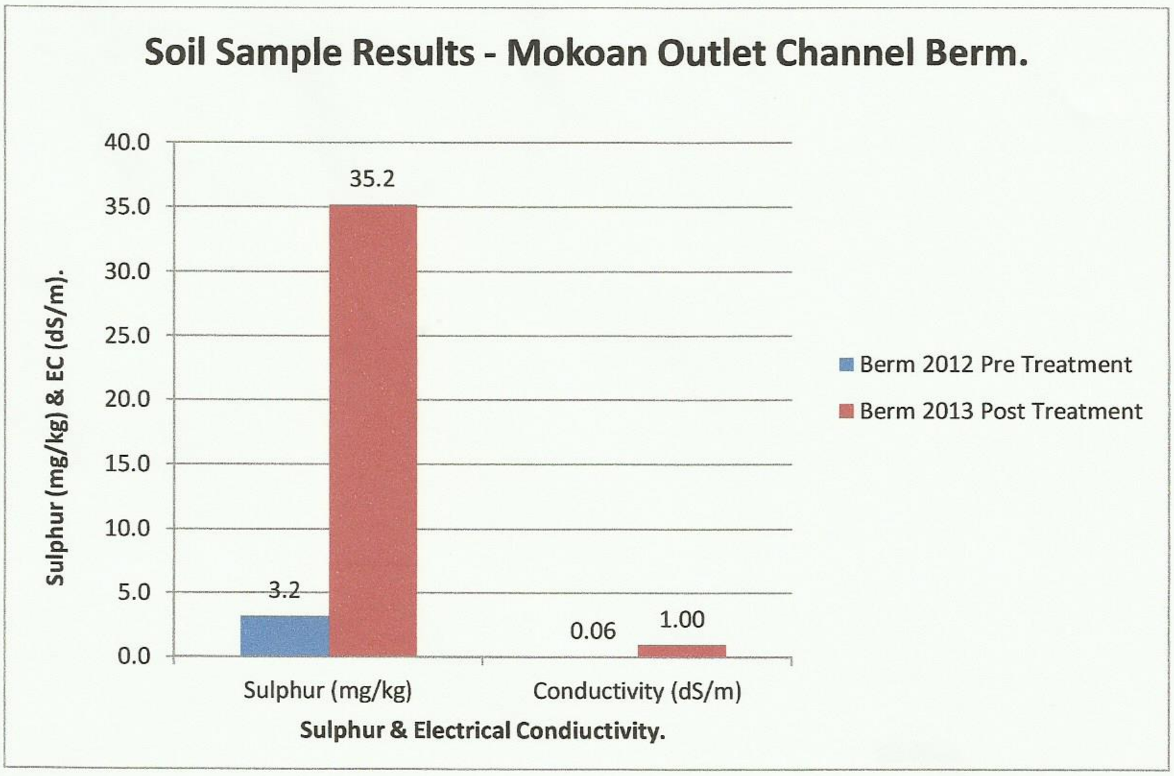

Figure 7. Changes in Sulphur & Electrical Conductivity after applying the treatment to the berm.

9. Conclusion and Recommendations

This paper presents a technique for stabilisation of a steep channel batter which has suffered from rill erosion due to sodic and dispersive soil. The concept is not unique but presents as a simple and quick approach for the stabilisation of a long and steep bank based on established agricultural techniques. Initial observations indicate that the technique has improved soil properties and there is evidence of plant colonisation, which should provide enhanced biological stabilisation over time. The treatment was shallow and has been successful with as little as 125mm of rainfall.

This technique eliminated the need to undertake spreading and incorporation of mined gypsum. The volume of material used was 800 litres in comparison to mined gypsum, where approximately 20 tonnes would be required for a 5.0 t/ha application across the 4 hectares of berm and batter. A spreader truck, front end loader, cultivation equipment and a tractor would have been required in order provide a best case treatment using mined gypsum and significantly more rainfall would be required for dissolution. The risk of rill erosion and soil loss is greater using bulk gypsum particularly on this steep slope. Chemical stabilisation using mined is likely to be less efficient and more expensive using best practice. Mechanical stabilisation using compaction and use of geosynthetics were not an option due to cost and the need to revegetate the bank.

The boom applied liquid gypsum provided a reduction in ESP from 11% (sodic) to 4% (non-sodic) and increase in calcium base saturation on the berm from 37 to 47%. This has provided confidence that the use of liquid gypsum is effective at providing a shallow response for the stabilisation of dispersive and sodic soil. These results reinforce the need for further research and replicated trials as well as an economic appraisal. This project was not subject to a cost benefit analysis however the investigators readily identified the costs associated with bulk gypsum and tillage equipment.

The soil response to the liquid gypsum treatment was enhanced by the use of custom built harrows, providing a scabbled surface and area for water and seed to lodge in nooks and crannies on the batter and berm. It is likely that the response is due to the combination approach of physical and chemical amelioration used as opposed to one technique alone.

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