Strategies for grass establishment to control erosion on Roma flood levee batters

Y. Gyasi-Agyei

School of Engineering and Technology, Central Queensland University, Australia, Bruce Highway, Rockhampton Campus, QLD 4702, Australia

R. Koech

School of Health, Medical and Applied Sciences, Central Queensland University, Australia, Bundaberg Campus, University Drive, Bundaberg, QLD 4670, Australia

G. Bebington

Infrastructure Office, Maranoa Regional Council, Roma, QLD 4455, Australia

ABSTRACT: An earthen levee was constructed to protect areas of Roma township, Australia, against periodic floods. This paper presents strategies used to establish grasses to control erosion on the levee batters. As a result of water scarcity in the semi-arid environment, precision irrigation involving the use of drip laterals was an integral part of the strategies implemented. However, the water source was alkaline, saline and sodic. The water pH of nearly 9 was adjusted by mixing 85% phosphoric acid with the irrigation water, the right amount added determined by titration tests carried out in a laboratory. The sodicity of the water was improved by mixing liquid gypsum with the water. Buffel and Rhodes grasses were seeded as they are popular for permanent pasture. The treatments imposed on the batters have worked very well with over 80% grass cover at all sections on the levee batters achieved during the first 6 months.

1 INTRODUCTION

Roma town, the head office of the Maranoa Regional Council (MRC) in Queensland, Australia, with a population of 6,906 (2011 census) has a long history of significant flooding. Of particular interest are the 3 consecutive years of flooding in 2010, 2011, and 2012. Some statistics of the unprecedented 2012 flood which was estimated to be over 1% annual exceedance probability were one fatality, about 580 submerged properties above floor level, and an estimated flood peak of 2,200 m³/s of the Bunjil Creek flowing through the town. A Stage 1 flood mitigation project consisting of 5.2 km of earthen levee (average height of 2.8 m) was constructed in 2014 to protect areas of Roma against a repeat of the 2012 flood event with a freeboard of 800 mm. Should the event of 2012 reoccur, the levee is expected to reduce the above-floor flood risk of 580 homes to 120 homes (GHD, 2016).

The 5.5 ha levee batters, slope angle of 1(V):1.5(H), had to be protected using vegetation to control erosion, and also to provide aesthetic pleasing environments. Unfortunately there was no topsoil available to cover the batters, therefore, organic wastes from the Maranoa Regional Council were processed with conditioners to generate soil that was conducive for establishing grasses.

Grass cover plays a significant role in reducing erosion (e.g. Goldman et al. 1986, Gray & Sotir 1996, Gyasi-Agyei et al. 2001). It reduces raindrop impact by the shielding effect of foliage and plant residues, thus reduces raindrop splash detachment rates. Another important role is the increase in infiltration rates in upper soil layers caused by root systems and holes where roots have decayed, yielding less runoff to detach and transport sediment. The embedded rooting systems of grasses increase soil cohesion, thus increasing resistance to erosion and rill development.

In 1997, Queensland Rail (now known as AURION) and Central Queensland University (CQUniversity) initiated the HEFRAIL project to investigate cost effective ways of establishing grasses to minimise erosion on the batters of railway embankments and cuttings within the semi-arid environment of Central Queensland, Australia. Several field experiments involving surface preparation, soil treatment, seeding, and hydraulic modelling of water flow through driplines were carried out (Gyasi-Agyei et al. 2001, Gyasi-Agyei 2003, Gyasi-Agyei 2004a, b, Gyasi-Agyei 2007, Gyasi-Agyei 2013) in order to establish standards and guidelines for the railway company. As a result of water scarcity in the arid environment, precision irrigation involving the use of drip laterals has been an integral part of HEFRAIL. How-

ever, there were key elements of the Roma levee project that called for proper investigations regarding various aspects of HEFRAIL.

Roma town water supply from boreholes had to be sourced for the drip irrigation, but chemical analysis of the water indicated it is alkaline, saline and sodic and was therefore not conducive for establishing grasses unless treated. This paper presents the strategies implemented on the Roma levee batters to achieve adequate grass cover against erosion, and also to provide aesthetic pleasing environments.

2 MATERIALS AND METHODS

2.1 Site description

Roma, located at latitude 26°34'24"S and longitude 148°47'12"E, and at an elevation of 299.4 m above sea level, is 479 km from Brisbane, Queensland, Australia. Its climate is a humid subtropical, with mean annual rainfall of about 600 mm with each month likely to experience a few wet days, although summer months from December to February experience the highest monthly rainfall. Mean maximum daily temperatures range between 20 °C and 34 °C and winter minimum seldom drops below −3 °C. Figure 1 shows the Roma township and the location of the levee. Five levee sections, indicated as Sites B, C, D, E and F were selected for treatment on both sides. Table 1 provides the basic properties of the levee sections. A typical cross section of the levee is shown in Figure 2. The top of the levee is used as access road and has a width of 3 m.

Figure 1. Roma township showing location of the airport and levee sites; the yellow short lines indicate the extent of the sites and the black dots are chainages in m.

Table 1. Basic properties of the levee sites.

Site	Length m	Height range mm	Batter area m ²	Number of bays	Number of tanks
B	509	1940-3150	11278	14	4
C	757	2430-2910	15224	15	5
D	642	2430-2910	10834	10	4
E	325	2910-3150	7895	8	3
F	590	2180-2700	9760	11	4

Figure 2. Levee typical cross section.

2.2 Irrigation water

Roma township water supply is from a number of independent boreholes drawing from the same geological formation, hence of similar water quality. Over 90% of the water required for the project was sourced from Borehole 13 but at different tapping points of the water supply system. However, the irrigation water sourcing was monitored to ensure minimal impact on water availability to the community within the levee corridor.

Poly tanks, 5000 l each, were placed next to the levee at each site and filled with water from the town water supply network during off peak periods. Using poly tanks also facilitated the acid dosing to bring the high pH of the water of nearly 9 to a more acceptable value of 7 (neutral) for grass establishment. Figure 3 shows the parallel arrangement of the 4 poly tanks at each of Sites B, D and F. An automated irrigation control valve was installed to allow filling of the tanks at the desired periods of the day as mentioned above. A float valve was installed inside the first tank to shut off the water supply when the tanks were full.

Figure 3. Water supply and acid mixing set up for 4 tanks at Sites B, D and F.

Table 2 presents some water quality parameters of Borehole 13 water, tests carried out by the Forensic and Scientific Services department of Queensland Health. The main problems with the irrigation water were excessive Total Alkalinity (>100) and Sodium Absorption Ratio (SAR>14), therefore making it unsuitable for irrigation unless treated. Continued use of sodic water can turn a non-sodic soil to sodic soil with dire consequences. Sodicity in soils can be permanent and can cause the soil to break down into fine parti-

cles that can block pore spaces thus reducing infiltration and aeration. Surface crusting that develops can cause germination problems.

One effective way to improve sodic irrigation water is the addition of gypsum, a rich calcium source (e.g., Bajwa and Josan 1989, Oster 1982). Liquid gypsum was preferred as it was easily mixed with the water. A commercial liquid gypsum (Ganixx-Bio Gypsum, <http://www.resbioman.com.au/nutrition>) was selected from a host of others based on a recommendation by a horticulturalist. It contains 32% calcium and 15% sulphur with particle size of between 1 and 2 μm . The application of the liquid gypsum was at a rate of 180 l/ha distributed over 3 application times, at the beginning, 4 weeks and then 12 weeks after seeding. A mixture of 50 l of the liquid gypsum, 1.25 l of inoculant and 15,000 l of water in a water truck was sprayed on the batters. The inoculant contained beneficial micro-organisms that promote cellular growth of roots and foliage.

Table 2. Water quality parameters

Items	Properties
Conductivity	913 $\mu\text{S}/\text{cm}$
pH	8.78
Total hardness	3.6 mg CaCO_3/L
Sodium	212 mg/l
Potassium	0.8 mg/l
Calcium	1.4 mg/l
Magnesium	0 mg/l
Bicarbonate	385 mg/l
Carbonate	15 mg/l
Chloride	64 mg/l
Nitrate	< 0.5 mg/l
Sulphate	32 mg/l
Sodium adsorption ratio	48
Total dissolved solids	533 mg/l
Total alkalinity	341 mg CaCO_3/l

The alkaline water with high bicarbonate and carbonate levels can precipitate calcium from the soil with the associated risk of rendering non-sodic soil sodic. Acids are commonly used to adjust the alkalinity of irrigation water (e.g., <https://ag.umass.edu/greenhouse-floriculture/fact-sheets/adjusting-alkalinity-with-acids>). The water pH of 9 was adjusted by mixing 85% phosphoric acid with the water in the poly tanks, the right amount to add being determined by titration tests carried out at the chemistry laboratory of CQUniversity. In addition to the pH adjustment, application of phosphoric acid also supplied phosphorous required for grass establishment. Keeping the pH around 7 helps to maintain nutrient balance and prevents formation of scales in the irrigation equipment.

Water samples from two boreholes (B13 and B12) were used for the titration tests. Incremental doses of 10 μl of the 85% concentration phosphoric acid were added to 50 ml of water samples. The mixture was stirred thoroughly using a magnetic stirrer, and then pH determined at each dosing until the pH reached 7,

the target pH in the field. Two 50 ml samples were tested for each of the two boreholes, thus having 4 titration curves (B13_1, B13_2, B12_1, B12_4) as shown in Figure 4. The titration data of the 4 data sets were binned into 17 pH classes of equal number of points, and the mean pH and amount of acid to add determined. These points, shown as average values in the black line in Figure 4, were fitted with a fourth order polynomial trend which was used as the representative titration curve for the irrigation water. About 0.04 ml of acid is required to reduce the pH of 1 l of borehole water to a pH of 7.1 which was considered to be suitable for the grass establishment. This implied that, for each 5000 l tank 200 ml of 85% concentration phosphoric acid was required. Therefore 200 ml of 85% phosphoric acid was added to each 5,000 l poly tank and recirculated through the pump and tanks (red route in Figure 3) until the pH was uniform before being fed to the irrigation system. Also, the pH was monitored at the end of selected laterals to confirm uniformity of the mixing.

Figure 4. Titration curve for the irrigation water from boreholes 12 (B12) and 13 (B13).

2.3 Grass Species

In selecting plant species for steep slope erosion control and stabilisation, a number of criteria must be satisfied (e.g. Goldman et al. 1986):

- complete soil cover;
- rapid germination and fast growing;
- easy to plant;
- adaptation to poor soils;
- adaptation to local conditions
- good soil binder
- regrowth in subsequent years;
- commercially available;
- low maintenance;
- low cost;
- low fire hazard; and

- drought tolerance.

The plant must meet as many of the above criteria as possible. Of particular importance are the species that grow fast and achieve complete soil protection in the first few months after sowing. Since a single plant type is likely to be more susceptible to failure because of disease, unusual weather, lack of key ingredients, or some factor peculiar to it, a mixture of plant species are recommended. The mixture may consist of an annual grass, perennial grasses and legumes. Annual grasses are quick to germinate and provide a fast ground cover. Perennial grasses develop more slowly than annuals and may require irrigation in regions with a dry season. Their seedlings may not compete well in mixtures with the annual grasses. Since legumes have the ability to synthesise their own nitrogen they are invaluable additions to infertile soils.

Buffel grass (*Cenchrus ciliaris*) and Rhodes grass (*Chloris gayana*) are the preferred grasses for erosion control as they are popular for permanent pasture and, therefore, present no risk of introducing noxious weed. Buffel grass is considered the most drought tolerant grass in Australia and has adapted to a range of soil texture, surviving in regions with annual rainfall between 300 mm and 750 mm. Soil pH between 7 and 8 is ideal for buffel grass establishment. Under the right conditions it can develop deep, strong and fibrous root system to depths greater than 2 m. Despite its high potential for erosion control it is fairly slow to establish. However, it is tolerant to cutting and grazing. Gayndah cultivar is the preferred variety for erosion control because of its greater level of ground cover. Like many grasses, it can withstand up to 5 days of flooding but prolonged flooding of over 20 days may cause losses of between 15% and 70%. It is very tolerant of fire, and re-sprouts quickly at the onset of rainfall (http://www.tropicalforages.info/key/Forages/Media/Html/Cenchrus_ciliaris.htm).

Rhodes grass has similar features to buffel grass except that it is easier to establish. It is stoloniferous and develops better ground cover for effective erosion control. Also, it is more tolerant of high sodium levels and pH, and can tolerate flooding of up to 15 days without any adverse effect. However, it is less drought tolerant compared with buffel grass, requiring an annual rainfall range of between 500 and 1500 mm (http://www.tropicalforages.info/key/Forages/Media/Html/Chloris_gayana.htm). Reclaimer cultivar of Rhodes grass was selected because it has an aggressive growth and spreading habit that makes it ideal for erosion control. Because it is difficult to establish the perennials during winter, annual Rye grass was included in the mixture for quick ground cover in order to minimise the risk of washout should there be a heavy storm event, which is generally rare in winter though. It is quick to establish even in poor soils and has an extensive and soil-holding root system. It

grows well in winter and is expected to die within one year for the perennials to take over.

Previous studies (Fox et al. 2011) carried out plot scale experiments to establish the optimum seed mixtures of the perennials and Japanese Millet (an annual grass) for erosion control. While the Japanese Millet provided a quick cover, it suppressed the perennials and, after a few months when it was dead, the perennials struggled to establish. The use of sulphuric acid (H_2SO_4) to improve the germination rate of buffel grass was successful but there were safety issues associated with bulk handling (Bhattarai et al. 2008). Hence for the Roma levee project coated Reclaimer Rhodes, Gayndah buffel and Rye grasses were mixed at a 2:2:1 ratio and applied at a rate of 250 kg/ha. Fertiliser (80kg/Ha) and the seed mixture were spread on the batters and raked into the soil to a depth of between 20 and 30 mm.

2.4 The Dripline Properties and Network Layout

Commercially available heavy duty non-drain pressure compensating anti-siphon dripline was sourced. It has the following properties:

- pressure compensating range of 5.1 m to 40.1 m;
- internal diameter of 19 mm;
- emitter spacing of 300 mm;
- emitter insertion head loss coefficient of 0.36;
- nominal emitter discharge of 2.1 l/h; and
- standard coil length of 350 m.

These specifications of the drip lateral were chosen based on the experience with the railway corridor erosion control projects. The lateral rolls were from the same manufacturing batch and, therefore, expected to have the same emitter type and hydraulic characteristics. This type of drip lateral is moulded from low-density polyethylene for flexibility and durability, and the emitters are enclosed and inseparably welded to the inside wall of the tubing as it is extruded in the manufacturing process. Its non-drain feature reduces time at start-up before emitter pressure compensates, making it suitable for short pulse irrigation cycles. The risk of soil being “vacuumed” into the dripper is reduced by its anti-siphon feature. Also, the risk of blockages is reduced by the emitter’s “self-flushing” action at the beginning and end of each irrigation cycle.

The levee runs through several property boundaries with many fence lines and access road ramps for crossing from one side to the other. These fence lines and ramps dictated the bay and lateral lengths as it was difficult to lay the driplines across these geometric controls. HEFRAIL processes recommend laying the driplines at intervals increasing from 0.5 m at the top to 2 m at the bottom of the embankment batters. Because quick establishment of over 90% grass cover was required it was decided to use a constant interval of 1 m between the laterals. End sleeves were used to

seal the lateral ends, folding 0.2 m to facilitate flushing of the laterals from time to time. Where possible, pairs of bays were linked to the same water take off from the mains in order to reduce the number of crossings at the top of the levee. Each bay has its own ball valve so that they could be isolated for maintenance as occasional blow outs due to loose joints and weak damaged sections cannot be totally eliminated. Also, the ball valve can be used to regulate the entry pressure of each bay thus adjusting the pressures to within acceptable limits. Other specifications are the 25 mm secondary sub-mains from which the laterals take off and the 40 mm sub-mains that link the mains and the secondary lateral sub-mains. Hence the size of the mains was the only variable to be selected based on hydraulic simulation (Gyasi-Agyei, 2007) subject to the geometrical constraints, with the aim of minimising the time required for irrigation. For Site F, which has the lowest levee height, 63 mm mains was selected and for the remaining sites 75 mm mains was selected. Each irrigation site along the levee consisted of several bays of different lengths dictated by the geometrical controls of property boundary fence lines and access road ramps as mentioned earlier. The design layout for Site E is shown in Figure 5.

Figure 5. Dripline network layout for Sites E.

3 GRASS COVER AND CHALLENGES

To ensure adequate mixing, the water was recirculated in the tanks using the pump for about 30 minutes, monitoring the pH with litmus paper every 5 minutes. Initially 250 ml acid was added to each tank and the monitored pH at sampled locations along the driplines indicated a range of 6.5 to 7.1. Therefore, the acid quantity was reduced to 200 ml per tank and recirculated for 30 minutes to reach an average pH of around 7.1.

Table 3 indicates the seeding dates as well as the dates that irrigation was turned on for each site. Site

B was the first site setup in early June 2017. Establishing the grasses in winter is always a challenge due to poor germination rates as a result of the cold temperature and limited rainfall activities. However, it was decided to establish the grasses as soon as the levee topsoiling process was completed in order to minimise the risk of potential washout by rare rainfall events. The first 3 months after seeding experienced low temperature days with the minimum dropping below freezing point (Table 4). Contraction of the driplines due to the night freezing temperatures caused damage to the connections resulting in some leakages. However, some of the unusually high dripline leakages and bursts could be attributed to obvious damage on the dripline rolls as a result of packaging and transportation.

Table 3. Seeding and irrigation dates

Site	Seeding date	Daily irrigation start date	3 days irrigation start date
B	1-3/06/2017	19/06/2017	28/08/3017
C	05/06/2017	21/06/2017	28/08/3017
D	09/06/2017	25/06/2017	28/08/3017
F	11/06/2017	23/06/2017	28/08/3017
E	15/07/2017	21/07/2017	28/08/3017

Table 4. Temperature statistics during the monitoring period, data obtained from <http://www.bom.gov.au/climate/data/>.

Month	Minimum daily temperature (°C)			Maximum daily temperature (°C)			Total rain (mm)
	min	mean	max	min	mean	max	
Jun	-2.6	3.7	13.0	17.0	22.6	26.9	6.2
Jul	-2.7	4.5	13.1	16.1	23.3	28.2	27.6
Aug	-1.8	3.2	12.0	18.3	24.8	33.2	6.4
Sep	-0.5	8.7	22.1	21.8	30.5	40.9	0.6
Oct	10.4	16.1	21.2	18.0	29.1	36.4	92.0
Nov	6.1	15.0	21.2	26.3	30.6	34.9	70.2
Dec	10.3	19.5	24.1	27.5	35.1	41.4	83.4
Jan	14.3	21.7	26.0	34.3	37.5	42.3	0.0
Feb	13.9	19.6	27.0	21.2	34.0	44.0	125.0
Mar	12.8	17.3	23.6	24.5	31.2	36.2	92.6

Rainfall in June, August and September was below the long term monthly averages for the site (Table 4, 5), with September recording only 0.6 mm. This was not helpful for the establishment of the grasses as the irrigation is seen as supplemental to natural rainfall. The five wet days recorded in July (total monthly of 27.6 mm) were very helpful and a significant grass growth was observed. Due to financial constraints, irrigation was terminated on 08/12/2017 even though the grass had not reached the expected maturity of seeding. December experienced slightly above average annual rainfall but there was no rainfall during January. However, February and March rainfall exceeded their long term average values, although much of the rain was concentrated on a few consecutive wet

days. With respect to grass establishment, uniformly distributed light showers are much desired.

Table 5. Days with rainfall greater than 5 mm during the monitoring period.

Date	Rain mm	Date	Rain mm
2017-06-30	6.2	2017-12-03	44.6
2017-07-07	5.2	2017-12-22	17.6
2017-07-16	14.8	2017-12-26	12.8
2017-08-04	6.4	2018-02-03	19.4
2017-10-02	17.6	2018-02-04	19.8
2017-10-03	22.0	2018-02-20	12.6
2017-10-07	17.2	2018-02-21	52.6
2017-10-17	9.6	2018-02-22	8.2
2017-10-18	8.0	2018-02-28	8.8
2017-10-21	13.2	2018-03-04	13.4
2017-11-07	18.6	2018-03-05	44.2
2017-11-18	27.6	2018-03-06	6.6
2017-11-19	20.4	2018-03-07	27.8

In a past project, mixing an annual grass such as rye grass with the perennials suppressed the perennials by dominating the germination rates. After the annual grass had died it became difficult for the perennials to establish. But again, because a quick grass cover was required, it was important to use the annual grass that is quicker to germinate in the seed mixture. The vegetation cover is over 80% on almost all parts of the levee batters, but there have been unforeseen problems with animals.

Due to poor or ineffective fencing at some sites, kangaroos and cattle have been feeding on the grasses, particularly during the winter months when green pastures could only be found on the levee batters. Because the animals selectively feed on the grass, weeds have naturally developed and are dominant in some sections that need to be controlled. It was hoped that, during summer months when the adjoining pastures turned green, the established grasses would be spared. Unfortunately this has not been the case and animal grazing is continuing unabated. The only way to prevent the animals from eating the established grasses is putting in place adequate fencing. At sites with adequate fencing, or where there are no cattle on the adjoining properties the grasses have established very well. While the installed electric fence at some sites are keeping big cows away, the small size cows and the kangaroos could not be prevented from feeding on the established grasses.

Runners of the grasses that are supposed to be developing roots and spread to achieve 100% cover are being eaten by the animals. Clearance of foliage by animal feeding has also exposed some soil surfaces to direct sunlight with an increase in evaporation, thus requiring more irrigation water or rainfall for survival. The grass parent roots density is quite good at the disturbed sites and may sprout during the next wet season to achieve the required coverage. Previous work on railway batters that have steeper slope angle

of 1(H):1.4(H) did not have this problem as the animals could not stand on the batters and feed. The levee batter slope angle of 1(H):4(V) makes it easier for the animals to walk around much like on a flat paddock.

When grass establishment takes place in favourable summer conditions, it takes about 3 to 4 months to reach maturity. Seed development by the grasses is an indication that they have reached maturity and can be self-sustaining, and that is when irrigation can be terminated. An active campaign of weed control and seeding should be carried out until the desired grass coverage is achieved. The weeds need to be controlled using chemicals that will spare the grasses. For patches where weeds are over 80% of the cover, a chemical may be used to kill all vegetation. A seed mixture of 50:50 of Gayndah buffel and Reclaimer Rhodes shall be used, the rate of application determined by the existing grass cover. For the weed dominant areas it is better to kill the weeds after September and seed within two weeks. Hopefully the wet season which begins in October will support seed germination and sustained growth. Clearing the weeds which are protecting the batters against erosion will expose the batters to erosion and scouring should there be significant storms.

Figures 6 shows a photo gallery of the batters with the laid driplines, and progress of the grasses, as well as some noxious weed developments.

4 CONCLUSIONS

A 5.2 km earthen flood levee was constructed in 2014 to protect areas of Roma against repeat flooding. This paper deals with the establishment of grasses with the aid of a drip irrigation system on the levee batters to control erosion. The Roma town water supply from boreholes used for irrigation is alkaline and it had to be treated with phosphoric acid. The right amount of acid to be used was determined by titration tests in a laboratory. In order not to interfere with the town water supply, poly tanks were filled before pumping through the drip irrigation networks. Also, the poly tanks facilitated the mixing of the acid with water. A mixture of Gayndah buffel, Reclaimer Rhodes and Rye grass seeds, along with fertiliser were spread on the batters and raked into the top 20-30 mm of the soil. Liquid gypsum was also sprayed on to the batters to improve irrigation water sodicity.

While over 80% grass cover has been achieved at all sections on the levee batters, being the only green pasture within the vicinity, particularly during the winter months, the revegetated batters have attracted kangaroo and cattle to feed on the established grasses. This is of great concern as the grass runners are not developing as they should. This factor was not considered as the previous study on the steeper railway batters did not encounter this problem. Adequate

fencing needs to be put in place at all levee sections to prevent animals from feeding on the established grasses, and to allow the grass runners to develop.

Weeds control measures should have been put in place during the initial stages to avoid weed dominant batter sections, particularly at sites D and E. Grass establishment should be seen as a farming activity and best farming practices should have been enforced. This is not to understate the erosion control protection offered by the weeds.

The quality of the topsoil mixture is questionable as there are no plant activities at some sections. Investment in the topsoil is very important as the longevity of the established grasses depends on the growth medium.

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Site F: drip irrigation layout

Site F: showing access road

Site F: established

Site F: subject to grazing

Site B: established

Site F: poor quality topsoil

Site D: weed dominant

Site E: established – 3 tanks

Figure 6. Images taken on 19/09/2017 (top row) and on 04/04/2018 (remaining rows) to show progress and challenges.