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Report on polyacrylamide, a practice to reduce sediment and insoluble chemicals in tailwater

Tara Slaven

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Report on Polyacrylamide:

A practice to reduce sediment and insoluble chemicals in tailwater

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Background

The final milestone of the ‘Development of ORIA sustainable farm management extension plan’ project was to implement one priority activity identified in the plan developed through the project.

A workshop was held with surface irrigators in July 2009 to identify priorities for improving tailwater quality. At the workshop, the irrigators ranked farming practices that address this issue in order of their likelihood to adopt. The three surface irrigator representatives identified polyacrylamide (PAM)—a flocculent used to improve the quality of tailwater—as the most adoptable practice. The two major barriers to adoption of PAM were identified as the cost and application.

A decision was made at the workshop to further investigate the use of PAM, particularly how to reduce the costs and ways to manage the practical issues with application. A literature review, economic analysis and investigation into product availability were conducted to provide information to help address the identified barriers. This report is a record of the findings. It also identifies some of the gaps in knowledge.

Tailwater quality and flocculents

The Ord River Irrigation Area (ORIA) stage 1 was developed to use a flow-through irrigation system. This means that irrigation water applied to farms drains directly into the lower Ord River. This waste water, or tailwater, carries sediment, chemicals and nutrients that could be detrimental to the health of the river.

Flocculents are one option available to farmers to improve the quality of tailwater leaving the farm. Flocculents can reduce sediment and insoluble chemicals and nutrients in tailwater. It works by clumping suspended particles, for example clay particles, together. The weight of the clumps causes them to fall out of suspension and not drain to the river in the tailwater. Certain insoluble chemicals and nutrients, such as endosulphan and phosphorous, attach to clay particles and also drop out of suspension.

One type of flocculent that is used in agriculture is polyacrylamide. Anionic polyacrylamide (PAM) has been trialled in the ORIA to reduce sediment, chemicals and nutrients in tailwater (Oliver and Kookana 2006; Slaven et al. 2009). Trial results have shown that PAM applied with surface irrigation significantly reduces all three contaminants in tailwater. Other benefits of using PAM included:

- Reduced cost of delving on farm drains
- Reduction in the amount of irrigation water required.

Use of PAM in the ORIA

Fourteen irrigators were interviewed about their current practices and attitudes towards practices such as the use of flocculents. Half of the respondents had used PAM in the past. Only one was currently using PAM. The reasons given for not using PAM were:

1. Difficulties with application (5)
2. Cost (3)
3. Potential off-site impacts (3)
4. Thought it was not necessary (3).
Methods of application

There are a number of formulations of PAM that can be used—powder, pucks, liquid and granular. The granular formulation is the only form that had not been tried in the ORIA. Liquid is currently the preferred method of application, although each form has its advantages and disadvantages (Table 1).

Table 1  A summary of advantages and disadvantages of each formulation of PAM

<table>
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<tr>
<th>Formulation</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tr>
<td>Powder</td>
<td>Cheaper to transport in bulk</td>
<td>Hydroscopic, making application difficult</td>
</tr>
<tr>
<td>Pucks</td>
<td>Cheaper to transport in bulk</td>
<td>Labour intensive to apply</td>
</tr>
<tr>
<td>Liquid</td>
<td>Relatively easy to apply</td>
<td>Difficult to get correct application rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not as effective in reducing phosphorus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Relatively expensive to transport.</td>
</tr>
<tr>
<td>Granular</td>
<td>Cheaper to transport in bulk</td>
<td>Labour intensive to apply</td>
</tr>
</tbody>
</table>

Each formulation is discussed individually in terms of how it is applied and local experience/trials.

Powder

In the past a powder form has been used. Due to its hydroscopic properties it was very difficult to apply and to get the correct application rate. The powder was applied through a funnel-like applicator. The powder would swell because of moisture adsorbed from the air and block the applicator.

Liquid

The one respondent that was using PAM was using the liquid formulation. There are no problems using an applicator to apply the PAM in the current liquid formulation. However, there are issues with mixing it effectively with the irrigation water (Tara Slaven pers. comm. 2010). Currently, the liquid PAM is pumped from a container through an applicator into the irrigation channel. The rate can be adjusted by altering the speed that the PAM is pumped. At the irrigation channel the PAM needs to be agitated to ensure it mixes with the irrigation water. If this does not happen, the PAM sinks to the bottom of the channel and it is not transported through the siphons and on to the field. Previous local research (Oliver and Kookana 2006; Slaven et al. 2009) has shown that when PAM is agitated properly there is a significant reduction of sediment in tailwater. However, other studies (Misra & Hood 2007; Slaven 2009) reported that the benefits of applying PAM in irrigation water were highly dependant on application rate. Furthermore, liquid PAM also seems to be ineffective in reducing the amount of phosphorus in tailwater. Oliver and Kookana (2006) found that liquid PAM was not as effective in reducing phosphorus as pucks were. Trials conducted on the Sandalwood confirmed this (Slaven 2009).

Pucks

Small disc shaped cakes, or pucks, of PAM have been used in the past in the ORIA. The application method of this formulation is to place one puck in each irrigation furrow. While it is a labour-intensive process, Oliver and Kookana (2006) found that pucks significantly reduced the amount of sediment and phosphorus in tailwater.
Granular

The granular formulation can be applied in the head channel or in the furrow. To apply it in the furrows, an augured metering system can be used. This is referred to as the ‘patch method’ (Nishihara and Shock 2001). When applying it in the head channel, the granules are placed near the siphon where the water is slightly agitated. This helps dissolve the PAM and apply it effectively.

Which formulation to chose?

In choosing which product to use it is important to identify why PAM is being applied. If the aim is only to reduce sediment in tailwater, then liquid PAM is suitable (Oliver and Kookana 2006). If it is phosphorus that needs to be reduced, then, according to the research, pucks seem to be the best way to apply PAM. In saying this, it must be noted that only limited research has been conducted on the different PAM formulations within the ORIA. Further research is necessary to confirm the findings from Oliver & Kookana (2006) and Slaven (2009).

Economic analysis

The on-farm financial implications of using PAM are important in determining whether to adopt the treatment.

Although the cost of PAM is less than $100 per hectare, the application is at the beginning of the cropping cycle. The additional outlay for PAM, spread over a typical farm with 300 hectares of crop, could be $30 000. This has a high opportunity cost, especially if growers are funding crop establishment using banking overdraft facilities.

For this study, the economic analysis of PAM is based on the use of partial budgets and parametric budgets. The reason is that the benefits of PAM seem to accrue within a short time horizon of less than one year. Although growers in the region do perceive there to be off-site benefits of using PAM due to the improved tailwater quality, this analysis is limited to the on-farm benefits.

Partial and parametric budgets explained

Partial and parametric budgets are farm management decision-support tools. They are used to determine the expected return from making a change where the benefit or cost accrues in the same year that the innovation or change is made.

The partial budget is used to determine the net benefit/cost of adopting a new innovation. The budget includes two main parts:

1. The benefits of adopting an innovation (saved costs and extra revenue)
2. The costs of adopting it (revenue forgone and extra costs).

The decision rule for a partial budget is that if benefit exceeds cost then, based on financial considerations only, the innovation is beneficial and would be adopted. If the cost of the innovation exceeds the benefit it is not likely the new practice would be adopted by growers.

A parametric budget is a derivation of a partial budget in that it creates an algebraic representation of the partial budget. A parametric budget allows variation in the values of the critical variables. For example, variations in the value of the cost of PAM per unit can determine the critical value at which a grower will use PAM.
Cost of using PAM – assumptions

The values used to calculate the assumptions and the partial and parametric budgets were obtained from local growers or using the data set from Oliver and Kookana (2006). The following assumptions were used to calculate the cost of using PAM per cropping cycle:

- The crop is a broad acre grass.
- Liquid PAM is added to the irrigation water in the head channel by mixing. Liquid PAM was used for this analysis instead of other forms because of the availability of price information from input suppliers.
- Crop water use of 8 mega litres of irrigation water per hectare.
- PAM will lead to a saving of 10 per cent in the amount of water applied.
- Insecticides and fungicides are used in the crop cycle and a saving of $10/ha is made using PAM.
- The use of liquid PAM has no effect on the loss of phosphorus in tailwater (Oliver and Kookana 2006).
- The cost of PAM is $72.30 per cropping cycle, per hectare. That is, two applications per cropping cycle, at 3 litres per hectare per application, at a cost of $12.05 per litre.
- The cost of applying two applications of PAM to a 40 hectare cropping bay is two hours of labour costing $30 per hour, plus $9.60 for fuel to run the generator to mix the PAM into the irrigation water. This equates to $1.74 per hectare.

Using these assumptions the total cost of PAM per cropping cycle is $74.04 per hectare (the cost of PAM $72.30 plus the cost of applying it $1.93).

Partial budget analysis and results

The cost-benefit analysis of using PAM was calculated using the following assumptions:

- The cost of using PAM is $74.04 per hectare.
- The reduction in sediment loss is 900 kg/ha per application for two applications per year, with a sediment cost of $40 per tonne which equates to a benefit of $72 per hectare.
- The cost of delving on farm drains is reduced, saving $20 per hectare per cropping cycle.
- The water saving per hectare is 10 per cent or 0.8 mega litres which equates to a saving of $3.70 per hectare (or $4.62 per mega litre).
- The reduction in the loss of chemicals is $10 per hectare.
- The loss in phosphorus is worth $0 per hectare.

The partial budget analysis found the base financial benefit of using PAM per hectare is $31.66 per hectare (total savings $105.70 minus the cost of PAM $74.04).

Parametric budget analysis and results

Parametric budgeting is a mathematical tool used to assist in calculating the value of critical parameters in a profit function. That is, the cost of making a change to the farming system may be expensive compared with the benefit. So, how much benefit is needed to pay for the change? The underlying principle of the technique is that an equation for profit is developed and the value of one variable is varied at a time. The purpose of this is to find the variable...
value at which a grower would adopt a new farming practice. It is assumed that the impact on cash flow is the only measureable benefit of the new technique.

A parametric change in profit function was developed for PAM and the likely changes in profit were due to changes in the following variables:

- The value of sediment kept on farm
- The cost of PAM
- The price of irrigation water
- The saving in the cost of delving drains
- The loss of phosphorus per hectare.

The formula used to calculate the parametric change is set-out in Appendix 1.

**Sediment value**

The value of saved sediment is the major factor contributing to beneficial adoption of PAM. If topsoil is worth nothing, then the overall cost of PAM is $36.15 per hectare per year. For there to be a net benefit, the value of sediment needs to be equivalent to $19.53 per tonne or greater.

**The cost of PAM**

As the price of PAM increases the financial benefit from using PAM would logically decrease. The price per litre at which there is no net financial benefit from using PAM is $17.05 per litre.

**The cost of irrigation water**

The cost of irrigation water can be considered a non-critical variable as, at all values above zero for the cost of irrigation water, there are benefits from using PAM.

**The cost of delving drains**

Delving on-farm drains is an annual management cost. During the wet season, sediment is deposited into the irrigation drains. The source of this sediment, based on grower opinions, is on-farm road surfaces. Oliver and Kookana (2006) indicate that the application of PAM reduces the sediment load in tailwater. For this analysis it was assumed that all the sediment found in on-farm drains came from irrigation applications.

**The phosphorus issue**

Anecdotally, one of the main reasons for using PAM is to reduce the loss of phosphorus in tailwater. As phosphorus is an expensive input required for crop nutrition, any saving is beneficial. If PAM did retain phosphorus on farm there would be two potential advantages—increased yields and savings from reduced nutrient applications per hectare per year.

However, trial results indicated negligible changes in the loss of phosphorus when using liquid PAM (Oliver and Kookana 2006). If there was even a slight reduction in the amount of this nutrient in the tailwater, it would be expected that growers would be willing to adopt PAM.

In the future, as the price of fertilisers increase, then, intuitively, the benefits of using PAM increase at a greater than linear rate. Increases in the cost of fertiliser are likely to exceed the corresponding price increases of PAM.
Tailwater recycling

The requirement to recycle tailwater in new irrigation developments could create a situation where the benefits of applying PAM are prominent. The current flow-through system means that any sediment load in tailwater is not retained on farm. In a recycling system, a tailwater sump would act as a settling pond for any sediment and chemicals from the tailwater. The sump would also capture and accumulate lost nutrients, such as phosphorus. However, further work is needed to determine how this nutrient would settle in the sump and whether it could be reused as part of tailwater recycling.

If settling does occur in the tailwater sump, then the volume of sediment lost from the irrigation bays could fill the sump in a relatively short timeframe. If the PAM reduced the amount of sediment being deposited, then the life of the sump could be prolonged.

Reducing the cost of PAM

At the workshop in July 2009, one attendee suggested that PAM could be imported from China. The reason for the suggestion was to reduce the price of PAM. Follow-up on this suggestion found that the Government of Western Australia has an office in Shanghai to help locate resources for the State (see contacts list), and that the Ord River District Co-operative was willing to become the importer. However, this option was not pursued as the volume of PAM required was not cost-effective to freight.

Another suggestion during informal discussions was to form a partnership with Argyle Diamond Mine. It was thought they would use flocculents in their processing. However, the flocculent currently being used by the mine is not suitable for irrigated agriculture.

Negotiations with the mine about changing flocculents may be an option.

There are at least two PAM manufacturers within Australia. Their contact details are listed at the end of this report. Anecdotally, the pucks used in earlier trials came from the United Kingdom and other products from the United States. It is possible that a deal could be struck with an Australian manufacturer.

The liquid PAM currently being used in the ORIA is manufactured in South Australia (see contact list). Instead of transporting the PAM to the ORIA in liquid form, there may be the option to transport it in solid form to be mixed on arrival. The Ord River District Co-operative now has the facility to make liquid fertilisers in Kununurra. Using that facility to make liquid PAM warrants further investigation.

Potential off-site impacts

A couple of growers indicated a concern that the PAM was just another chemical being washed into the river.

‘It’s still unproven the effect on the environment of the actual flocculent… it goes back into the natural environment and that’s the reason that I stopped it.’

A literature review indicated that the off-site impacts of PAM were minimal (Phillips 2003). This review reported that PAM is non-toxic to humans, fish and plants. It was also reported that PAM is broken down by cultivation and sunlight (Phillips 2003). Misra and Hood (2007) reported that anionic PAM remains largely attached to soil or sediment. This means that the potential of it ending up in the river is small. The rate of degradation of PAM in the soil is largely unknown, but is believed to be slow. As PAM degrades, acrylamides form. These are a known neurotoxin for humans. However, the amount of amides in PAM are minimised during processing.
Monitoring of PAM in the drains and river will be essential if there is to be large-scale adoption in the ORIA.

**Is it necessary?**

A few surface irrigators considered the use of PAM as unnecessary. There are other methods available to reduce sediment in tailwater. Some of those methods include:

- wet season cover crops with minimum tillage
- minimum tillage
- increased water use efficiency, therefore reduced tailwater.

Other methods are also available to reduce chemicals in tailwater:

- only spraying the top of the beds
- only spraying when there is full canopy cover
- delaying irrigation for a few days after spraying.

PAM is only one tool for consideration.

**Future research**

There are still many unanswered questions about the use of PAM, especially about its use in the ORIA.

Research needs that have been identified locally are:

- determination of the best application method (liquid or pucks)
- application rates for different soil types
- number of applications per season
- measuring production benefits
- measure water savings
- monitoring off-site impacts.

The presence of calcium ions is supposed to act as a bridging cation and improve the overall performance of PAM (Mira and Hood 2007). This theory also needs to be incorporated into any future trials.

Other research needs identified by Mira and Hood (2007) that are applicable to the use of PAM in tailwater recycling situations (such as Ord expansion) are:

- impact on infiltration at a commercial scale (that is, does it reduce sealing and sodicity; and increase infiltration and deep drainage)
- substantiate the benefits and management to reduce seepage losses from dams and channels
- investigate the potential to reduce evaporation from large dams and channels
- break down of residue of smaller chain length
- development of a code of best practice
- optimal mix of strategies (PAM is only one option).  

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Conclusions

The main barrier to the adoption of PAM seems to be the timing of the cost outlay. This outlay could add significantly to the initial crop establishment costs at a time of year when growers receive no income. However, the partial and parametric analysis indicates that there are benefits from using PAM as part of the crop management cycle. These benefits are from saving water, retaining sediment on-farm and reducing the cost of delving drains. There are other potential economic benefits including the retainment of phosphorus as a plant nutrient on-farm and subsequent yield increases.

Additionally, the off-site environmental impacts seem to be negligible. Even so, PAM would need to be monitored in the drains and lower Ord if it were to be widely adopted.

The potential for the use of PAM in the expansion area is significant because of the caveat for tailwater recycling. It could be used for reducing contaminants in tailwater as well as reducing seepage in storage facilities.

Growers at the workshop identified PAM as the most likely practice to be adopted to improve tailwater quality. However, the survey results showed that most growers have tried using PAM and have since abandoned the practice. There is a need for more research before PAM can be widely and successfully re-adopted. Application rate, application method, number of applications and the interaction with soil type needs further investigation. Extension of the properties of PAM is also needed to address concerns about off-site impacts.

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Appendix 1. Parametric change equation

Each variable has two parts—quantity and value. Multiplied together they show the monetary flow in the calculation of the net change of adopting PAM.

The change in profit function is shown below:

\[
\text{Profit change} = \sum_{i=1}^{n} P_i Q_i
\]

Where \( P_i \) is the value per unit of the \( i \)th variable
Where \( Q_i \) is the amount of units of the \( i \)th variable
Where \( i \) are the variables from 1 to \( n \).

The expansion of the above profit function for the use of PAM is shown by:

\[
\text{Profit change} = P_1 Q_1 + P_2 Q_2 + P_3 Q_3 + P_4 Q_4 + P_5 Q_5
\]

Where

\( P_1 \) = the value of sediment lost per hectare per year,
\( Q_1 \) = the quantity of sediment lost per hectare per year

And similarly:

variable 2 represents PAM price and quantity
variable 3 represents irrigation water price and amount saved based on 10% saving of 8 mega litres
variable 4 represents drain delving cost and number of delvings per hectare per year
variable 5 represents the quantity of phosphorus loss and the price per unit of phosphorus

Inserting the known variables from grower discussions and the trial results from Oliver and Kookana 2006 into the change in profit function develops the following equation.

\[
\text{Profit change} = 1.8 P_1 - (6 P_2 + 1.74) + 0.8 P_3 + 20 Q_4 + 0 P_5
\]

Note in the above equation that the cost of PAM, variable 2 is the only variable which is a cost whereas all other variables are potential benefits as they are savings.

The critical values for each variable group in the PAM parametric change in profit function and the value needed for growers to adopt the use of PAM in their cropping enterprise are explained below. By setting the left hand side of the equation (profit change) to zero the critical variable values in quantity and price of each variable can be calculated whilst keeping all other variables constant. By adding the cost of PAM per hectare, per year, to each side the equation is:

\[
6 P_2 + 1.74 = 1.8 P_1 + 0.8 P_3 + 20 Q_4 + 0 P_5
\]

If it is assumed that delving of drains is carried out once per year then \( Q_4 \) is equal to 1, and subtracting 1.93 from each side, the equation can then be rearranged

\[
6 P_2 = 1.8 P_1 + 0.8 P_3 + 18.26 + 0 P_5
\]
By inserting the known variable values into the equation and then solving the equation for the one unknown variable, an estimate of the critical value for that variable is calculated. All other variables are held constant at their known value.