THE USE OF BAUXITE RESIDUE TO CONTROL DIFFUSE PHOSPHORUS POLLUTION IN WESTERN AUSTRALIA — A WIN–WIN–WIN OUTCOME

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Abstract

The Department of Agriculture, Western Australia has been working with Alcoa World Alumina Australia Ltd for more than ten years investigating the potential to use bauxite residues as soil amendments for the poor, acidic, sandy soils of the Swan Coastal Plain.

Regional waterways, especially the Peel Inlet and Harvey Estuary, have historically been susceptible to nuisance algal blooms fed by phosphorus in run-off from farmland and urban areas. While the incidence of algal blooms has recently been substantially reduced in the estuary system by the construction of a new channel to the Indian Ocean known as the Dawesville Channel, the main feeder river systems are now experiencing substantial algal blooms. The major mechanism for the reduced algal growth in the estuary is an increase in the salinity of the water body and, to a lesser extent, the flushing of phosphorus into the Indian Ocean. These mechanisms have limited effect in the rivers away from the influence of the new channel. While the incidence of nuisance algal blooms in the estuary has declined, this approach has not reduced the amount of nutrients flowing through the catchment and entering the waterways.

Extensive laboratory, field and catchment-scale trials have repeatedly shown the ability of soil amendment with fine bauxite residue (now trademarked in this context as Alkaloam) to reduce the leaching of nutrients to sensitive regional waterways by up to 75%, while at the same time, increasing pasture productivity by up to 25% (up to 200% in well-controlled experimental situations). This is now widely acknowledged as the only land management option developed globally which has been shown to reduce non-point-source phosphorus export immediately upon application. Alkaloam is now available on a commercial basis to landholders in the Peel-Harvey Catchment and is seen as an exciting solution to a significant land degradation problem. This paper examines the effectiveness of Alkaloam in retaining phosphorus, increasing plant production and assisting in minimising waste production from refineries — win–win–win.

The project has previously won a State Landcare Award and was a finalist in the National Landcare Awards. It has also recently been recognised by a Department of Agriculture Technical Excellence and Innovation Award and was a finalist in the 2001 WA Premier’s Awards for excellence in Public Sector Management.

1. Introduction

1.1 *Location and characteristics of the Peel Harvey Catchment*

The Peel-Harvey Catchment lies approximately 70km south of Perth in Western Australia and covers an area of approximately 3072km^2. It extends east into forested portions of the Darling Scarp, but the coastal portion of the catchment covers about 190,000 ha which extends as far north as Kwinana and south to Harvey. The location of the catchment within Western Australia can be seen in Figure 1.

The region experiences a Mediterranean climate, characterised by warm dry summers and cool wet winters. The annual rainfall of about 950 mm falls mainly over the winter months. This winter rainfall is in excess of evaporation resulting in more than 30% of the rainfall in run-off. The coastal plain catchment is very flat with low undulations of up to 3 metres. The soils are the result of alluvial deposition, overlain in most of the catchment by deep, weathered sands which form low, parallel dune systems running from the north to the south of the catchment. Over 65% of the catchment has a coarse sandy surface of varying depths to impermeable layers of ironstone or clay, the rest has clay or loam alluvium at the surface. Inundation is common during winter because of the very flat landscape and the short and intense period of rain. There are also lakes and some areas of permanent waterlogging. An extensive artificial drainage network has been constructed and, while this greatly reduces inundation, stream-flow generally rises, peaks and falls over several days because water pools and is stored on the flat landscape. The run-off from the clay soils is predominantly over the surface whilst the sandy soils have a combination of sub-surface drainage through the topsoil and surface flow when the soil becomes saturated. The sandy soils become saturated due to the impermeable clay and ironstone layers, which results in the sandy catchments storing more water and discharging it more slowly than the clay catchments. Drainage essentially moves in a westerly direction through the natural and artificial drainage systems, eventually reaching the Peel Inlet and Harvey Estuary. Water then leaves the catchment and enters the Indian Ocean.

The Peel Inlet and Harvey Estuarine System (Figure 1) has been affected by eutrophication and the excessive growth of benthic algae since about 1968 [1]. Algal growth has been stimulated by phosphorus from fertiliser used in the surrounding catchment, most of which (90%) comes from the coastal portion of the catchment which discharges directly into the water body [2]. The uncleared native forest to the east contributes very little phosphorus to the estuary compared with the cleared area of the coastal plain.

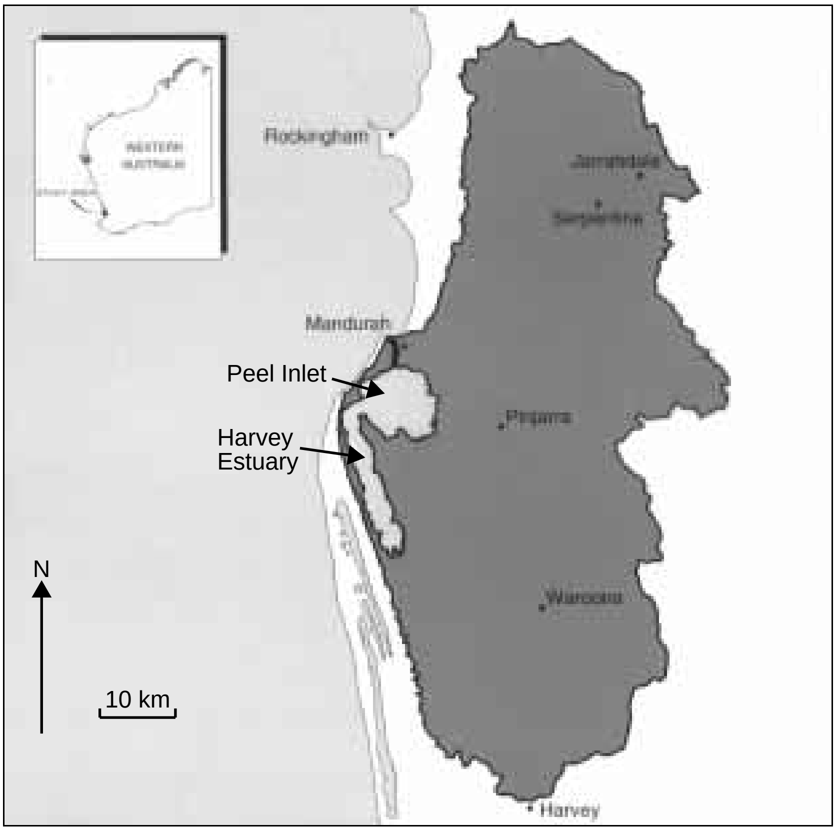

Figure 1 — Location of the Peel Harvey Catchment.

1.2 *Land use and fertiliser management*

There are a number of urbanised areas within the catchment as well as two bauxite refineries, but the predominant land use in terms of proportion of the land surface is agriculture. This is generally beef grazing, but there are also some areas where horticultural developments are being established. The predominant local fertilising strategy is to apply phosphorus as superphosphate fertiliser once a year just before the onset of winter rains to ryegrass and subterranean clover pastures. Phosphorus which is not utilised by plants is transported from the clay soils in the catchment by overland flow attached to clay particles, whilst the sandy soils discharge phosphorus initially either in a soluble form or bound to low molecular organics. The sandy soils are so poor in retaining phosphorus that only a small proportion of applied phosphorus remains after winter with most of it leaching through the soil or being washed over the surface when the soil is saturated. The hot, dry summers rapidly mineralise the phosphorus component of organic matter making it available for run-off during the first winter rains.

1.3 *Options for nutrient control and prevention of algal problems*

In recognition of the detrimental environmental and social effects of the continuing algal blooms which were occurring in the Peel Inlet and Harvey Estuary, the WA state government initiated a plan to reduce the incidence and effects of the algal blooms during the 1980s and 1990s. This was done using three separate approaches: by increasing the oceanic flushing of the estuary system through the excavation of a new channel to the Indian Ocean at the junction of the Inlet and Estuary (the Dawesville Channel); by ongoing harvesting and disposal of macroalgal blooms, and; by an Integrated Catchment Management (ICM) approach which included amendment of the soils with appropriate soil improvers.

As agriculture was the dominant land use in the region, the Department of Agriculture, was appointed as the lead government agency responsible for the reduction of nutrient loads into the Peel Inlet and Harvey Estuary through the ICM approach.

In 1994, a Public Environmental Review [3] was undertaken by the Department of Agriculture to assess the impact of bauxite residue application on to farmland in the Peel-Harvey coastal catchment. The Environmental Protection Authority of WA found the project acceptable with the condition that there was suitable monitoring upon the release of bauxite residue for widespread use which was to be reviewed after five years [4, 5]. The Department of Agriculture established a monitoring program to assess large-scale trials prior to the release of bauxite residue to determine base-line or background information about the environmental impacts of soil amendment with bauxite residue. This monitoring was to measure the long-term effectiveness of the bauxite residue to retain nutrients and was to be used to define the scope of the future monitoring commitments.

The alumina industry in the south-west of Western Australia produces 15 million tonnes of bauxite residue annually. The fine fraction (< 150 µm) of residue after the treatment of bauxite with caustic soda to remove the alumina is often called red mud. Red mud is now trademarked by Alcoa World Alumina as Alkaloam when used as an agricultural soil amendment after appropriate preparation. The residue is mainly silica and iron and aluminium oxides. It is composed predominantly of silt sized particles and has a pH (both 1:5 water and 1:5 CaCl2) of about 11, because of residues of sodium hydroxide and sodium carbonate. As the bauxite residue dries, it combines with the carbon dioxide from the air and the dominant alkaline material converts from sodium hydroxide to sodium carbonate and the pH falls below 9. The high iron and aluminium oxides combined with the residual alkali results in the material having a very strong affinity for phosphorus.

This paper reports the results of several studies into the effectiveness of bauxite residue to reduce phosphorus leaching and increase plant production and also discusses the results of the associated environmental monitoring programme.

2. Phosphorus control

2.1 *Laboratory trials*

Laboratory trials were undertaken to assess the best application rate of Alkaloam to retain phosphorus applied as fertiliser and the length of time that phosphorus continued to be taken up by Alkaloam. The composition of leachates from Alkaloam amended soils was compared with drinking water standards for humans and untreated controls. Monthly rainfall was simulated and leachate was collected from lysimeters filled with bleached grey sand representative of the region amended with 5-80 t/ha of Alkaloam. Leachates from over 12 months of simulated rainfall were tested for potential pollutants (Cd, Al, Fe, As, F, SO_4), electrical conductivity, pH, and phosphorus. The rainfall simulation was continued for the equivalent of 5 years and phosphorus levels were monitored during this time.

The ionic concentrations of the contaminants from columns treated with Alkaloam were similar to the concentrations in the controls, or fell to similar levels after the equivalent of 3 months of rainfall. The concentrations of these leachates were below the maximum recommended limits for drinking water. Phosphorus reductions of up to 90% were measured with Alkaloam amendment, with the best application rates of Alkaloam for the reduction of phosphorus leaching were between 10 and 20 t/ha. The improved nutrient retention from Alkaloam continues for the equivalent of at least 5 years of fertiliser application.

2.2 *Catchment trials*

The Meredith catchment is a sub-catchment of the Peel-Harvey. It is situated about 150 km south of Perth with a total area of about 4360 ha upstream of a monitoring point which had been monitored for phosphorus concentration and water flow for 12 years prior to the application of Alkaloam.

The soil is a Bassendean sand known locally as Joel or Gavin sand [6]. It is a coarse, acidic sand with a low capacity to retain nutrients [7]. The pasture vegetation was mainly subterranean clover (Trifolium sub-terraneum) and annual ryegrass (Lolium rigidurn). About 1600 ha of the catchment was treated with 20 t/ha of Alkaloam. This was the majority of cleared grazing land that had been fertilised. After Alkaloam amendment, the drain water flow was monitored using a broad crested 'V' notch weir and float recorder from a stilling well. The water was sampled daily using an automatic sampler providing a composite from four samples. Every fortnight the site was sampled manually for heavy metals as well as for nitrogen and phosphorus. On these days, the phosphorus sampling was duplicated with both manual and automatic samples taken.

The phosphorus concentration dropped significantly in the drainage water from the Meredith catchment after treatment with 20 t/ha Alkaloam when compared with the previous ten years. The phosphorus concentration in the run-off varied seasonally with a rapid rise at the start of flow in winter and then a slow tailing off in concentration over winter and spring. Adjustment of the phosphorus concentrations for seasonal variations in run-off showed a reduction of 0.3 mg/L compared with the median level of 0.94 mg/L over the previous ten years. This was a reduction of 32%. The result was based on the Mann-Whitney test (Willcoxon Rank Sum Test) on analysis of the median P concentrations ($P < 0.05$). The other water quality criteria measured at the Meredith drain were generally the same as or less than those measured at other sites.

Also, within the Meredith Catchment, a pair of adjacent, similar catchments were monitored for nutrient discharge. Alkaloam was applied to the treatment catchment (32 ha) at a rate of 80 t/ha using agricultural spreaders and the control catchment (24 ha) was not treated. Both catchments were cleared immediately before the experiment after about ten years of inactivity where re-growth of native vegetation had occurred and fertiliser had not been applied. The phosphorus concentration of the water and discharge rate using a sharp crested 'V' notch weir were monitored for the first year. Only the phosphorus concentration was monitored for the subsequent years monitoring to assess the longevity of the phosphorus retention by the Alkaloam. Two fertiliser applications were made to each catchment. The first application was before the opening rains at 150 kg/ha of superphosphate, 8.3 % phosphorus equivalent to 12.45 kg P/ha. The second application was at the end of winter at 150 kg/ha of super phosphate/potash 3:2, 5.3% phosphorus equivalent to 7.95 kg P/ha. The total phosphorus application was 20.4 kg P/ha for the untreated catchment, and 63.4 kg P/ha for the treated catchment. The higher rate of phosphorus on the treated catchment resulted from phosphorus in gypsum applied at an equivalent rate of 41.5 kg P/ha. Stream flow was monitored with 120° 'V' notch weirs constructed on the catchment drains at the entry points to the Meredith drain. Water samples were taken every six hours from the flow by automatic samplers and combined to make a 24 hour sample and analysed for total phosphorus. Flow height was measured at 15 minute intervals using floats connected to a data logger. Daily rainfall was also measured on an adjacent property. The volume of water that flowed over the weirs was calculated from the height of water passing over the weir and transformed into instantaneous flow using a rating curve. Daily flow was calculated through linear interpolation.

The concentration of phosphorus in the streamflow from the catchment treated with bauxite residue was consistently lower (median of 0.5 mg/L) than those from the untreated catchment (up to 5 mg/L). There were only two small phosphorus spikes in the streamflow from the treated catchment. The first occurred after heavy rain and the second after the second fertiliser application, neither of which reached the levels commonly measured in the untreated catchment.

Phosphorus loss to surface drainage from the catchment treated with 80 t/ha bauxite residue (4.2 kg P/ha) was reduced by 70% when compared with the untreated catchment (13.8 kg P/ha). A reduction in P loss of this magnitude continued for five years until monitoring ceased.

Further analysis of changes in the phosphorus levels in the Meredith Drain over time has also been undertaken through an analysis of the WA Water and Rivers Commission (WRC) gauging station data at the Meredith Drain. 10 years data before Alkaloam amendment, and six years data after was analysed. The data has been analysed using monthly water quality data to allow some interpretations to be made on seasonal water quality variations before and after Alkaloam amendment.

This information can be seen graphically in Figures 3 and 4.

These graphs indicate a consistent and continuing reduction in phosphorus concentration of up to 80% in the water in the Meredith Drain after Alkaloam amendment of the catchment soils. Statistical analysis indicates significant reductions in this data set for the individual months of June and August, and a significant reduction in the overall monthly data set ($P<0.0001$) using a paired t-test.

Similar information has also been obtained for other regional drains (Harvey River, Mayfield Drain and Nambeelup Brook) for varying periods of time dependent upon data availability. Statistical analysis of these data sets does not indicate the same statistically significant reductions in phosphorus concentrations over the same time period. The reductions in water phosphorus concentration appear to be limited, regionally, to the Meredith Drain.

This data has also been compared with a number of other data series to try and gauge some understanding of any causative factors other than amendment with Alkaloam which may be producing a decline in the phosphorus export from the Meredith Drain. When the data is been compared with the sale price of beef over the same period (as an indicator of the potential returns gained over this period by beef farmers) and the amount of superphosphate sold in this region over this time (as an approximate indicator of the amount of fertiliser applied to farmland over this period) no statistical correlation has been observed [8].

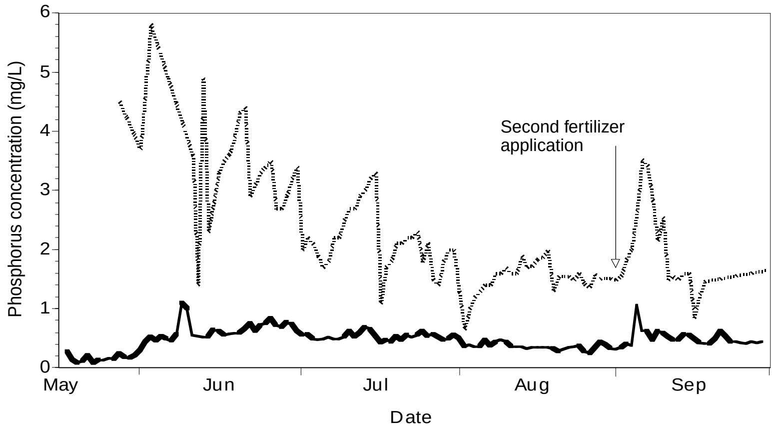

Figure 2 — The phosphorus concentration in the streamflow from the catchments. The untreated catchment is represented by the dashed line.

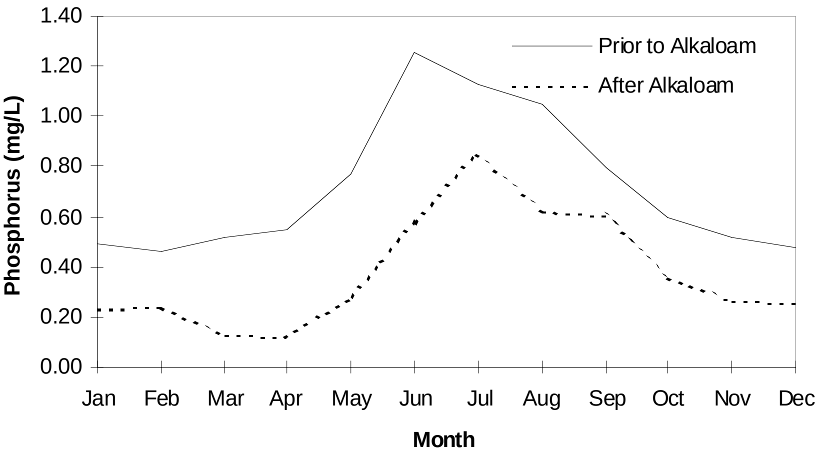

Figure 3 — Monthly phosphorus concentrations — Meredith Drain

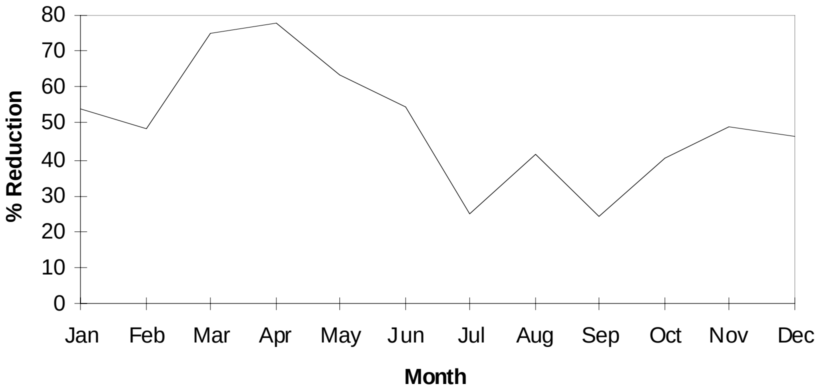

Figure 4 — Monthly % phosphorus reductions — Meredith Drain after Alkaloam amendment

The only causative factor for the observable and statistically valid reduction in phosphorus concentration in the Meredith Drain appears to be Alkaloam amendment.

3. Agricultural Productivity

When Alkaloam is applied to the acidic, sandy soils of the Swan Coastal Plain the alkalinity acts to increase the pH as well as improving the nutrient retention. These changes improve the soil as a medium for growing clover. It is often remarked by landholders that if Alkaloam stops phosphorus from being leached, does it have an impact on the ability of plants to take up phosphorus? Trials were established to determine the effect on clover plant growth of the addition of increasing rates of Alkaloam.

The impact that increasing the amount of Alkaloam has on the effectiveness of the phosphorus fertiliser was also investigated. This was achieved by superimposing different amounts of phosphorus fertiliser on each of the rates of Alkaloam. To further test the impact of Alkaloam and phosphorus uptake over time, another treatment was imposed on the trial. This was achieved by applying phosphorus each year to the different treatments of phosphorus and Alkaloam, thereby allowing a picture of how each treatment developed over time by comparing previous applications with freshly applied phosphorus. The Alkaloam was also compared with agricultural lime.

When 20 t/ha of Alkaloam was applied to the plots, yields of dry matter were doubled when compared with the untreated controls. This was so in the year the Alkaloam was applied and in the year after application. As more phosphorus is applied to clover the yield increases to a maximum plateau. The Alkaloam increased the magnitude of this maximum plateau (see Figure 5). This effect occurred for freshly applied phosphorus and for phosphorus applied in previous years.

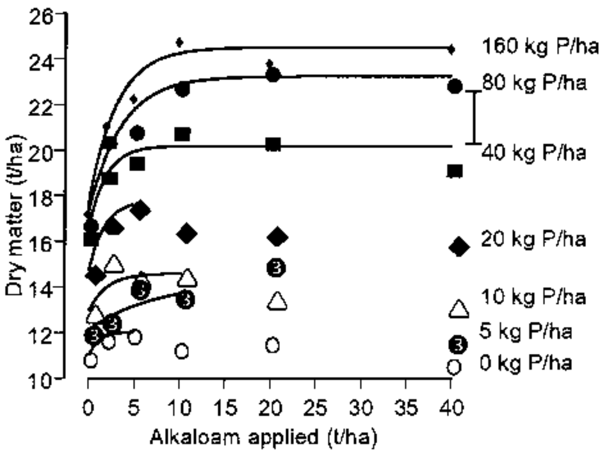

Figure 5 — The effect of Alkaloam and phosphorus fertiliser on yield totaled for all four years of the trial. Not all of the fertiliser application rates could be adequately fitted to the growth curve (Mitserlich). The error bar shows the significant differences ($P > 0.05$) between the means (symbols).

The efficiency of phosphorus fertilisers was initially reduced despite the yields being increased by the effect of Alkaloam increasing the pH. This increase in phosphorus requirement could be attributed to the increased phosphorus sorption or precipitation when the fertiliser was in close contact with the freshly applied alkaline Alkaloam.

When Alkaloam had been applied for more than a year, the effectiveness of the phosphorus fertiliser was increased, i.e. less phosphorus fertiliser was needed to increase the yield on Alkaloam treated soil than on untreated soil. Again, overall yields were higher on the Alkaloam treated soil due to the increased pH of the soil. This improvement in phosphorus effectiveness relative to the first year was likely to be due to the reduction in sorption of phosphorus because the soil had neutralised the Alkaloam and some of the phosphorus already existing in the soil had reduced the capacity of the Alkaloam to adsorb freshly applied phosphorus.

The Alkaloam also had the effect of retaining more phosphorus in the soil in a form available for plant growth (Figure 6). These residues of phosphorus lasted several years after application. This effect could be seen in increases in plant yield, increases in phosphorus taken up by the plant and increases in plant available phosphorus as shown by the soil phosphorus test.

Surveys of landholders involved in the early commercial Alkaloam spreading campaigns (2001 and 2002) indicate that the pasture improvements predicted by the research and monitoring programmes are apparent at a farm scale. The majority of participants in spreading campaigns have reported observable increases in pasture production, a lengthening of the season over which their pasture is productive and preferential grazing by livestock of amended areas over areas which did not receive Alkaloam. Many landholders involved in the campaign have applied for repeated or additional Alkaloam applications to further areas of their properties.

3.1 *Metal uptake by plants*

The uptake of metals by plants grown on Alkaloam has been investigated in both clover plants [9] and vegetables [10]. Clover was grown in sandy soil treated with up to 80 t/ha Alkaloam analysed for N, P, K, Ca, Cu, Zn, Mg, B, Fe, S, Mo, As, Cd, Hg, Pb, Th and U in the fresh clover pasture and in hay baled from the plots.

The concentrations of contaminants in clover tissue were below the detectable limits for all of the rates of Alkaloam applied except one control plot without Alkaloam and one replicate of the 20 t/ha Alkaloam which had As at 2 μg/g (the detectable limit). The concentration of Cd was highest in the controls (0.5 to 1.5 μg/g) and declined in the clover tissue as the rate of Alkaloam increased.

The concentrations of the Pb, Th, U, Hg and As in the plant tissue were all low and did not increase with the application of Alkaloam. The presence of Cd in the control plots was probably due to the application of superphosphate and the decrease in Cd concentration with increasing Alkaloam was probably due to the increase in pH and sorption making the Cd less available. The Cu, Mn and Zn levels rose with the application of Alkaloam. This is also likely to be due to the liming effect of the Alkaloam making these elements less available. This is similar to the effect of conventional agricultural lime and it is common practice to test pasture for deficiency or apply these nutrient metals when correcting soil pH with lime. Mo was increased with the application of Alkaloam although not to the point that it could cause Cu deficiency in animals grazing the pasture. Again this is monitored and corrected by applying Cu as is normally the practice with lime application.

The concentrations of contaminants were also investigated in lettuce, cabbage, carrots, onions, potatoes, cauliflower and Chinese cabbage when up to 256 t/ha of Alkaloam (treated with 10% phosphogypsum) was applied. There was no increase in the concentrations of any of the heavy metals Cd, Cr, Ni and Pb in carrot roots as the level of Alkaloam + gypsum (RMG) increased in the range to 250 t/ha [10]. Decreases in Pb and Cd in the roots and Ni in the leaves were attributed to increases in pH at increasing levels of RMG as well as the increase in iron and aluminium oxides. Similar results were found with Chinese cabbage and onions for the elements Cr, Co, Cu, As, Se, Mo, Cd, Sb, Ba and Pb where Ba, Cu and Ni concentrations decreased with increasing levels of RMG. When lettuce, cauliflower and potatoes were examined, an increase in the concentration of As, Se, Sb, Cr and Ba, was detected which is likely to be due to the increase in pH. However, even with the increase, these levels were always less than 4% of the legal limits.

The leaching of radionuclides (^{232}Th, ^{226}Ra, ^{228}Ra, ^{40}K) from soil amended with RMG at 9 rates (0, 2, 4, 6, 8, 16, 32, 64, 128 and 256 t/ha) was measured using columns and intense leaching of 34 mm/day [11]. The increase in ^{232}Th specific activity in Joel sand amended with RMG was well below safety limits even at the highest rate. Neither ^{40}K nor ^{226}Ra were detectable in RMG amended sands up to 256 t RMG/ha. There was no evidence of leaching of ^{226}Ra or ^{228}Ra at any rate of RMG, where both the treatment and control were less than 40 mBq/L. The uptake of radionuclides of U, Th, K, Ra, Pb and Cs by lettuce, cauliflower and potato crops is not significantly affected by the application of Alkaloam up to 480 t/ha. Also there is evidence that ^{137}Cs in cabbage plants may be considerably reduced by the application of Alkaloam. Radiation exposure from radionuclides in vegetable crops grown on soils amended with Alkaloam will not be significantly different from those incurred elsewhere [12].

The impact of Alkaloam on the background gamma radiation levels has also been studied at a number of field sites on the Swan Coastal Plain in Western Australia. To achieve an increase in the background dose of 1 mSv/year would require the application of 1500 t/ha of Alkaloam and continuous occupation on the site [13, 14]. The background radiation level of 0.5 mSv/year on the Swan Coastal Plain is very low [15] and 1500 t/ha would increase this to 1.5 mS/year. As a comparison, the background levels of some suburbs on the Darling Scarp adjacent to the Swan Coastal Plain are between 2 and 3.5 mSv/year. Inside brick houses on the Swan Coastal Plain the background dose varies between 1 and 2 mSv/year (Toussaint pers. comm.).

4. Environmental approvals and monitoring

As well as authorising the Department of Agriculture to undertake widespread application of Alkaloam within the boundaries of the Peel Harvey Catchment, the WA Environmental Protection Authority approval of the project also imposed a number of environmental requirements. These are essentially focused on the development of appropriate research and monitoring programmes which should be designed to both prove the efficacy of Alkaloam in terms of phosphorus retention, and also to test the environmental safety of the material in other regards.

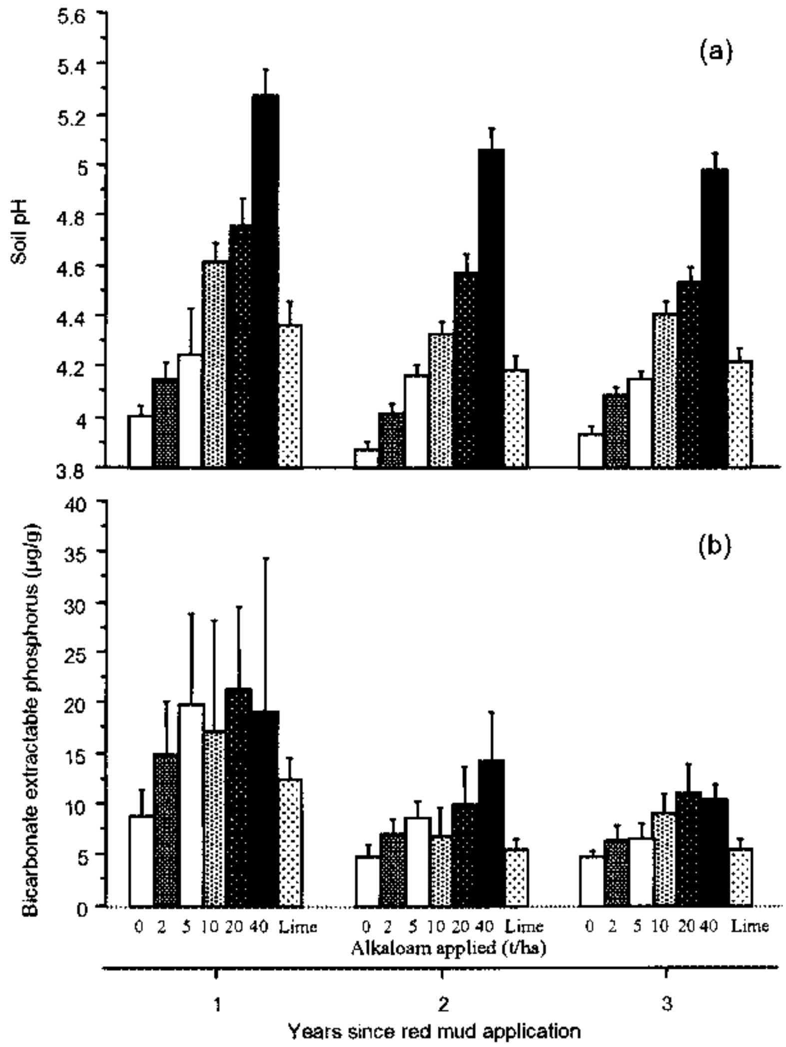

Figure 6 — Soil pH (a), bicarbonate extractable soil P (b) as affected by Alkaloam, lime and the time since application of Alkaloam. Soil P corresponds to the 80 kg P/ha treatment.

To meet these commitments, an extensive suite of ground and surface water monitoring points has been established throughout the Peel-Harvey region. These points represent an especially important resource in terms of regional water-metal monitoring points as no other agency routinely measures the metal levels in surface or groundwater resources at anything other than extremely long sampling periods. This resource has already been utilised by State and Federal environment agencies for State of the Environment reporting.

Water quality was measured at 22 sites throughout the catchment of the Peel Inlet and Harvey Estuary. Sampling occurred fortnightly during winter, monthly during summer and has now been continuing for 8 years. The monitoring sites were grouped together to form four different water types: estuarine water bodies, fresh dams and rivers, agricultural drains and artificial water-bodies. The water was analysed for Ag, Al, As, Cu, Cr, F, Hg, P, Pb, N, Se, pH, turbidity, electrical conductivity, and colour.

All water quality information collected so far indicates little significant differences between the concentrations of contaminants in the Meredith Drain water (draining Alkaloam amended land) and the water in the other agricultural drains.

Additionally, extensive leachate analysis following the Toxicity Characteristic Leaching Procedure (TCLP) and Australian Standard Leaching Procedure (ASLP) have been undertaken on soil and Alkaloam samples. All results indicate that the amendment of catchment soils with Alkaloam poses no environmental risk in terms of contaminant export to regional ground and surface waters. TCLP results indicate that Alkaloam is stable enough to qualify for disposal in the least secure of municipal landfill sites.

Regional vegetation, dust and animal health surveys are also undertaken through the monitoring programmes. As with the other data sets, no negative environmental impacts have been detected.

5. Conclusions and Recommendations

The phosphorus retention of Alkaloam has been found to be very high and long-lasting when examined at the laboratory, sub-catchment and catchment scales. From the monitoring data to date, there does not appear to be any significant increase in the discharge of other contaminants from the application of Alkaloam. The drainage from agricultural land, in general, was very low in heavy metal concentration whilst the concentration of heavy metals measured at monitoring points in or near the estuary was high, especially at the beginning of winter. These heavy metals are likely to be coming from the populated area of the lower reaches of the catchment as most materials carried in drainage water appear to become diluted or become assimilated during transport, i.e. the concentration is usually at its highest when closest to the source. This issue has been reported to the relevant state environmental protection agencies for their action.

Alkaloam increases pasture production when applied at rates between 5 and 80 t/ha, with most benefit occurring at rates equivalent to traditional agricultural liming rates. Alkaloam also produces a liming effect when applied to the surface of the soil, without the need for incorporation into the soil as is the case with crushed limestone.

The potential of Alkaloam soil amendment as a valuable management option to reduce phosphorus leaching can be seen when the entire Peel-Harvey Catchment is considered. The Peel-Harvey estuary has a mean annual load of 140 t of phosphorus, which has historically produced seasonal algal blooms. The WA EPA has set a target phosphorus load of 70 t. Through the use of Alkaloam alone there is the potential to reduce the present phosphorus load by 30% to 98t. This is a substantial part of the reduction needed to reach the overall reduced target load. These reductions are based on 50,000 ha of deep grey sandy soils and 70,000 ha sand over clay that could be treated by Alkaloam in a catchment with a total area of 190,000 ha [16].

The Department of Agriculture, Western Australia has also been investigating the use of other soil amendments and alternative fertilisers as possible new tools to promote more sustainable agricultural land management practices. By-products from mineral sands processing, power generation and wool washing are or have already been examined with some materials now available and being used commercially. A new fertiliser which combines a traditional phosphatic fertiliser with Alkaloam is also being examined in partnership with the fertiliser industry. Promisingly, results similar to those achieved by soil amendment with Alkaloam are so far being observed.

Interest in the potential for the beneficial use of industrial by-products in agriculture, along with the recognition of the need for transparent and objective assessments of their efficacy and environmental safety is gaining momentum in WA. A joint industry/government/university initiative is currently being developed which will result in the establishment of a Centre for Excellence for Land and Resource Synergy. The development of safe, beneficial soil amendments and fertilisers from the re-use of industrial by-products produces clear benefits for the environment, the agricultural sector and the industries which need to manage these by-products. A win–win–win outcome.

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