

Management Of High Rainfall Cropping To Improve Water Quality And Productivity

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Executive Summary

High rainfall cropping is one of the many industries contributing to the excessive nutrients in Australia's rivers and lakes. This paper examines some of the processes responsible for the exports of nitrogen and phosphorus from high rainfall cropping systems, with an emphasis on southern Australia. Using monitoring data, the pathways through which nutrients are exported are examined along with the effectiveness of some potential remedial strategies.

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Introduction

The export of pollutants from agricultural production systems into our rivers is a major environmental problem. The adverse effects of nutrient exports, especially phosphorus and nitrogen, are well illustrated by the increasing frequency of potentially toxic blue-green algal blooms (Department of Natural Resources and Environment, 1996), the assessment that water supplies are unfit for drinking and tourists avoiding affected holiday destinations.

All land uses contribute nutrients to our water supplies including the forestry, grazing and cropping industries, sewage treatment plants, urban areas and manufacturing industries. The relative importance of nutrient sources varies from catchment to catchment. Agricultural industries are particularly important because they occupy most of the landmass. In addition, by making nutrients available to plants, we are making them available to water. So some nutrient exports are a consequence of all plant production systems.

To facilitate discussion, the problem of excessive nutrient exports is assumed to have four elements:

- Source materials that supply nutrients;
- Mobilisation processes that release those nutrients;
- Transport processes that transport the nutrients to where the adverse effects are expressed, and;
- Adverse impacts that may be expressed through organisms such as blue-green algae or other aquatic flora.

If any of these elements are missing there is no problem.

This document investigates phosphorus and nitrogen exports from high rainfall cropping systems, particularly on poorly drained soils in south-eastern Australia. Its aim is to provide, in a readily understandable form, the current state of scientific knowledge relating to nutrient exports and their off-site impacts.

Water quality, why now?

The 'Mobilisation of phosphorus and nitrogen in cropping systems in south-west Victoria' project (Tim Johnston, pers. comm.) has recently provided important information on the nature and quantities of phosphorus and nitrogen exported from high rainfall cropping systems in southern Australia (Tables 1 and 2, Figures 1 and 2). These data are important for two reasons:

- phosphorus and nitrogen concentrations were well in excess of stream targets; and
- there is increasing pressure for agricultural industries to improve their environmental performance and this pressure is being articulated through the strategies being developed by Catchment Management Authorities (CMA's).

The condition of streams in many high rainfall catchments where cropping currently exists and into which cropping could expand is already classed as degraded or poor in respect to phosphorus and nitrogen concentrations (refer Victorian Water Quality Monitoring Network, (Cottingham et al., 1995)). Clearly, high rainfall cropping can exacerbate these problems.

In summary important findings were:

- the phosphorus concentrations in overland flow were approximately an order of magnitude greater than stream targets (stream targets are generally 0.05-0.10 mg P/L or a matchbox full of phosphorus in an Olympic sized swimming pool);
- the nitrogen concentrations in overland flow were more variable than phosphorus concentrations and approximately an order of magnitude or more greater than stream targets (streams with > 1 mg N/L are generally classed as degraded);
- most phosphorus exported from the Mt Pollock trial site was probably in a dissolved and probably in a reactive form (i.e. about 0.45 μm , the size of a virus or smaller and is highly available to aquatic organisms and very potent);
- most nitrogen exported from the Mt Pollock trial site was in the form of nitrate (which is dissolved in the water); and
- if this water were to originate from a sewerage treatment plant it may not be licensed by the Victorian Environment Protection Authority for discharge to streams in many parts of Victoria on the phosphorus concentration alone (Peter Marwood, per. Comm., May 2002).

Table 1. Annual, flow weighted mean total phosphorus and nitrogen (mg/L) concentrations in runoff from the Mt Pollock site in 2000-05.

Year	Flat shallow cultivated crop	Plots 0.2 ha		Plot 1.5 ha Conventional Pasture
		Flat deep cultivated crop	Raised bed crop	
Phosphorus				
2000	0.56 (65%)	0.51# (58%)	0.34 (47%)	1.0 (64%)
2001	2.4 (87%)	1.7# (79%)	1.3 (80%)	1.5 (63%)
2002	1.1 (83%)	0.70# (60%)	0.72 (64%)	No flow
2003	No significant flow	No significant flow	1.1 (51%)	1.0 (63%)
2004	1.7 [59%]	1.5 [33%]	1.2 [33%]	2.0 [70%]
2005	0.7 [76%]	0.6 [72%]	0.9 [50%]	0.7 [91%]
Nitrogen				
2000	23	29#	23	13
2001	25	30#	36	10
2002	51	49#	28	No flow
2003	No significant flow	No significant flow	10	5
2004	8.3	9.8	5.3	8.8
2005	4.3	4.4	6.8	8.4

Time-weighted mean concentrations

() Total Reactive Phosphorus as a percentage of Total Phosphorus

[] Total Dissolved Phosphorus as a percentage of Total Phosphorus

Figure 1. Characteristics of phosphorus in overland flow from low intensity storms between June and September 2001.

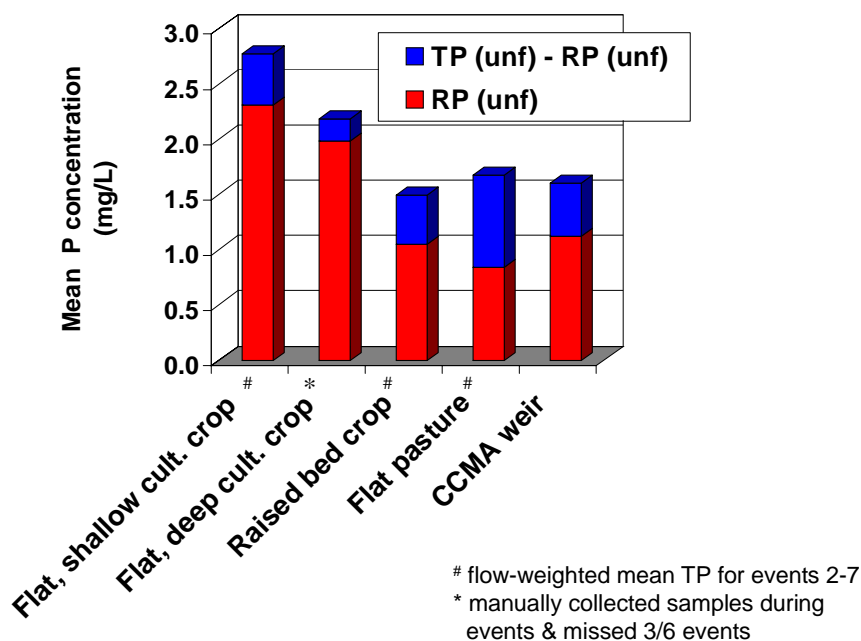
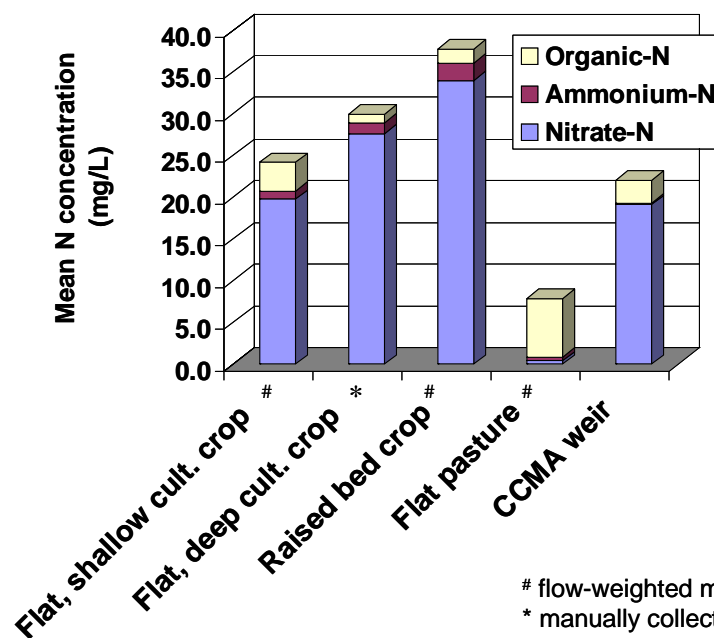


Table 2. Annual phosphorus and nitrogen loads (kg/ha annually) in runoff from the Mt Pollock site in 2000-05.

Year	Flat shallow cultivated crop	Plots 0.2 ha		Plot 1.5 ha Conventional pasture
		Flat deep cultivated crop	Raised bed crop	
Phosphorus				
2000	<0.01	<0.01	<0.01	0.1
2001	1.4	0.9#	1.0	1.2
2002	0.09	0.03#	0.09	No flow
2003	No significant flow	No significant flow	<0.01	<0.01
2004	0.2	0.1	0.1	0.1
2005	0.1	0.1	0.1	0.1
Nitrogen				
2000	0.44	0.70	0.58	1.3
2001	26	25#	43	14
2002	3.8	4.9#	5.4	No flow
2003	No significant flow	No significant flow	0.10	<0.01
2004	1.2	0.7	0.6	0.5
2005	0.9	0.6	1.1	1.2

Based on time-weighted mean concentrations

Figure 2. Characteristics of nitrogen in overland flow from low intensity storms between June and September 2001.



Take home message

We have a potential problem!!!!

What does the Mt Pollock data tell us about nutrient mobilisation?

Phosphorus and nitrogen can be mobilised in a dissolved form (<0.45 µm, about the size of a virus or smaller) or as soil-bound particles that are greater than 0.45 µm (Nash et al., 2002). Nitrogen, especially as nitrate, is characteristically found in the dissolved form in runoff.

Historically, it has been assumed that the detachment of phosphorus-laden sediments followed by their transport in water has caused most phosphorus exports from cropping systems. These processes have been extensively studied and stubble retention systems have been introduced to reduce soil detachment (i.e. by intercepting raindrops before their energy could detach soil particles) (Nash and Halliwell, 1999). Other measures to reduce sediment transport include grassed buffer strips and riparian vegetation (streamside reserves). The finding that phosphorus exported from the Mt Pollock site is mobilised primarily in a dissolved form is in conflict with past beliefs. However, phosphorus being mobilised in a dissolved form from areas where there is no predisposition to erosion (e.g. no long slopes) is consistent with there being little kinetic energy available to detach and transport sediment on these poorly drained sites (i.e. if the water had enough energy to carry sediments then the sites would not be poorly drained).

The mobilisation of dissolved phosphorus and nitrogen are largely the result of chemical processes. As a consequence of being <0.45 µm, there is little evidence to suggest that dissolved phosphorus and nitrogen exports are lowered by the introduction of measures aimed at reducing sediment detachment and transport (Dillaha et al., 1988; Hairsine and Grayson, 1993; Grayson et al., 1994; Hairsine, 1996). There are limited opportunities for removing dissolved phosphorus or dissolved nitrogen from overland flow, and remedial strategies are generally aimed at preventing phosphorus and nitrogen mobilisation by modifying the nutrient sources.

The results from Mt Pollock that most of the phosphorus was in a reactive form and the nitrogen was nitrate are also important. Nitrate is the most biologically available and mobile form of nitrogen and is often added to crops in fertilisers. Intra-crystalline phosphorus (i.e. trapped in soil), the type often found in erosion products, needs to be released from the soil particles before it is available to plants. Consequently, only 20-60% of the phosphorus exported in sediments is available to aquatic plants (bioavailable). On the other hand reactive phosphorus (dissolved) is usually 100% bioavailable (Sharpley, 1993). It follows that the impacts on receiving waters from high rainfall cropping systems may be greater than the total phosphorus and nitrogen concentrations alone would suggest.

Take home messages

Where phosphorus and nitrogen are mobilised by erosion (detachment and transport) processes we have management strategies (i.e. buffer strips, detention basins, stubble retention) to reduce nutrient exports.

Where phosphorus and nitrogen are mobilised in a dissolved form (about the size of a virus or smaller) it is difficult to physically remove the nutrients from water so the management strategies we have for sediments mobilised as a result of erosion are of limited value (in some cases they can make things worse).

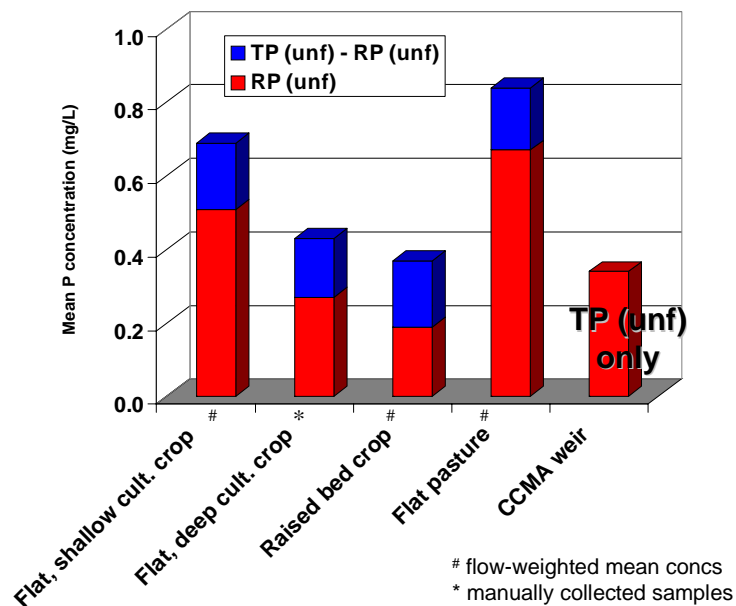
Where phosphorus is mobilised as dissolved reactive phosphorus and nitrogen is mobilised as nitrate, they are 100% biologically available and will have a bigger impact on receiving waters than their concentrations would otherwise imply.

Are the results from Mt Pollock atypical?

Highly unlikely! Experience with grazing systems suggests that the concentrations and loads of nutrients measured in the 'Mobilisation of phosphorus and nitrogen in cropping systems in south-west Victoria' project by Tim Johnston are within the expected range. The high percentage of nitrogen as nitrate and phosphorus in the reactive form was also expected. Characteristically, the soils used for these systems are poorly drained, with a slope of less than 1%, and are managed to minimise detachment and transport of sediments. The low slope would reduce sediment transport and provide extra time for the phosphorus to dissolve in the water and therefore become available for overland flow.

The results from low intensity storms between June and September 2001 and a high intensity storm in April 2001 (Figures 1 and 3) provide strong additional evidence that these data are not atypical. With rainfall of this intensity, detachment and transport of sediment would be expected. Although stubble had been retained on-site at the time, the large percentage of phosphorus in a reactive and most likely dissolved form (Tim Johnston, pers. Comm., November 2002) strongly suggests that dissolution is an important process in these systems.

Figure 3. Characteristics of phosphorus in overland flow from a high intensity storm in April 2001.



Take home messages

The Mt Pollock results are likely to be typical of many similar cropping areas.

- Erosion occurs where there are steep slopes (i.e. water has lots of energy) and bare ground (i.e. because the rain can break down soil particles) and with heavy rain while dissolution occurs on gentle slopes or where water has lost its kinetic energy (i.e. dissolution is like making a cup of tea, the longer it brews the stronger it is!).

Nitrogen should be found in streams as nitrate. But why would the phosphorus in streams be found attached to sediment if it is exported from cropland in a dissolved form?

Phosphorus has a high affinity for in-stream sediments. So phosphorus can enter a stream in a dissolved form, attach to sediment and become particulate phosphorus shortly afterwards (Sharpley et al., 1981). Because most phosphorus exports occur in a few large storms annually, the turbulence and re-suspension of sediments in streams during these periods would be expected to result in dissolved phosphorus attaching to sediments. As streams were sampled at regular time intervals rather than continuously, it is not surprising that significant inputs of dissolved phosphorus in storms would go unnoticed.

The high affinity of phosphorus for sediments also explains why reducing erosion can sometimes increase phosphorus exports. Phosphorus that attaches to sediment in transit can be dropped out of the runoff water with the sediment before it reaches a stream, for example, in a riparian buffer strip (streamside vegetation). When there is no sediment, the dissolved phosphorus can often pass directly through buffer strips.

Take home message

When you think about it, what actually happens to nutrients is really common sense.

How much phosphorus and nitrogen are a problem?

Water quality criteria can vary depending on the potential use of the water. For example, the most stringent criteria apply to water used for domestic purposes. The phosphorus standard of 0.05 mg P/L is equivalent to about 0.2 kg of diammonium phosphate (DAP) or less than a matchbox full of phosphorus, in an Olympic sized swimming pool. The nitrogen standard of <1 mg N/L is equivalent to about a 5 kg bag of nitrate fertiliser represented as DAP in an Olympic sized swimming pool. It should be noted that these numbers are for illustration only and that fertilisers are not the only source of nutrients exported from our farms.

Take home message

A small amount of nutrient has a big impact on receiving waters.

What do we know about the pathways through which phosphorus and nitrogen are exported?

Nutrients are exported from agricultural systems with water that moves over or through the soil. The pathways through which pollutants are transported are described in detail elsewhere (Nash et al., 2002). In summary, particulate materials (>0.45 μm) are generally transported over the soil surface. The same generally applies to surface active pollutants (i.e. pollutants that have a high affinity for sediment) in a dissolved phase (<0.45 μm) such as phosphorus. Surface inactive pollutants that are in the dissolved phase, for example nitrate, tend to be transported through both surface and subsurface pathways (Figure 4).

Water may travel sub-surface for some distance, for example as interflow (passing through the surface soil), and be expressed as overland flow (runoff). Consequently, just because nutrients are mobilised does not mean that they will be exported from a cropping site.

Is it the same in Queensland or Western Australia?

The results of any nutrient export study depend on the site in question, rainfall and how the water moves. Both detachment (i.e. erosion) and dissolution occur wherever water moves over the soil. It is only the relative importance of the different processes

that changes with location and management. In the semi-arid tropics of Queensland, rain intensities are high so there is a pre-disposition to erosion rather than dissolution. Under such circumstances erosion is relatively easy to see with the naked eye compared to dissolution. In Western Australian some soils are shallow sands overlying slowly permeable, lateritic ironstone gravel or clay. In these soils, where sub-surface drainage is restricted, P is known to move laterally (Bolland, 1999).

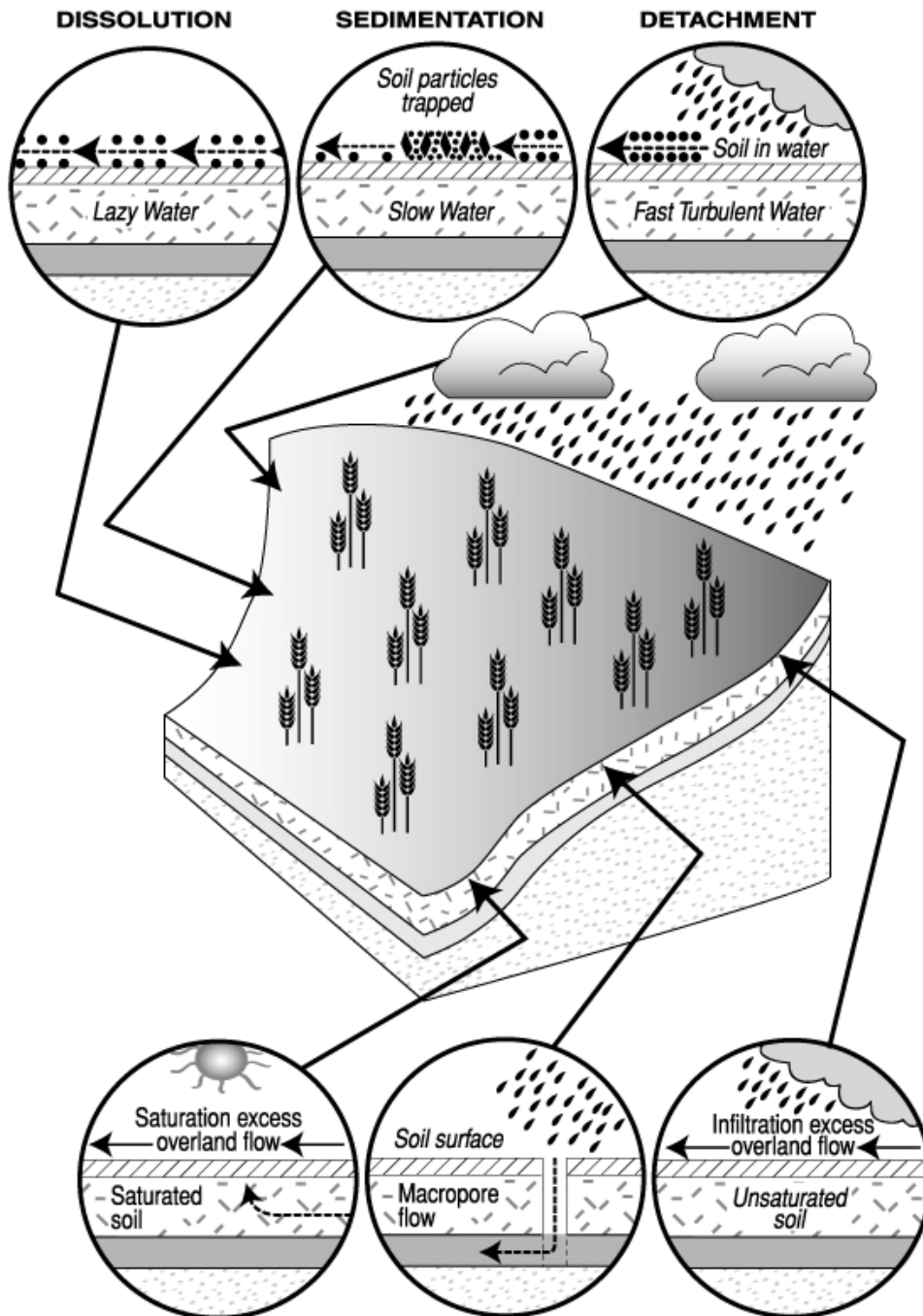
Take home message

Farms are complex systems and you need to understand how the water moves in order to work out which processes will be most important for nutrient exports from a particular site.

What can we do to reduce dissolved nutrient exports?

Compared to sediment mobilisation and transport, studies investigating the dissolution of phosphorus and nitrogen from cropping systems have been limited (Mathers et al., 2007). There are a number of insights and technologies, especially nutrient tracing techniques (Nash and Murdoch, 1997; Nash and Halliwell, 1998, 1999, 1999; Nash and Halliwell, 2000; Nash et al., 2000; Nash et al., 2001; Nash et al., 2002) that have been developed for the grazing industry and that can be applied to other high rainfall agricultural systems.

Figure 4. Hydrology and pollutant mobilisation processes

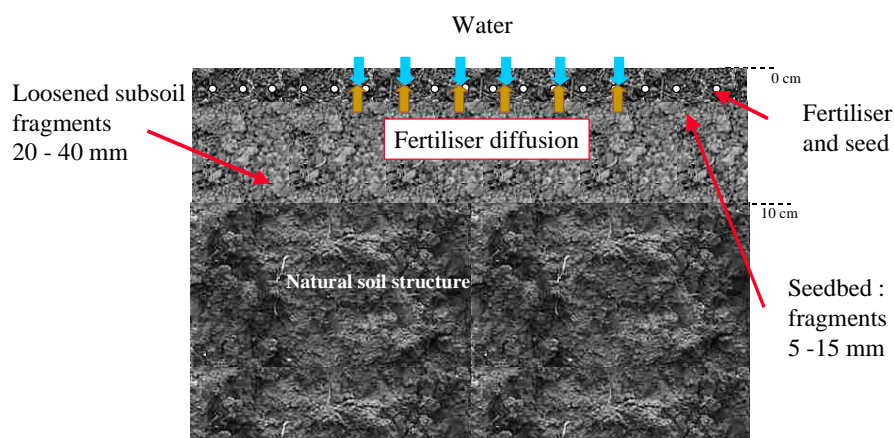


Adapted from (Nash et al., 2002)

What we do know is that when rain falls it washes over the plants onto the soil surface. From there the water may move over or through the soil (Figures 3-5, (Nash et al., 2002)). Consequently most phosphorus and nitrogen exports are likely to be initiated at or near the soil surface (possibly depending where fertilisers are placed), often in the top 5-20 mm (Ahuja et al., 1981; Ahuja and Lehman, 1983; Sharpley,

1985). The rainwater, plants, added fertilisers, animal waste products and the soil matrix all contribute to the nutrients found in the water. With a few notable exceptions (Greenhill et al., 1983; Sharpley et al., 1985), it is generally accepted that rainfall makes little direct contribution to the phosphorus (Greenhill et al., 1983) or nitrogen exported in water.

Figure 5. A diagrammatic representation of fertiliser diffusion and water movement in a conventional cropping system.

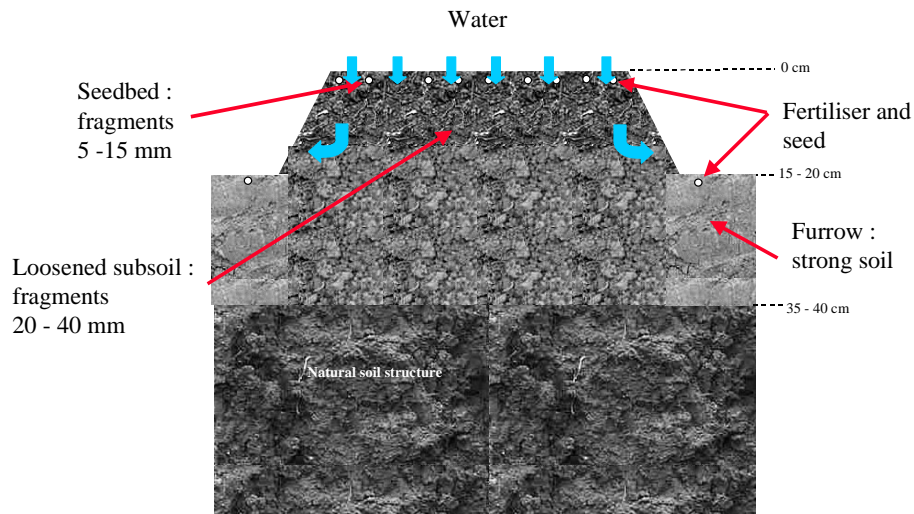


As there are limited options for removing dissolved phosphorus and nitrogen from overland flow, efforts to reduce exports are generally related to the manipulation of the nutrient sources at or near the surface. For example, dissolution of phosphorus and nitrogen can be lessened by:

- Reducing the quantities of phosphorus and nitrogen available for mobilisation at vulnerable times of the year. For example by optimising fertiliser application timing, using alternative compounds (i.e. mono-calcium phosphate or diammonium phosphate or urea) and formulations (i.e. granulation); and
- Locating the phosphorus and nitrogen sources away from zones where mobilisation into overland flow occurs (i.e. away from the surface), refer (Sharpley, 1985).

Recent studies show that there are differences in nutrient accumulation at the soil surface depending on tillage and stubble management (Mathers and Nash, 2007). It is likely that these studies will yield additional ways in which nutrient exports can be curtailed.

Figure 6. A diagrammatic representation of water movement through a raised bed cropping system.



Take home messages

With current technology we have limited options for reducing phosphorus, and even fewer options for reducing nitrogen exports from cropland.

Farms are complex biological systems and simple solutions to nutrient exports are often simply wrong!

The grains industry is working to reduce nutrient exports from high rainfall cropping systems.

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