

Objectives of the study

1. Quantify potential benefits and disadvantages using fluid fertilisers.
2. Identify where the benefits of fluid fertilisers are likely to be significant, in terms of climate, soil type and cropping system.
3. Identify and describe barriers to using fluid fertilisers, and steps that might be taken to overcome them.
4. Provide recommendations to the GRDC on future actions.

Methodology

The project has collated research information from a wide variety of sources, from Australia and overseas. Contact has been made with people from the fertiliser industry in all states as well as farmers using fluid fertilisers. Trends in pricing, new products and possibilities have been examined.

Actual case studies of farmers using fluid fertilisers and potential scenarios are presented to analyse the potential advantages of using fluid fertilisers, both economically and practically, in terms of logistics and handling.

The project team met with researchers and farmers over two days in a workshop in Adelaide to discuss their findings and experience from local farmer contact in five states. The workshop identified the situations where fluid fertilisers are likely to have an increasing role, along with steps to overcome barriers to their use by farmers.

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A note on the definition of *liquid fertiliser* and *fluid fertiliser*

The project started with an examination of *liquid fertilisers*. The term *fluid fertiliser* has been adopted throughout this report to include both liquid fertilisers and suspensions.

Liquid fertilisers are clear homogenous solutions, while *suspensions* are mixtures of fertiliser and water, where some of the fertiliser may not dissolve.

Anhydrous ammonia is a significant fertiliser, which is stored and transported in pressurised tanks as a liquid. This report on fluid fertilisers does not examine the use of anhydrous ammonia.

1. Executive summary

1.1 Fluid P fertilisers

Research work in South Australia has demonstrated more efficient uptake of phosphorus (P) and improved yields of wheat when fluid phosphate fertiliser is used on calcareous soils.

It appears that, on these highly calcareous soils, P added as granular fertiliser is rapidly precipitated as insoluble calcium phosphates, which are not available to plants. The fluid P fertiliser is better distributed and may remain in solution longer, with less fixation of insoluble forms of P. In some experiments, there is evidence that fluid fertilisers have actually released some of the insoluble P from the soil, rather than contributed to the immobile pool.

Farmers on the Eyre Peninsula in South Australia are using less P in a fluid form and achieving better yields. Despite the higher cost of fluid P fertilisers, it is possible farmers can make money using fluid P fertilisers on these calcareous soils.

The question that arises from this research is whether these effects and benefits extend to soils in other parts of South Australia and in other states. The limited research data indicate that there are some benefits from fluid P fertilisers on P fixing soils, either high or low in pH, but that on the majority of cropping soils, there is no difference between the granular and fluid P fertiliser.

Preliminary results from pot trial work on a range of Victorian soils suggest there may be benefits from fluid P fertilisers. However, pot trials have limitations in predicting the potential for fluid fertiliser responses. Fluid fertilisers have been reported as providing early vegetative response, but not a grain yield response. The response in pot trials could well indicate a vegetative response, which may not result in yield responses in the field.

Results from trials on fluid P fertilisers conducted in other parts of Australia are listed in the research summaries later in this report (Appendix 1). These include eight trials in South Australia, 14 trials in Western Australia, one trial in Victoria, and five trials on wheat and sorghum in Queensland. The trials have been conducted on a mixture of high pH and low pH soils, generally in conjunction with additions of nitrogen and other nutrients.

In two trials conducted in Western Australia there was an improved response from fluid P fertiliser on low pH soils described as having a high P fixation potential. In two of the trials conducted in Western Australia, one in Victoria and two in South Australia, granular P fertilisers produced better yields than fluid P.

However, some of these trials do not provide satisfactory evidence either way. This is because there was no response to P fertiliser or because deficiencies of nutrients other than P may have prevented a response to P. In some cases there may have been problems with the application of the fluid fertilisers.

A factorial design is appropriate to test response to other nutrients. On alkaline clay soils in South Australia there have been instances where a response to zinc has not occurred unless it has been applied with N and P in fluid form.

Despite some limitations of the research information to date, it generally indicates that fluid P fertilisers are not likely to provide additional response over granular P fertilisers, unless there are soil limitations to P availability and/or immobilisation of fertiliser P.

This suggests that most cropping soils in Australia will not show improved crop yields from applications of fluid P fertiliser. In some instances, research suggests lower rates of P applied in fluid form may produce similar yields to larger amounts in granular form, but the extra cost of fluid P means that a large improvement in efficiency or an improvement in yield is needed for fluid P fertilisers to be viable.

An important difference to the South Australian soils, which contain high levels of calcium carbonate, is that most cropping soils in other parts of Australia do not appear to have the problem of plants being deficient in phosphate despite the presence of high levels of P in the soil.

These conclusions are supported by research in the United States of America. While soil and climate situations in the United States are different from those in Australia, there are many soils and rainfall situations that should have provided a testing ground for liquid fertiliser responses.

According to Dr Sam Kinchloe, writing in the *Efficient Fertiliser Use Manual*, "a considerable amount of research supports the conclusion that there are essentially no differences among the fluid, suspension and dry fertilisers when they are compared over the long term under conditions of similar nutrient rates, placements, and chemical forms."

Despite the conclusion that most cropping soils in Australia will not show improved crop yields from applications of fluid P fertiliser, there is a need for more research to define the extent of 'responsive' soils and to better understand the situations and mechanisms that can result in a response from fluid P.

There is also a need to continue existing research on calcareous soils to optimise the benefits and costs. There is a major drawback with the cost of fluid fertiliser. Suspensions of granular fertilisers offer scope for bringing down the cost of fluid P.

Further research should be conducted on calcareous soils with fluid suspensions that can be produced locally or sourced from the point of manufacture where they can be based on monoammonium phosphate (MAP) or diammonium phosphate (DAP) before they are dried and granulated, removing these costs from the process.

1.2 Fluid N fertilisers

The use of fluid nitrogen (N) fertilisers is increasing, particularly in Western Australia where convenience of use is the stimulus for farmers to change from granular fertilisers. A similar motivation appears to influence farmers in the United States to use fluid fertiliser, where around 20% of all fertiliser (excluding anhydrous ammonia) is applied in fluid form.

There are extra costs associated with changing to fluid fertilisers, with the average farmer spending around \$70,000 to install storage tanks and modify equipment to handle fluids. The cost of the nitrogen in a fluid form in Western Australia is around 20% higher, with additional freight costs.

This means it is difficult to justify the extra cost of fluid N fertiliser on convenience grounds, because the additional cost of using fluid N could amount to \$15,000 on a typical farm with 1000 ha of crop.

In the eastern states of Australia, the current pricing of fluid N products makes them around double the cost per kg of N and very few graingrowers use fluid N fertilisers in their cropping program. The main use of fluid N fertiliser has been in post-sowing applications of additional nitrogen.

Post-sowing applications of nitrogen can help to adjust nitrogen supply in response to yield potential, but research indicates variable results and some loss of nitrogen is possible. In northern Australia, post-sowing applications of nitrogen are unreliable because follow-up rainfall may be too late to benefit the crop.

1.3 The future of fluids

The use of fluid P fertilisers is likely to increase on soils with problems of phosphate availability. Lower cost suspensions of P fertiliser could enhance the use of and profit from these fertilisers. Cost is a major barrier to the use of fluid N fertiliser, which will expand if the prices become more competitive.

Better application methods may also help. Farmers using fluid fertilisers have had problems with the availability of suitable equipment and advice. New equipment is becoming available to handle fluid fertilisers, including airseeders, which have a fluid fertiliser tank. Special pumps and handling equipment are being imported from overseas and experience in their use is now building in Australia.

Multiple blends of nutrients, including potassium, sulphur and trace elements, are convenient to use in a fluid form. There are indications of improved efficiency from adding some trace elements to starter fertilisers. The young plant roots will proliferate in the bands of applied phosphate and also absorb other nutrients.

Precision farming techniques with variable rate application of fertiliser may stimulate further use of fluid fertilisers. The benefits of variable rate application are likely to be greatest on large farms in low rainfall areas, where cost savings on fertiliser application are important.

2. Overview of current usage of fluid fertilisers

Farmers are increasing their usage of fluid fertiliser in Australia, but it is still less than 2% of total fertiliser use, according to the most recent survey by the Fertiliser Industry Federation of Australia (see Table 1).

This is much lower than in the United States of America, where some estimates of fluid fertilisers as a percentage of the total fertiliser use are as high as 40%. However, US fluid fertiliser figures include anhydrous ammonia, which comprises around 20% of fertiliser use. Without the inclusion of ammonia, fluid fertilisers represent around 20% of the total US fertiliser consumption of around 20 million tonnes per annum.

In Western Europe, more than 90% of fertilisers used are granulated or prilled solid fertiliser, with 10% in fluid form, mostly urea-ammonium nitrate solution (UAN) (Isherwood 2001).

In recent years, use of fluid fertilisers has increased in Western Australia and in South Australia. In Western Australia the main interest has been in the application of nitrogen. In South Australia, the interest has been in response to research work that has demonstrated more efficient uptake of phosphorus and improved yields of wheat on calcareous soils.

Very few graingrowers in other states are using fluid fertilisers as a regular part of their cropping programs. There has been no research demonstrating agronomic benefits and the cost of the nutrient in fluid form or logistical problems associated with fluid fertiliser have generally deterred farmers from its use.

A liquid nitrogen product, Easy N, has been available for many years in Queensland and northern New South Wales, but it is used in limited quantities, mainly by wheat growers in post-sowing applications of additional nitrogen in years of good yield potential. More liquid nitrogen has been used on cotton than on grain crops in northern Australia.

Why then are fluid fertilisers being used in South Australia and Western Australia and not in other states? In South Australia farmers are using fluid P fertilisers, which are more expensive, but they are finding that there are significant yield responses or that they can use less P and achieve the same result for the same cost. In Western Australia, farmers are using fluid N fertilisers, because the cost is only marginally higher than for solid fertilisers. In other states, UAN or other fluid N products are generally twice the price, which makes their use uneconomic.

A significant proportion of the fluid fertiliser sold is used by fruit and vegetable growers, where the extra cost and logistical problems of fluid fertilisers are not as significant as they are for broadacre farmers.

Table 1. Fertiliser sales in Australia. 2002 calendar year *

	Product (t)	Nutrient (t)			
		N	P	K	S
Solid fertilisers (including Anhydrous Ammonia)					
NSW	1,355,389	283,338	128,507	11,516	78,983
NT	6,799	1,067	730	427	443
QLD	580,581	179,145	20,186	39,017	21,539
SA	586,524	103,628	68,502	6,296	32,785
TAS	190,557	18,071	15,738	13,317	12,517
VIC	1,150,290	135,988	110,823	37,381	84,979
WA	1,484,675	230,248	125,606	70,214	115,551
Total	5,354,815	951,484	470,093	178,168	346,796
Liquid fertilisers #					
NSW	3,881	449	98	314	56
NT	3.0	0.2	0.1	0.1	0.0
QLD	4,107	572	91	251	56
SA	3,493	226	51	56	109
TAS	89	7	3	4	1
VIC	4,575	829	51	142	85
WA	59,564	18,698	12	19	161
Total	75,711	20,782	306	785	467
Liquid fertilisers as % of total fertilisers used					
NSW	0.29	0.16	0.08	2.65	0.07
NT	0.04	0.02	0.01	0.02	0.00
QLD	0.70	0.32	0.45	0.64	0.26
SA	0.59	0.22	0.07	0.88	0.33
TAS	0.05	0.04	0.02	0.03	0.00
VIC	0.40	0.61	0.05	0.38	0.10
WA	3.86	7.51	0.01	0.03	0.14
Total	1.39%	2.14%	0.06%	0.44%	0.13%

* From a survey by the Fertiliser Industry Federation of Australia

Some suppliers of liquid fertilisers are not represented in the FIFA

3. Trends and potential for use of fluid fertilisers

An increase in the use of fluid forms of fertiliser is likely if the cost of nutrients becomes more competitive and the logistics of handling large amounts of liquid are better managed.

The main potential growth area is the use of fluid phosphorus fertiliser on calcareous soils in southern Australia. The geographic extent and characteristics of these responsive soils need further clarification, but it is estimated that there could be as many as 3000 farms, growing almost 2 million hectares of crop, that could show benefits from the use of fluid P fertiliser. There are currently around 80 farmers using fluid P fertiliser for some or all of their fertiliser requirements.

Some parts of the Victorian Mallee have soils with a high enough calcium level to produce responses to fluid fertiliser. A small part of Western Australia also has highly calcareous soils.

If consistent benefits from fluid P fertiliser are found on low pH soils where high iron and aluminium levels or other soil factors may be causing problems with P availability, then the potential use of fluid P fertiliser will expand.

There has been a rapid increase in use of fluid nitrogen fertiliser in Western Australia in recent years. If this increase in use continues, fluid nitrogen will become a significant percentage of fertiliser use.

New equipment is becoming available to handle fluid fertilisers, including airseeders that have a fluid fertiliser tank. Special pumps and other handling equipment are being imported from Europe and America.

The use of fluid fertiliser may have advantages in precision farming applications where variable rate application of fertiliser is being considered. It is possible to have variable application rates for different fertilisers, with one controller operating granular fertiliser being distributed by an airseeder, with another controller on a fluid fertiliser stream from a fluid tank on the same airseeder. Alternatively one of the nutrients could be applied in a separate operation using a boomspray.

Across Australia, soil fertility is generally declining with removal of crop and livestock products. Deficiency of nutrients such as potassium and sulphur is being identified more frequently, as well as of trace elements such as zinc and copper.

Fertiliser products are changing with more blends of nutrients being used by farmers. Fluid may offer some advantages in preparing and applying some of these blends.

These trends and potential benefits will be discussed later in this report.

4. Fluid fertiliser use in Australia – products and pricing

4.1 Cost of fluid fertiliser products

The most important factor in the use of fluid fertilisers is the cost per kilogram of nutrient. Generally this cost is higher than that of the granular fertiliser alternative.

Some of the fluid fertiliser products available are generic, but most fertilisers are being sold as specialty products which are blends or variations on generic fluid fertilisers. The main products in use are compared in the tables below with alternative fertilisers on an ingredient basis.

Table 2: Comparative cost of fluid and granular nitrogen fertiliser

	% nitrogen	\$/tonne	\$/kg N
Urea (Port WA)	46%	\$360	78c
Urea (Brisbane Qld)	46%	\$360	78c
UAN (Brisbane Qld)	32%	\$650	203c
Flexi-N (CSBP WA)	32%	\$300	94c

The most common fluid fertiliser in use in Western Australia is Flexi-N, which has a 20% price premium over the solid fertiliser product. By comparison, the quoted price for UAN solutions, ex Brisbane, results in a cost per kilo of N more than twice that of urea. Some discounts may be obtained for large quantities. One reason for the extra cost per kg of N in UAN is that it contains ammonium nitrate, for which the cost per kilogram of nitrogen is much higher than that for urea.

Table 3: Comparative cost of fluid and granular phosphorus fertilisers

	% P	% N	\$/l or kg	\$/kg P*
MAP (Brisbane Qld)	22%	12%	\$470	\$1.74
MAP technical grade	26%	12%	\$1200	\$4.15
LMAP liquid	21%	14%	\$1650	\$7.33
APP	22%	14%	\$1200	\$4.80
Phosphoric acid (Vic)	33%	-	\$1244	\$3.77

All fluid phosphate fertilisers are more expensive than the solid fertiliser alternative, and in some cases three to four times the cost per kilogram of phosphate.

4.2 Fluid fertiliser products currently on the market

Ammonium polyphosphate (APP) is sold by **Agrichem** as Polyphos, which has 13% nitrogen and 20% phosphorus, while their LMAP product has 14% nitrogen and 21% phosphorus. At a quoted price of \$1.65/litre, the LMAP product is an expensive form of phosphate, and more expensive than quoted prices for imported APP.

APP is a common fertiliser used in the United States and is generally quoted as a 10:34:0 product, where the 34% P is the oxide P_2O_5 . On a weight for volume elemental basis 10:34 is equivalent to 14:21.

Polyphosphate is made by heating phosphoric acid to remove water to produce superphosphoric acid. The result of this reaction is $H_5P_3O_{10}$ which is soluble in water, but in storage some of the poly-P will split to form ortho-P (phosphoric acid, which drops the pH of the solution and is more corrosive). Ammonia is added to neutralise the pH drop and improve the nutrient status of the fertiliser. The result is ammonium-poly-P (10-34-0).

As well as its APP products, Polyphos and LMAP™ (Liquid Managed Available Phosphorus), Agrichem sells other fluid fertiliser products which include:

- Supa N32 (UAN) (32-0-0)
- Nitrohumus 323 (32-0-0 + 3% humic acid)
- High NP (14-12-3 + trace elements)
- Agri K 415 (0-0-45)
- Endurance KS (0-0-30 + 25% sulphur)
- Supa Trace 10 (5% N + 3% Zn, 3% Fe, 2% Mn, 1% Cu, 0.77% B)
- Broadacre Zinc (65% Zn + 10% germination booster)

Incitec Pivot is trialing a suspension fluid product in southern Australia, Easy NP (10 % N and 13% P). Easy NP is manufactured by ammoniating fine-grade MAP (not technical grade). This results in a suspension of DAP/MAP crystals, which by its crystalline nature stays in suspension rather than settling out.

This product has been evaluated in Victoria and South Australia and is providing similar results to APP. This season it is being evaluated at Coonamble and Narromine in New South Wales. The commercial release of the product for next season will depend on the results from trials in 2003.

Easy NP has been evaluated at Emerald Rise in South Australia, together with other fertiliser slurry mixtures (Holloway, Frischke and Brace 2002). The suspensions performed well by comparison with other fluid P fertilisers, such as APP. APP is a clear liquid, which is easier to handle, but it is difficult to mix zinc and manganese sulphate with it. The suspensions are a thicker solution than clear fluid fertilisers, but were not as difficult to apply as expected.

In the United States, such suspensions represent a significant portion of the 'fluid P' market, and they are likely to become more important here. The main reason is that they can be manufactured locally at a cost that is not likely to be much greater per unit of nutrient than that of granular P fertilisers.

Ammonium polyphosphate products will always be expensive, unless manufactured in Australia. According to Roy Hildebrand from Incitec Pivot (Brisbane), his company is investigating APP but they have no intention of investing in manufacturing facilities at this stage.

Spraygro markets a range of fluid products in southern Australia, which includes:

- N Blast 42 (42:0:0). Lo Bi urea is used in this product, which according to Spraygro alleviates the potential for tip burn. This is used as a boost to yield and protein levels. Ideal for cereals.
- 42N (42:0:0) is a product produced from normal urea and as a boost to yield and protein levels.
- NBH 404 (40:0:0) is a mixture of nitrogen and humic acid (4%). It is used to boost protein and yield levels, with the humic acid designed to enhance uptake and improve soil cation exchange capacity.
- Nitrasulf (15:0:0) with 34 gm/L sulphur is a product designed to increase sulphur levels while nitrogen levels help to assist absorption. Ideal product for canola.

- Canola booster (6:0:0) + 15S + Mn, Zn, Cu, Bo, is a blend of nitrogen and trace elements designed to improve oil content in canola. This product, trialed before release in the South East of South Australia, is a multi fluid trace element fertiliser.
- Maxi Phos Injecta-21 (10:16:0) is suitable for use on alkaline calcareous soils.

CSBP in Western Australia began fluid fertiliser production in 1999 with the release of Flexi-N, a premium fluid nitrogen fertiliser for use in cereal and canola crops.

The range was soon expanded to include Flexi-NS and Liqui-NS. Flexi-NS is a premium fluid nitrogen and sulphur fertiliser designed for topping up cereal and canola crops with a high sulphur requirement. Liqui-NS has a similar use, however it is an economy fertiliser, and as such has limitations.

Premium fertilisers are more expensive. They have a higher concentration of nutrient, handle better (less blockages through boomsprays) and can be stored for more than 12 months without deteriorating. Economy fertilisers are cheaper, with a lower nutrient concentration, and should be used in the year of purchase.

CSBP then introduced Flexi-NP, Flexi-NK, Flexi-NPK and Liqui-NP in 2003. As their names suggest, they are either premium or economy liquids comprising the three major nutrients (nitrogen, phosphorus and potassium), and have been designed more for use at seeding than as a post-emergent top-up, due to their phosphorus content. The exception is Flexi-NK, which is suitable for use as a nitrogen and potassium top-up on both crops and pastures.

Table 4: Current products and pricing of CSBP fluid fertilisers

Product	Price (\$/t)	Analysis (% by weight)				Bulk density
		N%	P%	K%	S%	
Flexi-N	300	32.0				1.32
Flexi-NS	303	28.0			5.0	1.32
Flexi-NP	430	21.6	7.1			1.37
Flexi-NK	210	15.0		8.0		1.20
Flexi-NPK	383	12.6	8.2	5.2		1.33
Liqui-NS	207	21.5			5.5	1.24
Liqui-NP	380	8.9	11.8			1.34

Price (\$/t) is list price (ex GST) for October 2003 pick-up Kwinana.
No charges (freight etc) added or deducted.

Summit is a joint venture between Ag Direct Sales Pty Ltd (a WA-owned company) and Sumitomo Australia (based in New South Wales). It began in 1989 with a shipment of 5000 tonnes of DAP into Western Australia, and has since grown to become the second largest supplier of fertiliser in that state. Summit also trades via a 'cousin' operation in the eastern states. However, so far, their fluid fertilisers have been used only in Western Australia.

MAXamFLO was introduced as a liquid nitrogen and sulphur fertiliser in 2002. It was the first liquid combination of both nitrogen and sulphur available for broadacre use in Western Australia. MAPZFLO and VigourFLO were then introduced in 2003 — MAPZFLO as a phosphate-based liquid, and VigourFLO as a combination of the three macro nutrients, nitrogen, phosphorus and potassium.

Table 5: Current products and pricing of Summit fluid fertilisers

Product	Price (\$/t)	Analysis (% by weight)				Bulk density
		N%	P%	K%	S%	
MAXamFLO	217	22.0			6.2	1.26
MAPZFLO	394	4.9	12.9		1.1	1.35
VigourFLO	380	5.0	8.7	7.0	0.8	1.35
Price (\$/t) is list price (ex GST) for October 2003 pick-up Kwinana. No charges (freight etc) added or deducted.						

All three products are used at seeding (banded or dribbled onto the furrow, or through the boomspray), although an estimated 40% of MAXamFLO is used post-emergent as a top-up. Generally speaking, Summit fluids contain more phosphorus and sulphur than their CSBP counterparts, but less nitrogen (with the exception of MAXamFLO). At present they have no equivalent for Flexi-N, Flexi-NP, Flexi NS or Flexi-NK.

Rural Liquid Fertilisers (RLF) is the only other company currently supplying a significant amount of macro liquids to broadacre agriculture in Western Australia. RLF began in Western Australia in 1991, and now operates Australia-wide.

RLF has five fluid fertilisers in its broadacre range: Cereal Plus, Canola Plus, Legume Plus, Pasture Plus, and Cotton Plus, of which the first three are the most commonly used in Western Australia.

Fertisol fluid fertiliser products include:

- UAN N42% (Urea Ammonium Nitrate)
- UAN N42% + 5% Humic Plus
- UAN with various trace elements to order
- NP (9:14:0 Zn 0.6%)
- NPK (7:12:9 Zn 0.6%)
- NP / NPK with Zn, Cu and Mn – various analysis
- NP / NPK with various trace elements to order
- Omniboost K (crop foliar application)

4.3 Farmer-prepared fluid fertilisers

It is possible for farmers to prepare both nitrogenous and phosphorus fertilisers, or mixtures from the solid fertiliser materials currently sold in Australia.

Clear solutions of mixed analysis including P require the use of phosphoric acid. If suitable fluid mixing equipment is available, slurry-type fluid products can be made, often with a higher analysis than with clear solutions.

There are various problems in dissolving granular fertilisers, which include the effect of temperature. Often heating is required to dissolve the fertiliser quickly (see Table 6).

Commercial fertilisers do not dissolve completely. Undissolved residues collect in the mixing tank and may cause blockages in application and handling equipment unless adequate filtration is installed. Provision should also be made for periodically cleaning out mixing and storage tanks.

However, it should be possible for farmers to overcome the problems of producing their own suspension fluid fertilisers, which would be much cheaper than commercial products. The equipment for heating to dissolve urea in water could be mobile and shared by farmers.

Various forms of MAP and DAP have different levels of impurity and solubility. The more iron and other minerals, the harder the granule, but the more insoluble the product. Incitec Pivot has been importing a relatively pure form of MAP called SMAP, which can be dissolved in water.

Table 6: Solubility and pH of some commercial fertilisers

Product	Solubility in kg/1000 litres			pH of solution	Comments
	10 ⁰ C	20 ⁰ C	26 ⁰ C		
Urea	840	1073	1233	9.5	Solution cools as it dissolves
Ammonium nitrate	1580	1991	2259	5.6	Corrosive to galvanised iron and brass
MAP	295	384	434	4.5	Corrosive to carbon steel
DAP	628	696	730	7.6	Corrosive to carbon steel
Sulphate of potash	92	115	120	8.5	Corrosive to mild steel
Potassium nitrate	210	335	403	10.8	Solution cools as it dissolves. Corrosive to metals

Source: *Fertiliser Handbook*, Incitec Ltd. Revised 1990

5. Benefits of fluid fertilisers over granular products

With the cost of nutrients in fluid fertilisers generally higher than in granular fertilisers, significant gains in crop yield or efficiency of fertiliser use are needed to warrant switching to fluid fertilisers.

Research in South Australia has demonstrated instances of higher yields and/or similar crop responses from less nutrients when P is applied in a fluid form than from granular fertilisers. Generally the research in other areas of Australia and overseas does not indicate any significant gain.

Farmers need to be able to predict the soil conditions or situations where fluid fertilisers will respond better than granular forms and whether they will be cost-competitive, before their use is likely to increase significantly.

The other major advantage of fluid fertilisers is convenience of use. However, farmers need to invest a significant amount of capital in storage facilities and application equipment to achieve benefits of convenience.

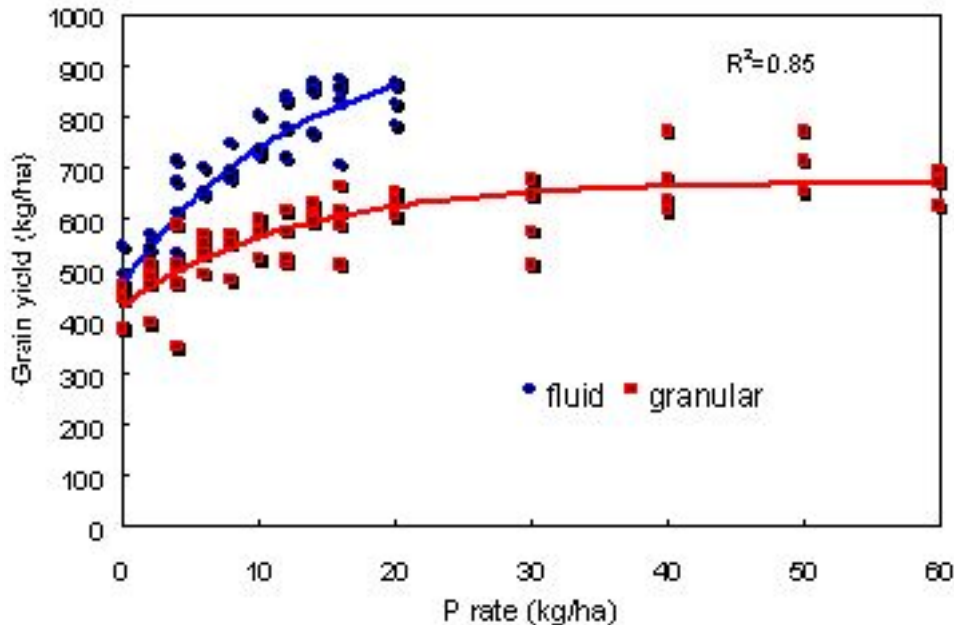
The benefits and economics of fluid fertilisers are discussed in more detail under the following headings:

1. **Higher yields:** In some instances yields have been greater with fluid fertilisers containing phosphate, compared to granular fertiliser, irrespective of rate of nutrient applied.
2. **Efficiency:** Some soil types are responsive to fluid fertilisers where a similar response occurs with a lower rate of nutrient. Efficiency may be a response of nutrient availability, placement or nutrient interactions.
3. **Placement** of fertiliser can be important with respect to avoiding seedling damage and maximising the efficiency of early uptake of phosphorus by the plant. Fluid fertilisers may provide more precise placement or advantages in keeping fertiliser away from the seed.
4. **Convenience** may be an advantage in some instances, with fluid fertilisers requiring less labour at critical periods such as planting time. Pumps and tankers may be more efficient than bins and augers.
5. **Blends** of fertilisers are becoming more common. Fluid fertilisers may be easier to blend and/or may have some advantages over granular products with respect to settling out.
6. **Mixing** with other products, such as insecticides and fungicides, may be possible when fluid fertilisers are used in post-planting situations.
7. **Precision application** and variable rate application of fertilisers, based on yield mapping and soil type variation, may be more convenient with fluid fertilisers.
8. **Losses** of fertiliser by leaching or volatilisation may be reduced in some instances where fluids are used instead of granular products.
9. **Timing** may be important. Fluid fertilisers have some advantages in the post-planting applications of nitrogen.
10. **Early vigour** from applied P in fluid form may be an advantage.

5.1 Higher yields

In some instances yields have been increased with fluid fertilisers instead of granular products, irrespective of the rate of nutrient applied. Holloway and other researchers have demonstrated this result on calcareous soils on the Eyre Peninsula of South Australia.

Figure 1: Grain yield response of wheat to fluid and granular P fertilisers, Yandra SA, 1999



In trials conducted from 1998 to 2001, grain yield responses from fluid P fertiliser at the Yandra site averaged 24%, with a range of 14– 31%.

In 1999, as demonstrated above, a gain in yield of approximately 200 kg/ha would have added around \$36/ha to gross income. If 12 kg of P were used in the form of APP at a cost of \$5.50/kg P, the extra cost over an application of 15 kg/ha P as DAP at \$2.30/kg P would be \$30/ha.

In a good year (e.g. 2000) with a yield response of 14%, improving wheat yield from 2.33 t/ha to 2.66 t/ha, the gain in value would be approximately \$60/ha, compared to the additional cost of fertiliser at \$30/ha.

Some farmers are using phosphoric acid, which has a lower cost per kilogram of P, of around \$3.50. The future use of suspensions could bring this cost down even lower.

Despite this trial work, the general conclusion to be drawn from fluid fertiliser research, both in Australia and in the United States, is that, in the majority of soils and situations, no differences in yield are expected from fluid fertiliser than from granular forms.

This is discussed in more detail in research work assembled later in this report) Appendix 1), but in a total of more than 20 useful trials in South Australia, Western Australia, Victoria and Queensland, only two significant responses have been recorded from fluid P fertilisers compared to MAP, whether applied with or without added nitrogen.

In two of the trials conducted in Western Australia, and two in South Australia, granular P fertilisers produced better yields than fluid P applications.

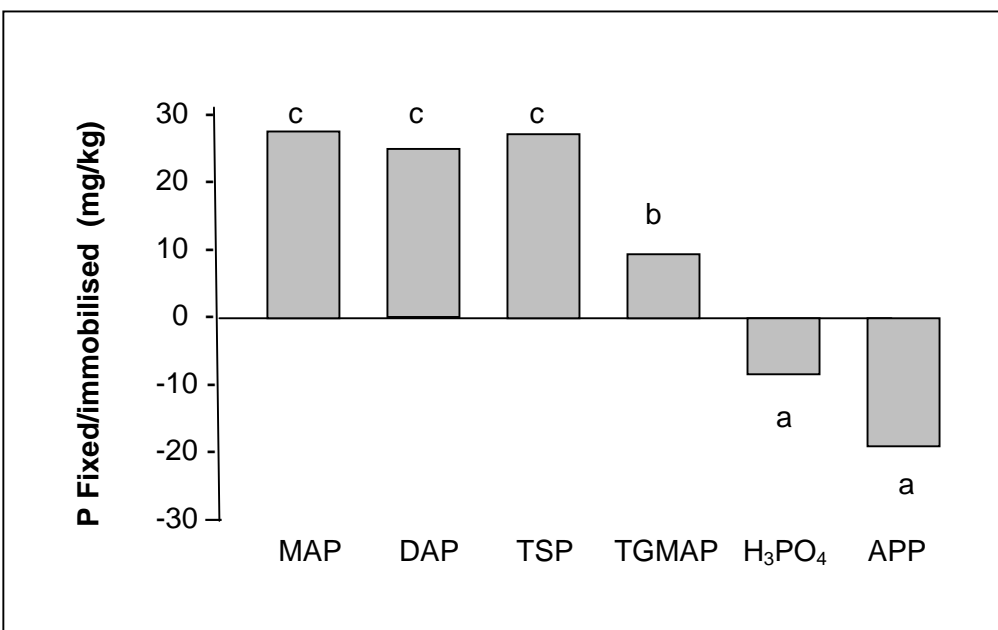
5.2 Efficiency of plant uptake of applied nutrients

Some soil types are responsive to fluid fertilisers where a similar response occurs with a much lower rate of nutrient. Efficiency may be a response of nutrient availability, placement or nutrient interactions. The most important interaction relates to the fixation of phosphate fertiliser, and the preliminary evidence that some forms of P may respond differently in the soil solution.

Research by McLaughlin et al. (2002) has demonstrated less fixation of fertiliser in the soil, and in the case of ammonium polyphosphate (APP) a significant mobilisation of soil reserves of P following application (see Figure 2).

Figure 2: Amount of phosphorus fixed by a calcareous soil

(After the addition of fertilisers, monoammonium phosphate (MAP), diammonium phosphate (DAP), triple superphosphate (TSP), technical Grade MAP in solution (TGMAP), phosphoric acid (H_3PO_4) and ammonium polyphosphate (APP).)



Studies indicate there is a greater rate of P diffusion away from the bands of fluid fertilisers compared to the granular formulations. This is demonstrated by the reduced fixation of technical grade MAP in suspension, compared to granular MAP.

Phosphoric acid (H_3PO_4) also showed a slight mobilisation of P (approximately 4 mg/kg of P), which is likely to be a result of acidification in the fertilised band in the soil.

Although there is some evidence for mobilisation of P when APP is used, the field trial results do not generally support an increase in P efficiency from APP compared with other fluid P fertilisers. If there was a significant P mobilisation, this should produce a greatly enhanced response from APP, compared to such mixtures as liquid MAP.

While it may be possible to achieve similar crop yields from much less P applied in fluid form, the effect of long-term fertilisation needs to be considered. Crop removal rates for wheat are in the vicinity of 3.5 kg P/tonne of grain. This means that if more than 7 kg P/ha is added on a site producing an average yield of 2 t/ha, the P content of the soil will build up and responses to P may diminish.

This has been the case in some parts of southern Australia, with a long-term history of superphosphate usage, and in northern Australia where MAP fertilisers have been used continuously for many years.

5.3 Placement

Placement of fertiliser can be important in terms of the timing and quantity of uptake of nutrients and possible advantages in keeping fertiliser away from the seed.

Research in South Australia has compared the effect of placing P, either with the seed or 2 cm below it, using both fluid and granular fertilisers at three separate sites. An average of 11% more grain was produced when both fluid and granular fertilisers were placed *below* the seed compared to *with* the seed. At these three sites, the fluid fertilisers still yielded higher than the granular products.

In Queensland and northern New South Wales, a series of trials was conducted during the 1980s by Consolidated Fertilisers Ltd on the deep placement of nitrogen and phosphate fertilisers. The results were varied, with some small beneficial responses in some years and at some sites, and negative responses at other times. The negative responses were explained by the adverse seedbed disruption on clay soils when a fertiliser application tine is operating below the normal seeding depth and cultivated layer. Large clods of earth are sometimes displaced, resulting in excessive drying of the soil and/or poor soil seed contact and poor plant stands.

5.4 Convenience

Farmers in Western Australia are increasing their use of fluid fertiliser, largely due to the ease of storage and handling. Extra costs may be involved in storage tanks, but the use of pumps, rather than augers, may be an advantage in some instances.

However, it is possible to set up very efficient application systems for granular fertilisers, with bulk delivery and storage of these fertilisers in silos, which may also be used to store grain. Some farmers argue the convenience benefits are minimal.

One of the major benefits of using fluid N fertilisers, identified by farmers in Western Australia, is that they require less labour at critical periods such as planting time. If the fluid N fertilisers are delivered as required by the fertiliser company and applied by a spray contractor, then a farm may need one less labour unit at planting time.

The use of spreading contractors would achieve the same for granular fertiliser, but the availability of a spreading contractor may be more limited than that of spraying contractors.

Some fertiliser products, such as DAP, are hygroscopic and the absorption of water can cause handling difficulties during transport, storage and application.

5.5 Blends

There are some advantages using fluid products for blends of various nutrients. The fluid products are generally homogenous, without problems of different sized granules which may cause settling-out when blends of granular fertilisers are handled and distributed using airseeders.

Fluid fertilisers do not generally have compatibility problems, but products such as APP can form liquid gels when zinc and manganese sulphate are mixed.

5.6 Mixing

Post-emergence applications of fertiliser may be mixed with other products such as weedicides, insecticides and fungicides.

There are drawbacks, such as the potential for enhanced crop damage, when using nitrogen fertilisers with weedicides. A general interpretation of research and practical experience is that herbicides are normally compatible with fertilisers, but there is the potential risk of increased crop damage from herbicides on winter cereals.

There is always some risk of crop damage when hormone-type weedicides (such as 2,4-D and picloram) are used on rapidly-growing cereals. When applied with nitrogen fertiliser, these herbicides have a higher risk of crop damage because they are taken up by the plant more rapidly and the plant is given a growth boost by the nitrogen. However, crop damage from sulphonylurea herbicides is less likely to occur when plants are actively growing and stimulated by foliar-applied nitrogen.

5.7 Variable rate application

The use of variable rate application of fertilisers, based on yield mapping and soil type variation, is increasing. Controllers are available for variable rate application of granular fertilisers, but there may be some advantages to the use of fluid fertilisers in some situations. It is possible that variable rate application could be used differentially for two different nutrients applied at the same time, either by a fluid system with two tanks and distribution lines or by a granular and a fluid system operating at the same time.

5.8 Losses

Leaching or volatilisation of fertiliser can cause losses, particularly for nitrogen. Different forms of nutrients and application have different potential for loss.

For example, volatilisation of nitrogen can be significant for surface-applied urea, whereas loss from ammonium nitrate is minimal. UAN is a mixture of the two and there is some evidence of reduced ammonia losses from UAN in a fluid form than from the application of urea (see discussion on research).

High-pressure injection of fluid fertiliser is being trialed in South Australia and may offer a way to reduce losses of ammonia from surface-applied urea.

5.9 Timing

Fluid fertilisers have some advantages in the post-planting applications of nitrogen to top up the nitrogen supply to meet increased yield potential and/or to increase the nitrogen supply of wheat around flowering time to boost grain protein levels.

The advantages are that some direct absorption of nitrogen occurs via the plant foliage and the remaining nitrogen may be less prone to volatilisation losses. The results of research on this subject are mixed (see Research Reports 14–18 in Appendix 1), but in some instances, such as a trial of foliar UAN vs urea at the Mintaro Field Site in 2002 (not included in the research reports), late applications of foliar fertiliser improved grain protein levels by 1–2% compared with little or no response from broadcast urea in a dry year.

5.10 Early vigour

On the Eyre Peninsula, early growth of wheat is greater from fluid P and provides better protection against wind erosion and competition from weeds. The additional organic matter and residual effects from fluid P may improve yields over time.

6. Drawbacks with the use of fluid fertilisers

Farmers need to weigh up advantages and disadvantages of fluid fertiliser use, including the cost of nutrients, freight and application costs. The agronomic implications also need to be thoroughly understood, because there have been instances of yield reduction when fluid fertilisers are compared to granular fertilisers. Details are provided in research results later in this report.

6.1 Cost of nutrients

The main drawback with using fluid fertiliser is the cost differential for nutrients. As the fluid fertiliser industry grows, there may be some reduction in the cost, but some fluid products will always remain more expensive.

In the case of nitrogen, dissolved urea should not cost much more than the solid product, but the fluid form will be less concentrated and the cost of freight from port to farm will be higher because of the extra volume and the need for tankers, rather than cheaper backloading on trucks carting grain.

The cost of nitrogen in a UAN solution will depend upon the additional cost of ammonium nitrate over urea. In some instances, this cost has been twice that of urea, making the final cost of UAN, in \$/kg N terms, higher than urea.

The most expensive fluid phosphate fertiliser is APP, which is more than twice the cost per kg of P in a granular form, such as MAP. Phosphoric acid is cheaper, but like APP will always remain more expensive if it is imported in small quantities.

The most promising development in reducing the cost of fluid P fertiliser is the use of suspensions, where fine grades of MAP or DAP can be used. Slurry blends are likely to be used in the future with different forms of P, such as MAP and phosphoric acid.

6.2 Costs of storage, handling and application

The cost of transport has been mentioned as a disadvantage of fluid fertilisers, because dedicated road tankers are required and farmers are unable to make use of cheaper backloading freight rates from ports. This is likely to double the cost of freight from port, which, for a typical farmer 250 kilometres from port, means the fertiliser could cost \$20/tonne more.

There are costs involved in converting seeding and/or spraying equipment to handle and store fluid fertiliser on-farm. Farmers in Western Australia have typically spent in excess of \$50,000 on equipment and facilities to convert to fluid N fertiliser use. In South Australia, the cost to convert to using fluid P fertilisers has been less, partly because the fertiliser comes in shuttles or 200-litre drums and storage tanks are not necessarily needed.

Tanks for storing fluid fertiliser generally cost around \$6,000 (for 43,000 L capacity). Many farmers have purchased an old milk tanker or have a bulk tank on a truck to refill the fluid cart behind the planter, or the boomspray. This may cost less than \$10,000, or more than \$50,000 if a serviceable prime mover is needed especially for the bulk tanker. A seeding machine can be converted for fluid application for around \$5,000, and a fluid cart costs around \$25,000. If a new airseeder is being purchased (e.g. from Simplicity Airseeders), it will add around \$10,000 to the cost.

If the cost of converting to fluid fertiliser use is assumed to be in the vicinity of \$50,000, then with an interest rate of 8% and depreciation of 10% farmers face an annual cost of \$9,000 or an additional \$9/ha for a farm with around 1000 hectares of cropping land.

6.3 Other problems or disadvantages

One of the main problems with fluid fertiliser use is the corrosive nature of some of the products and the potential for high depreciation losses on expensive items of equipment, such as planters and boomsprays.

The two products of most concern are UAN and phosphoric acid. As well as corrosion and failure of pipes and fittings, the safety of operators is a major concern. There are some situations where farmers may wish to mix UAN with phosphoric acid, but the explosive nature of ammonium nitrate has to be kept in mind.

Leaf burn has been mentioned as a significant issue following application of foliar nitrogen. If water is the major limitation, there may not be much potential yield penalty, but under ideal conditions the leaf burn could cause loss.

One of the advantages mentioned by farmers is the potential to mix fluid nitrogen fertilisers with weedicides and fungicides, and so reduce application costs. Only a slight worsening of crop damage from such products would erode any benefits gained.

Water supply is a significant issue in some farming districts and, if fluid fertiliser has a large requirement for water, this presents a potential disadvantage.

Application of fertiliser in the vicinity of the seed remains a problem for fluid fertiliser, especially if nitrogen and phosphate are applied together. Too much nitrogen in close proximity with the seed can reduce germination and emergence.

Research in South Australia indicates best results from application of fertiliser approximately 5 centimetres below the seed. This can be done satisfactorily on sandy soils or those high in calcium carbonate, but research in Queensland has demonstrated adverse results from deep banding, where there is significant disruption of the seedbed on clay soils.

7. Economic comparisons of fluid fertiliser

7.1 Case study 1: Economics of fluid N use in Western Australia

In this case study, we assume a farm grows 1000 ha of crop each year around 200 kilometres from Perth. A comparison is made between the use of Flexi-N (UAN) fertiliser and urea on 750 ha of wheat each year. The remaining crop area is in legumes, such as lupins.

The farm is in the medium rainfall belt with average yields of 2.5 t/ha and average annual applications of 40 kg N/ha. The cost of storage tanks, purchasing a field supply tanker and converting the farm equipment is \$50,000.

- Cost of urea: 30,000 kg N = 65 tonnes @ \$380/t farm = \$24,700 or \$34/ha
- Cost for Flexi-N: 30,000 kg N = 94 tonnes @ \$330/t farm = \$31,000
- Annual interest (8%) and depreciation (10%) on the extra equipment required worth \$50,000 = \$9,000
- Total cost for Flexi-N = \$40,000 or \$53/ha
- Extra cost for Flexi-N = \$15,300

Farmers say it is more convenient to use fluid fertiliser, but it is difficult to see how improved convenience can warrant the extra cost of \$15,000 in using Flexi-N on such a farm.

Boomsprays are cheaper to use than fertiliser spreaders because they will usually cover more hectares per hour. This could save as much as \$4/ha in costs.

However, this saving is likely to be offset by the increased depreciation on a boomspray used to apply the fertiliser, due to the corrosive nature of the fertilisers. New boomsprays may cost only \$30,000 and can range in price up to \$300,000 for a large self-propelled machine. If the depreciation was doubled from 8% to 16%, the extra cost per year would range from \$2,400 on the \$30,000 machine, to \$24,000 for the large self-propelled machine. If the farm using a \$30,000 boomspray grew 600 ha, then the cost would be \$4/ha. A farmer owning a \$300,000 sprayer is likely to have more than 2400 ha, but this means the extra depreciation could be as high as \$10/ha.

Contractors are likely to charge more for fertiliser application, which would also eliminate any savings in cost between fertiliser spreading and boomsprays.

In eastern Australia, where the cost of UAN is much higher than in Western Australia, the extra cost of fluid N is prohibitive. The only way fluid N fertiliser can be competitive in price is if farmers set up their own facilities to dissolve urea in water.

7.2 Case study 2: Economics of fluid P use in South Australia

In this case study, we assume a farm grows 1500 ha of crop each year around 500 kilometres from Adelaide on the Eyre Peninsula. A comparison is made between the use of phosphoric acid fluid fertiliser and DAP on 1200 ha of wheat each year. Around 300 ha of legumes or canola are planted in years with an early break.

The farm is in a 300 mm rainfall belt with potential average yields of 1.2 t/ha, but only 1 t/ha is being achieved because phosphate availability on the highly calcareous soils is limiting yield. The cost of storage tanks and converting the farm equipment is \$15,000.

- Cost of DAP: 50 kg/ha (10 kg P/ha) x 1200 ha = 60 tonnes @ \$450/t farm = \$27,000 or \$22.5/ha
- Cost for phos. acid: 6 kg P/ha @ \$3.50/kg = \$21,000 or \$17.5/ha
- Additional N application (to make up for the N supplied by the DAP): 10 kg N/ha @ \$0.85/kg = \$8,500
- Annual interest (8%) and depreciation (10%) on \$15,000 worth of plant and equipment for using phos. acid = \$2,700
- Total cost for phos. acid + starter N = \$38,000 or \$31.7/ha

- Additional benefits from 0.2 t/ha extra yield of wheat = 1200 ha x 0.2 x \$170/t = \$40,800

Additional profit from use of phosphoric acid = \$29,800. Provided the yield benefits continue, the use of fluid P makes good economic sense.

There are also additional benefits on these soils, according to farmers, where the fluid P enhances early growth of the crop, provides better protection against soil erosion (from wind) and competes better with weeds. The additional organic matter and possible residual effects from fluid P may also improve yields over time.

8. Research on the use of fluid fertilisers

The outcomes from approximately 100 trials are provided in Appendix 1, containing research reports into the use of fluid fertilisers.

Significant yield and/or efficiency responses have been recorded in research trials on the Eyre Peninsula in South Australia. High yield responses appear to involve highly calcareous soils, where response to granular forms of phosphorus fertiliser is limited.

Results from pot trials on a range of Victorian soils, conducted in 2002, suggest there may be benefits from fluid P fertilisers. However, pot trials have limitations in predicting the potential for fluid fertiliser responses. Fluid fertilisers have been reported as providing early vegetative response, but not a grain yield response. The response in pot trials could well indicate a vegetative response, which may not result in yield responses in the field.

An audit of the research work assembled in this report shows very few trials with positive responses from fluid P fertilisers in other parts of Australia. Research overseas shows a similar conclusion — that, in most situations, there is no difference in the response to fluid fertiliser.

In eight trials conducted across South Australia (mostly in higher rainfall districts and/or where soils are not calcareous), there have not been significant responses to fluid fertiliser compared to granular forms.

Results are presented from 14 trials in Western Australia, which show a response to fluid P fertiliser in only two of these trials. Both sites were on low pH soils, which were described as having a high fixation potential for P. Other sandy soils, with a low pH, but not regarded as having a high P fixation potential, did not show any benefit from fluid P over granular P.

Several trials on wheat and sorghum in Queensland during the 1980s found no significant response from the use of phosphoric acid, compared to MAP, whether applied with or without added nitrogen.

Across Australia, there have been more trials with negative results from fluid P fertiliser than with positive outcomes. One trial from Victoria produced more yield from granular fertiliser compared to application of fluid P (Research Report 9). In two of the trials conducted in Western Australia (Research Report 10), and two in South Australia (Research Report 4), granular P fertilisers also produced better yields than fluid P.

Further research on the mechanisms of phosphate reactions in the soil might shine some light on the reasons for these negative results.

Research in the United States

Fluid fertilisers have been used widely in the United States of America. Dr Sam Kinchloe sums up the agronomic comparisons of fluid and dry fertilisers in the *Efficient Fertiliser Use Manual* (published on the Internet by IMC Global www.IMCglobal.com)

“Although numerous field studies have been performed comparing fluid and dry fertilisers under similar conditions, very little of this research is reported in refereed journals. Rather, it is usually found in experiment station annual reports, which are not widely available. The comparisons most often made have been among solid urea, solid ammonium nitrate and urea-ammonium nitrate (UAN) fluids; between dry ammonium phosphates and fluid ammonium phosphates; and between ammonium orthophosphates and ammonium polyphosphates.

“Experimental data from a wide range of studies overwhelmingly support the conclusion that there are essentially no differences amount the fluid, suspension and dry fertilisers when they are compared over the long term under conditions of similar nutrient rates, placements and chemical forms.

“When solids such as diammonium phosphate (DAP), monoammonium phosphate or ammonium polyphosphate were compared with fluids such as 10-34-0, 8-24-0, or 11-37-0 under similar conditions, long term studies have shown these to be essentially equal in nutritive value.”

While it is acknowledged that the soils and climate in the United States are different from those in Australia, it is likely that there are a wide range of soils and environments, some with the potential to immobilise phosphate in the soil.

Researchers on fluid P in Australia suggest the US research is irrelevant and that much more research work is needed in Australia before we can conclude that there is no significant difference between fluid and granular P fertilisers on the majority of cropping soils.

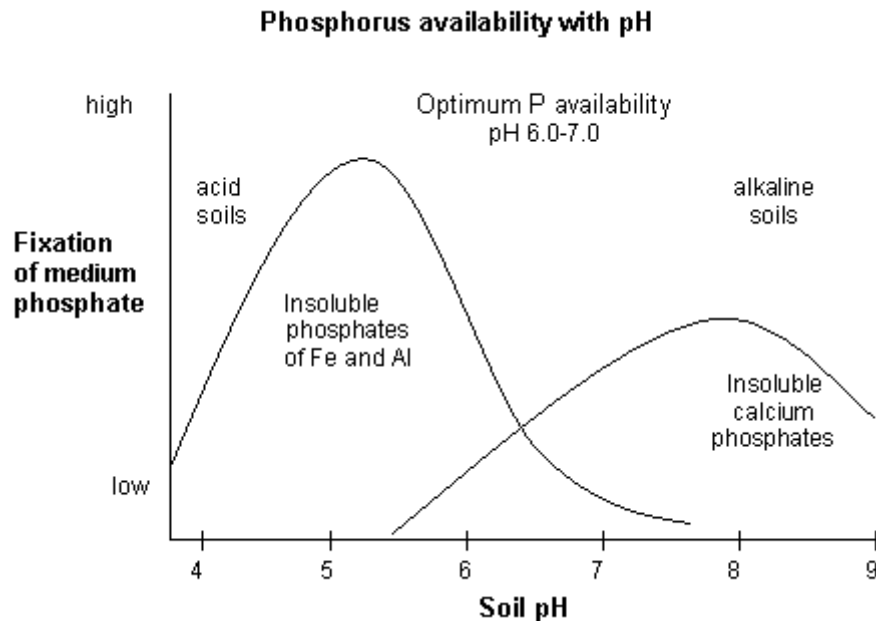
However, the US research and a significant amount of fluid fertiliser use by US farmers do not necessarily point to the likelihood of significant areas of Australia's farmland producing higher yields from the use of fluid P fertiliser.

9. Discussion of research results on fluid P fertilisers

On the highly calcareous soils of the Eyre Peninsula in South Australia, yield responses from fluid forms of P fertiliser have been as high as 45%. The response is little different between technical grade MAP (TGMAP), phosphoric acid (PA) or ammonium polyphosphate (APP).

The results of McLaughlin (2002) (see Figure 2) suggest that APP, and to a lesser extent PA, should be more responsive on these soils, because there is mobilisation of P from soil reserves, rather than fixation or immobilisation which occurs with granular P.

Figure 3. Phosphorus availability with pH



Source: Stephenson and Cole 1999.

Although there are some trial results that support a small increase in P efficiency when the fertiliser APP is used, the field results generally do not support the idea of P mobilisation and a greatly enhanced response from APP.

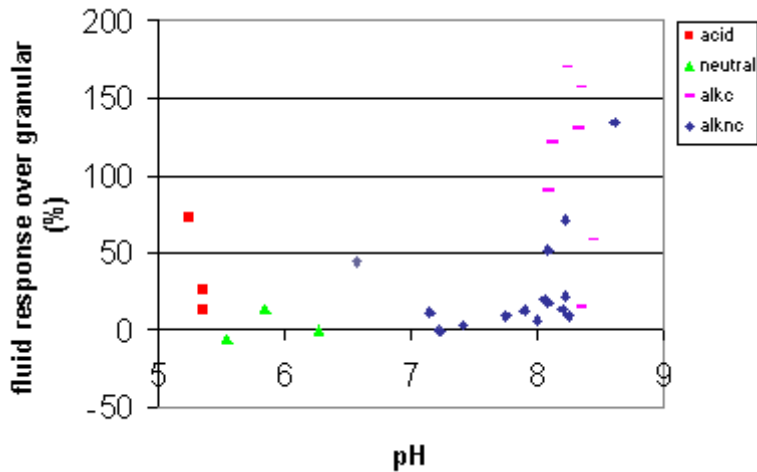
Significant benefits from using fluid P fertilisers appear to be limited to soils with high levels of calcium carbonate. Where iron and aluminium are involved in fixation of P at low pH levels (see Figure 3), there are some indications of improved response from fluid P, validated in two trials conducted at New Norcia in Western Australia (Research Reports 6 and 11).

This analysis of the relative advantage of fluid P fertiliser over granular fertiliser is supported by the research conducted over the last few years in South Australia. Mike McLaughlin provides an analysis of such trials in Figure 4, indicating greater response from fluid P fertilisers at low and high pH levels.

If high pH is important, the question arises as to why fluid forms of P fertiliser do not respond better on black clay soils with a high pH. The indications so far, from trials using phosphoric acid and APP in Queensland and northern New South Wales, suggest they do not. While these soils contain calcium carbonate, it is usually at depth and not high in the surface layers. This may reduce phosphate fixation, which is not high, given the general response of crops on low phosphate soils and good responses to P fertilisers, such as MAP.

Another factor may be the clay type. Kaolinite and other 1:1 clay types are known to fix phosphate more than montmorillonite clays which make up most of the clay fraction of the black earths or vertosols.

Figure 4: Yield response from fluid P fertiliser compared to granular related to soil pH



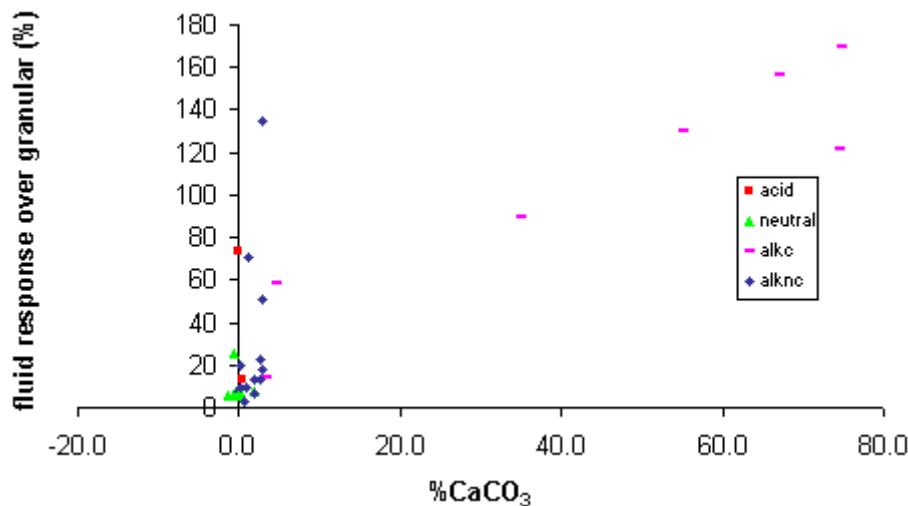
It would seem that the soils of the Upper Eyre Peninsula are unique in composition and, according to Holloway (2000), it is highly probable that chemical processes, when phosphate is added to highly calcareous soils, are unique as well.

Figure 5, supplied by McLaughlin, shows an improved response to fluid P fertilisers on soils with high calcium carbonate levels.

Bertrand et al. (2002) have shown that, on highly calcareous soils, P added as a granular fertiliser is rapidly precipitated as insoluble calcium phosphates, which are not part of the labile pool. Total P concentrations in these soils have reached 760 mg P/kg soil with no increase in exchangeable P. It has been shown that most of this total P has been derived from the addition of P fertiliser.

The likely criterion for a reliable response from fluid P, compared to granular P, is a soil with calcium carbonate levels in excess of 5% and commonly in the range of 20–50%, with indications of poor responsiveness to granular P fertilisers, shown by low plant tissue P, despite high soil P levels.

Figure 5: Yield response from fluid P fertiliser compared to granular related to soil calcium carbonate level



The results of fluid P work are variable, and may depend upon the soil and seasonal conditions. In some situations, the full benefit of P is not realised unless nitrogen, zinc or other micro-nutrients are added to alleviate deficiencies. In other instances, the techniques of distribution may affect the outcome.

Research on the Eyre Peninsula (Holloway et al. 2001a) has tested application rates of 65–414 L/ha. Generally there was no effect of rate, but at Yandra in 2000 the 65 L/ha rate (which was undiluted fertiliser) showed significantly less yield than 120 L/ha, which produced yields similar to higher rates.

In several trial situations, granular fertiliser has produced higher grain yields than fluid P fertiliser. In trials in the higher rainfall areas of the Lower and Mid –North of South Australia, Holloway (2001c) speculates that the use of nitrogen in a liquid form (UAN) with the phosphorus allowed rapid leaching of the nitrogen, which resulted in slower early growth in comparison with granular application of the same nutrients. This suggestion was supported by improved later growth in which fluid-treated plants were able to catch up to the granular-treated plants, presumably when roots reached nitrogen deeper in the profile.

Another possibility for differences in yield, may occur when there is good early growth from liquid phosphate treatments. Interactions with other nutrients may mean that other nutrients, such as nitrogen and manganese, are used up more quickly and become deficient later in the crop. Further interactions may occur when there is good early growth, which may use up more soil water before flowering and run into greater moisture stress during grainfill.

10. Glasshouse research on the potential for fluid P responses

Roger Armstrong at the Victorian Institute for Dryland Agriculture in Horsham, in conjunction with Mike McLaughlin, CSIRO South Australia, and Bob Holloway, SARDI Minnipa SA, conducted glasshouse trials which showed improved efficiency of fluid fertilisers compared to granular forms on a wide range of alkaline soils found in Victoria and including some acid soils (Research Report 7).

Charlie Walker of Incitec Pivot has conducted pot trials of calcareous mallee soils using a range of granular and fluid fertilisers with varying pH of reaction (Research Report 8). There were no significant differences in dry matter responses between P treatments, which included MAP digested in sulphuric acid.

The benefits of fluid P fertiliser on these Victorian soils have yet to be confirmed in the field. Incitec Pivot field trials in 2001, comparing fluid and granular phosphorus fertilisers on a Wimmera grey clay at Warracknabeal and Mallee sandy clay loam at Swan Hill, were complicated by nitrogen deficiencies at both sites. The yield results achieved in each treatment were inconclusive as each treatment received different rates of nitrogen.

At the Avon Richardson Cropping Group site, a comparison in 2001 of granular MAP with fluid MAP on wheat showed a significant difference in yield achieved from the wheat sown with granular MAP compared to the fluid MAP.

Pot trials may not provide a reliable guide of the potential for fluid fertiliser responses. Numerous reports of field trials with fluid fertilisers comment on an early vegetative response, which did not transpose into a grain yield response. The pot trials can indicate only a vegetative response, and are not indicative of grain yield responses in the field.

11. Discussion of research on fluid N fertilisers

Research has been conducted in Western Australia on urea-ammonium nitrate (UAN), which is now the most commonly used broadacre fluid fertiliser in that state, sold as Flexi-N.

The results from 35 trials over the past six years suggest there is no significant difference between using urea and Flexi-N, with 32 of the trials producing similar yields, and no trend towards either product. In the remaining three trials, Flexi-N produced a significantly higher yield at both east Pingelly and east Mullewa, while urea produced significantly more grain yield at Beverley.

Placement of nitrogen has also been researched in Western Australia by CSBP and the Western Australian No-Tillage Farmers Association (WANTFA). Flexi-N banded near the seed has been compared with Flexi-N applied through the boom and urea banded and/or topdressed in 10 trials conducted by CSBP over three years. In 7 of the 10 trials there was no significant difference in yield between either product when topdressed or banded, although early nutrient uptake and growth were improved with banding.

The early benefits of banding did not translate into a yield advantage due to the dry seasonal conditions. The remaining three trials showed Flexi-N to give a significant yield advantage when banded, as opposed to being applied by boomspray.

The results also suggest that Flexi-N is safer to band than urea, but that it can be toxic if placed too close to the seed at high rates (>100L/ha). The risk of toxicity is increased with Flexi-N banded on wide row spacings (>22cm). There appears to be an advantage in banding Flexi-N in weedy situations on wide rows. However, more work is needed to quantify this theory.

The conclusion, therefore, is that while there does not appear to be any yield advantage associated with using Flexi-N through the boom, as opposed to urea topdressed prior to sowing, there does appear to be an advantage when it is banded.

Summit has been conducting nitrogen source and application method trials since 1997. Urea, calcium ammonium nitrate (CAN), plastic-coated urea, agrotain-coated urea and fluid nitrogen (MAXamFLO) have all been compared, to determine which source of N is most likely to give the best return. In addition, each source has been applied in a number of ways, including with the seed, incorporated by sowing (IBS), incorporated after sowing (IAS), banded to the side and below the seed, behind the press wheel, or as a foliar application. In almost all cases (including MAXamFLO) there was no agronomic benefit associated with using an alternative source of N by the methods listed above. Urea topdressed and incorporated by sowing still appears to be effective and provide the most economical method of applying N fertiliser.

WANTFA trials under the direction of Bill Crabtree have shown that banding UAN was as effective as spraying it out, or topdressing urea.

In 2001 grain yield increased by 190 kg/ha where Flexi-N was used compared to urea at the first site. However, this was not repeated at the second site. Splitting the timing of N also increased wheat grain yield at site 1. This trend was more evident with Flexi-N than with urea. Unfortunately the first site was not randomised, so the results cannot be considered reliable. In 2002 there was a 17% increase in canola yield where the Flexi-N was banded, as opposed to broadcast.

A Flexi-N placement trial showed that up to 60 kg N/ha of Flexi-N can be safely banded, provided there is separation between the seed and Flexi-N of 3–4 cm.

11.1 Post-planting nitrogen

A significant aspect of fluid nitrogen use is the potential for late N applications to adjust N supply in line with yield expectations and/or to improve the protein content of the grain. Research shows the responses from late applications of nitrogen to be variable. In some cases there have been significant yield responses, while in others the application of late nitrogen has reduced grain yield. In other cases there is no response to nitrogen applied post-planting.

In general, the research suggests there is little or no difference between topdressed or foliar application of nitrogen. A small amount of nitrogen is absorbed by the plant from foliar sprays, but most of the spray lands on the ground and there needs to be follow-up rainfall for a response.

Responses are more likely at high yield levels, while adverse results are more likely at low yield levels where there is a dry finish to the season.

The relative advantage and costs of ammonium nitrate over urea need to be kept in mind when considering use of N applied either to the soil or as a foliar fertiliser. Quantitative analysis of the loss of urea as ammonia from the soil surface is very difficult and must take account of variations in season, weather and soil type.

One American study, using ammonia samplers and comparisons of yields and N uptake from treatments receiving different sources and/or application methods, compared losses from urea and UAN. Urea showed a loss of 24 kg N/ha over a 16-day period after application of 110 kg N/ha, compared to a loss of 10-13 kg N/ha for dribbled UAN. The loss from sprayed UAN was 18 kg N/ha. Subsequent corn yields showed a 1 t/ha increase with dribbled UAN, compared to urea (Fox and Piekielek 1994).

While ammonium sulphate and ammonium nitrate fertilisers are likely to be more efficient than broadcast urea, the cost per unit of N is almost twice as much and farmers can afford to apply more urea and accept some loss.

A common situation in Western Australia involves application of nitrogen by spray to the ground before planting. Depending upon the amount of soil disturbance by the planter, a significant amount of this nitrogen is covered by soil and protected against loss by volatilisation. Hence there is little or no advantage in using UAN solutions compared to urea in this situation, except that they can generally be made as a more concentrated product.

11.2 Other nutrients

There has been little research in Australia on the use of fluid forms of other nutrients, with the exception of zinc. Foliar sprays of zinc sulphate heptahydrate are commonly used to overcome zinc deficiency. Liquid zinc has been successfully applied in mixtures with liquid P fertilisers at planting time in South Australia, with the exception of problems occurring when zinc has been added to APP and precipitation has occurred.

Sulphur and potassium are available in blends with N in fertilisers in Western Australia (e.g. Flexi-NS, Flexi-NK and VigourFLO). However, there is no information from Australian or overseas research that sulphur or potassium is more effective in a fluid form than in a granular form. In most areas of Australia, the cheapest way to remedy sulphur deficiency is the application of gypsum. Where farmers have access to feedlot or poultry manure, the application of manure is the cheapest way to supply N, P and K along with other minor nutrients, such as sulphur.

12. Recommendations to the GRDC

There are two responses to the interpretation of information on fluid fertilisers prepared in this review.

The position argued in the report is that most cropping soils in Australia will not show improved crop yields from applications of fluid P fertiliser. The potential benefits of fluid fertilisers are likely to be restricted to soils that have problems with phosphate availability.

An alternative response is that there is not enough information to say where there will be improved responses from fluid P fertiliser.

Proponents of this response argue that there are insufficient results from properly conducted trials to say that most cropping soils are unlikely to respond. There have been difficulties with fluid application on some of the trials, and others have been poorly designed, without appropriate treatments where other nutrients are included at constant amounts.

Around 30 trials have now been conducted on the use of fluid P fertiliser, outside the Eyre Peninsula in South Australia. There are reasons to dismiss the results from some of these trials, but to dismiss more than half would be a hard-line scientific approach.

However, the data from only 15 of these trials provide a start towards developing an overall picture of response. As mentioned earlier, there are more trials with lower yields from fluid P fertiliser compared to granular products, than there are positive responses.

The project team is aware of 20 trials on fluid P fertiliser to be harvested in 2003, stretching from the Darling Downs in Queensland through New South Wales, Victoria, South Australia and Western Australia.

It is likely that the results of these trials, together with past results, will go a long way towards establishing the potential for responses from fluid P on the main cropping soils that are normally responsive to granular P fertilisers.

On this basis the authors of this report support further analysis of the fluid P work being conducted around Australia, but reject the need for a large-scale research effort to define responses on what would be a large number of soil types in a large number of geographic regions.

However, there is good evidence for responses from fluid P fertiliser on soils that have P availability problems. There is a need for more research to define the extent of 'responsive' soils, expanding on what we know about the calcareous soils in South Australia and possible responses where soils have a low pH and where there are significant problems caused by iron and aluminium.

In conjunction with this process of defining 'responsive' soils, further research work is needed to better understand the mechanisms that result in both positive and negative responses from fluid P. An improved understanding will allow for better extrapolation of where positive responses from fluid P fertilisers might arise.

There is also a need to continue research on the management of fluid P fertilisers on calcareous soils to optimise the benefits and costs.

Within the existing program of research in South Australia, there are some useful lines of enquiry regarding the application techniques for fluid fertilisers. High-pressure injection may be useful for application of liquid P fertilisers, but also for application of nitrogen away from the seed, but not leaving it on the surface.

Suspensions of granular fertilisers offer scope for bringing down the cost of fluid P. Further research should be conducted on calcareous soils with fluid suspensions that can be produced locally or sourced from the point of manufacture where they can be based on MAP or DAP before they are dried and granulated, removing these costs from the process.

In relation to the use of fluid N fertilisers, the project team is of the view that there is generally an economic disincentive in using fluid N fertiliser and that farmers need to scrutinise their farm situation carefully to see whether the convenience factors do in fact translate into benefits.

The major use of fluid N fertiliser, particularly in the eastern states, is likely to be the fluid application (sprayed or dribbled) of N after planting. There has been a considerable amount of research on this subject over the years, but this research provides variable results and could be collated and interpreted better to improve the chance of farmers achieving a profitable result from fertiliser applied post-planting.

Another issue is the compatibility and effect of mixing herbicides and fungicides with fluid N fertilisers. Information is available from manufacturers relating to their specific products, but more specific information on mixing and the possible effects of crop damage needs further compilation and analysis.

12.1 Recommendations to the GRDC for the support of further research

1. To further support the continuation of the existing research program in South Australia:
 - 1.3 To define the extent of the response in terms of soil type and cropping situations (e.g. low rainfall and/or dry seasons) of fluid P fertiliser on calcareous soils
 - 1.4 To further research the mechanisms of phosphate immobilisation and the responses occurring from fluid P fertilizer
 - 1.5 To examine application methods of fluid fertiliser, including high-pressure injection and the use of fluid suspensions
 - 1.6 To investigate with fertiliser suppliers potentially cheaper forms of fluid P, such as liquid MAP from the source of manufacture.
2. To support the compilation and interpretation of the 2003 trials around Australia on fluid P fertilisers.
3. To support targeted research on fluid P fertilisers in other situations around Australia where there are indications of potential response. This might include some P fixing soils, such as those with low pH and high iron or aluminium.
4. To support further or ongoing investigations into the accuracy and effectiveness of alternative phosphate soil tests, particularly on P fixing soils.
5. To support the compilation of research information and advisory guidelines to farmers on the use of post-sowing applications of nitrogen fertiliser. As well as defining the yield and protein benefits, such a review would examine limits and forms of nitrogen application that will minimise leaf burn, any detrimental effects of mixing fertiliser and pesticides and any evidence that late applications of nitrogen may affect the milling quality of wheat.

To make available to farmers some of the information collated on fluid fertilisers in this report.

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Appendix 1: Research reports

The results of research trials on fluid fertiliser are summarised in the following research reports.

1. Positive responses to fluid P, red-brown soils, South Australia
2. Positive responses to fluid P, grey soils, South Australia
3. Positive responses to fluid P, grey soils, high rainfall, South Australia
4. No response to fluid P at seven sites in South Australia
5. Variable responses to fertiliser, South Australia, 2001
6. Positive response to fluid P, Toodyay, Western Australia
7. Positive responses to fluid P in pot trials, Victoria
8. Inconclusive responses to fluid P in pot trials, Victoria
9. Lower yields from fluid P fertilisers, Victoria
10. Variable responses to fluid P, seven trials in Western Australia
11. One response to fluid P from three trials in Western Australia
12. No response to fluid P in Western Australia, urea >UAN
13. No response in trials with fluid P in Queensland
14. No response to foliar N in two trials, Victoria & South Australia
15. One response to foliar N in three trials, Victoria
16. No response to foliar urea and UAN, New South Wales
17. Variable yield increases from late nitrogen, South Australia
18. Fluid nitrogen responds in a similar way to urea, Western Australia
19. Variable yield increases from late nitrogen, Western Australia
20. No difference between nitrogen forms in Western Australia
21. Fluid nitrogen has placement benefits in Western Australia
22. No response to K or S in Western Australia
23. No response to zinc in Victoria
24. No response to zinc, Victorian Mallee

It should be noted that some of trials were unreplicated, while others had questionable experimental designs (lack of basal fertilisation, etc). While these are matters of concern, the authors have taken the view that the data should be reported rather than discarded.

In commenting on some of the nil responses, Dr Holloway suggests the application methods and procedures are important and may have impacted on results. It is likely, for example, that zinc added to APP caused precipitation in some instances and reduced the overall performance. In other trials the application of fluid fertiliser may not have been adequate. For example, in 2000 at Hart in South Australia, the fluid delivery system was not set up to deliver a continuous stream, which is critical in fluid application.

Research Report 1: Positive responses to fluid P, red-brown soils, South Australia

Fluid fertilisers on red-brown sandy loam soils in South Australia, 1998–2001

On a red-brown calcareous soil at Emerald Rise, a solution of technical grade MAP (TGMAP) produced 17% more grain than MAP. In a similar experiment, with added granular ammonium nitrate, there were no significant yield increases with TGMAP or phosphoric acid but ammonium polyphosphate (APP) produced significantly more grain than MAP (8%). The same fluids applied as foliar sprays had no effect on yield on a similar red-brown soil site at Karcultaby. At these two sites, responses have been interactive, with P, N and Zn all involved in determining grain yield, but only when applied as fluid.

At Emerald Rise in 2001, there was no response to P applied alone as phosphoric acid or triple superphosphate. But when P was applied as a fluid with N and Zn included in the solution, there was a significant interactive grain yield response to P, N and Zn, but still no response when the nutrients were applied in a granular form.

Table 8. Yield response of fluid fertilisers compared to granular forms

Red-brown sandy loams, South Australia

Calcium carbonate 2–15%

Summary of trials by Bob Holloway *et al*; 1998–2000

Fertiliser	P Rate	N Rate	Micronutrient	Yield increase* %	Notes
APP	10	10	nil	26	
APP + UAN	15	12	Zn surface pre-sowing	25	
Mean of APP				15	
PA + AN	10	15	Zn surface pre-sowing	21	
PA + urea	10	10-20	Zn solution banded	11	20N>10 1.2 Zn >0
Mean of PA				11	
TGMAP	10	15	Zn 7.8 solution band	17	
TGMAP	12	15	Zn 2.5 solution band	14	
Mean of TGMAP				15	
APP: ammonium polyphosphate PA: phosphoric acid TGMAP: technical grade MAP					
Means included a range of rates and mixtures with micronutrients including zinc, manganese and copper. Foliar zinc treatments were generally not effective. Precipitation of solutions occurred in some instances, such as when urea and manganese were included in the mixture.					
* Compared with equivalent granular nutrients based on MAP, DAP, TSP or urea					

Research Report 2: Positive responses to fluid P, grey soils, South Australia

Fluid fertilisers on grey highly calcareous sandy loam soils in higher rainfall zone in South Australia, 1998–2001

Experiments on a grey calcareous soil at Yandra with a technical grade MAP (TGMAP) + ammonium nitrate + zinc sulphate solution and granular MAP with ammonium nitrate and zinc sulphate, at the same rate of applied P, N and Zn, showed a 45% increase in grain yield of wheat with the fluid application. Similarly, an application of phosphoric acid with granular ammonium nitrate increased grain yield of wheat by 40% compared with MAP at the same site. An application of 4 kg P/ha as a solution of TGMAP produced the same yield statistically as 18 kg P/ha as MAP.

On a similar soil at Miltaburra, a range of fluid products (phosphoric acid, TGMAP, ammonium polyphosphate (APP)) were compared with MAP and all produced significantly higher grain yields than MAP, with differences ranging between 18% and 11%. Other experiments were conducted at the same site comparing similar products with combinations of zinc and nitrogen and there were no significant differences between fluid and granular products. Until 2002, responses at this site were restricted to P only.

Table 9. Yield response of fluid fertilisers compared to granular forms

Grey highly calcareous sandy loam soils in higher rainfall zone

Calcium carbonate 20–70%

Summary of trials by Bob Holloway *et al*; 1998–2000

Fertiliser	P Rate	N Rate	Micronutrient	Yield increase* %	Notes
APP	10	10	nil	0	
APP + ATS	5	5	nil	11	
PA + AN	10	15	Zn solution banded	47	
PA + urea	4,10, 20	15	nil	12	20N>10 1.2 Zn >0
PA + S acid+urea	10	20	Zn solution banded	13	
Mean APP & PA				24	
TGMAP + AN	10	15	Zn 7.8 solution band	45	
TG MAP + AN	10	20	Zn 2.5 solution band	7	
Mean of TGMAP				15	
APP: ammonium polyphosphate PA: phosphoric acid TGMAP: technical grade MAP					
Means included a range of rates and mixtures with micronutrients including zinc, manganese and copper. Foliar zinc treatments were generally not effective. Precipitation of solutions occurred in some instances, such as when urea and manganese were included in the mixture.					
* Compared with equivalent granular nutrients based on MAP, DAP, TSP or urea					

Research Report 3: Positive responses to fluid P, grey soils, low rainfall, South Australia

Fluid fertilisers on grey highly calcareous sandy loam soils in low rainfall zone in South Australia, 1998–2001

Yield responses up to 34% have been measured at low rainfall sites, where APP and UAN were applied with zinc. When additional nitrogen was applied to both APP and phosphoric acid, yield increases were small, indicating some interaction with nitrogen, and extra plant growth enhancing water use early in the crop, resulting in shortages at the critical grainfill period.

At Cungenena, on a grey highly calcareous soil, fine MAP (< 2 mm) produced significantly more grain than granular, but fluid APP produced more grain than either. This indicates that there is a stochastic relationship between the uptake of P by plants and fertiliser distribution in the soil.

Table 10. Yield response of fluid fertilisers compared to granular forms

Grey highly calcareous sandy loam soils in low rainfall zone

Calcium carbonate 20–70%

Summary of trials by Bob Holloway *et al*; 1998–2000

Fertiliser	P Rate	N Rate	Micronutrient	Yield increase * %	Notes
APP + AN	10	15	Zn surface pre-sowing	14	
APP + UAN	15	12	Zn surface pre-sowing	34	
APP + UAN	12	20	Zn 2.5 + Mn + Cu Surface pre-sowing	2	
Mean of APP				19	
PA + AN	10	15	Zn1 surface pre-sowing	30	
PA + urea	12	10	Zn2.5, Mn4, Cu1 (SP)	24	
PA + AS	12	20	Zn2.5, Mn 4, Cu1 (SP)	5	
Mean of PA				19	
TGMAP + AN	10	15	Zn1 surface pre-sowing	11	
TGMAP + AN	12	20	Zn 2.5, Mn4, Cu1 (SP)	5	
Mean of TGMAP				14	
APP: ammonium polyphosphate PA: phosphoric acid TGMAP: technical grade MAP AN: ammonium nitrate AS: ammonium sulphate					
Means included a range of rates and mixtures with micronutrients including zinc, manganese and copper.					
* Compared with equivalent granular nutrients based on MAP, DAP, TSP or urea					

Research Report 4: No response to fluid P at seven sites in South Australia

Improving SA crop productivity with fluid fertiliser technology 1999–2000: collated and edited by Dr Bob Holloway. SARDI final report.

Experiments were designed to compare the response of fluid and granular fertilisers.

Five sites in the mid-North – Yorke Peninsula area ranged from highly calcareous sandy loam to acidic clay loams. Sites were at the venues for the Hart (alkaline loamy mallee soil) and Minlaton (alkaline loam) field days and at Riverton (acidic clay loam) and Booborowie (sodic soil). Two sites on the lower Eyre Peninsula were a highly calcareous sandy loam at Coomaba (55% calcium carbonate) and a calcareous loam at Wildeloo.

The results of seven trials over 1999 and 2000 showed responses to phosphate fertiliser, but no advantage of fluid P fertilisers over granular DAP with zinc. The results of five of these trials are shown in Table 11.

Comments from Dr Holloway indicate there may have been some problems in some of these trials. In some instances the addition of zinc to APP caused precipitation and reduced the overall performance. The fluid delivery system at Hart in 2000 was not set up to deliver a continuous stream, which is critical in fluid application.

However, DAP + Zn granular appeared to perform consistently on these sites compared with TGMAP and phosphoric acid.

Table 11. Yield response of fluid and granular fertilisers in South Australia

Grain yields in kg/ha

Trials by Rohan Rainbow and others

Fertiliser	Hart 1999	Hart 2000	Riverton 2000	Minlaton 2000	Wildeloo 2000
APP + 1% Zn	3100	2500	4090	3370	3840
TGMAP fluid	2970	2830	4480	3530	3800*
APP + UAN	2756	2780	4550	3610	
DAP granular	2610	2870	4690	3550	3812*
DAP + Zn granular	2910	2910	4840	3620	
PA		2680	4390	3560	
PA + urea		2620	4390	3400	3880
Control (nil)	2760	2460	3990	3107	3140
LSD	320	190	240	150	250
APP: ammonium polyphosphate PA: phosphoric acid TGMAP: technical grade MAP AN: ammonium nitrate AS: ammonium sulphate					
* Treatments had added urea.					

Research Report 5: Variable responses to fertiliser, South Australia, 2001

Comparisons of fluid and granular fertiliser, South Australia, 2001

Andrew Lymburn, Agrichem

In three trials the wheat treated with fluid fertiliser showed good growth early in the season but, closer to harvest, the granular fertiliser treatments caught up, with little or no response to any fertiliser, even at high yield levels of 5.5 t/ha at Lock.

At Cockaleechee, on a buckshot loam, there was a small increase in yield with additional P applied as LMAP, but the increase of 180 kg/ha from 3 kg to 10 kg of P was not significant experimentally or profitable for farmers.

At Lock, wheat was grown on an alkaline sandy loam soil in a rotation after faba beans. The site received good rainfall and yielded over 5 t/ha, but there was no significant response to fertiliser. At Willura, the soil has a much lower pH than the calcareous soils of the Upper Eyre Peninsula testing pH 4.8, P (Colwell) was 54 ppm.

While there was a significant difference between the control and two fertiliser treatments — LMAP with additional nitrogen as UAN (134% of control) and MAP with added urea, there was little or no apparent response to P fertiliser alone and the better yield may have been the combination of N and P.

The inconsistency in this conclusion was that LMAP at 25 L/ha (5.2 kg P) with added UAN showed no yield advantage, while LMAP at 25 L/ha without UAN yielded above the control.

Table 12. Yield response of fluid fertilisers compared to granular forms

Willura, 2001

Trials by Andrew Lymburn

Fertiliser	kg N	kg P	Grain (kg/ha)	% over nil
Nil	0	0	2088 abc	100
LMAP 25 L	3.5	5.2	2273 ab	109
LMAP 50 L	7	10.4	2088 abc	100
LMAP/UAN	14	5.2	1994 bc	95
LMAP/UAN	14	10.4	2795 a	134
MAP/urea	14	17.6	2629 ab	126
DAP	14	16	2435 abc	117
LSD			121	
LMAP: fluid ammonium polyphosphate 14–21–0 UAN: urea ammonium nitrate fluid 32–0–0. MAP, urea and DAP applied as solid fertiliser				

Research Report 6: Positive response to fluid P, Toodyay, Western Australia

LMAP on wheat compared to granular fertiliser, Toodyay, Western Australia

Conducted by Agritech for Agrichem

The trial was conducted on a phosphate reactive iron site to evaluate LMAP and the potential for increased phosphate response from fluid fertilisers.

All treatments significantly increased wheat yield compared to the untreated control. The highest yielding treatment was LMAP 50 L/ha + UAN 23 L/ha + Asset 450 ml/ha, yielding 3.54 t/ha, 41% more than the untreated control. LMAP 25 L/ha + UAN 34 L/ha + Asset 450 ml/ha improved yield by 31%, while other treatments increased wheat yield by 13–22%. The addition of Asset 450 ml/ha to LMAP 25 L/ha did not affect wheat yield.

It is worth noting that, on this site, similar yields were achieved with 5 kg P in a fluid form to 16 kg and 17.6 kg of P in a granular form.

Table 13. Yield response of fluid fertilisers compared to granular forms

Toodyay, WA, 2001

Trials by Agritech for Agrichem

Fertiliser	kg N	kg P	Grain (t/ha)	% over nil
Nil	0	0	2.51	100
LMAP 25 L	3.5	5.2	2.86	113
LMAP/UAN	14	5.2	3.31	131
LMAP/UAN	14	10.4	3.54	141
MAP/urea	14	17.6	3.08	122
DAP	14	16	3.05	121
MAP	8	17.6	3.01	119
LSD			.292	
LMAP: fluid ammonium polyphosphate 14–21–0 UAN: urea ammonium nitrate fluid 32–0–0. MAP, urea and DAP applied as solid fertiliser				

Research Report 7: Positive responses to fluid P in pot trials, Victoria

Glasshouse trials of fluid fertilisers on Victorian cropping soils

'Fluid fertilisers – the next step towards raising yield potentials'. McLaughlin, M., Holloway, B., Armstrong, R., Brace, D., Lombi, E., McBeath, T. February 2003.

In glasshouse trials fluid fertilisers produced greater dry matter yields than granular formulations such as triple P in sodosols and calcarosols collected from the Victorian Mallee (Table 14). Fluid fertilisers were also superior to granular forms in vertosols, although they were not as responsive to P application as other alkaline soil types.

Table 14. Dry matter response (30 d.a.p) of wheat in a glasshouse across a range of soil types to the fluid fertilisers ammonium polyphosphate (APP) and phosphoric acid (H₃PO₄), compared to the granular formulation of triple P.

Soil type	No of soils	Colwell P	pH (water)	Control	APP	H ₃ PO ₄	Triple P
Wimmera (vertosols)	7	18	8.2	1.03c	1.67a	1.69a	1.44b
Birchip (sodosols, calcarosols)	3	31	6.8	1.36c	1.71a	1.80a	1.55b
Nth Mallee (calcarosols)	4	12	8	0.71c	1.31a	1.38a	1.03b
SA (grey calcarosols)	10	35	8.5	0.45b	0.86a	0.86a	0.51b
Acid soils (Vic, SA)	5	31	5.8	0.49c	1.33a	1.28a	1.12b

LSD (P= 5%) = 0.144 (Results labelled with the same letter not significantly different at P = 5%)

Crops supplied with fluid fertilisers have greater P uptake than granular forms. The greater availability of P appears to be due to a tendency for P derived from the granular forms to precipitate (become 'fixed') as insoluble forms of P.

The research team (McLaughlin et al. 2003) has found that fluid fertilisers minimise the amount of P deposited (fixed) into the P bank as well as helping crops to mobilise P from the pool (Table 15). These results suggest there is a way of helping growers to access this P and thus reducing the amounts of P applied to their crops.

Table 15. Amounts of phosphorus 'fixed' by a calcareous soil after addition of the granular MAP, DAP and TSP, compared to phosphorus mobilised from reserves in soil by the fluid fertiliser ammonium polyphosphate (APP).

	MAP	DAP	TSP	APP
P (fixed/mobilised) mg kg	27b	23b	25b	-18a

Results labelled with the same letter not significantly different at P = 0.05

Research Report 8: Inconclusive responses to fluid P in pot trials, Victoria

A comparison of fluid vs granular phosphorus in pot trials, Victoria, 2000–2001.

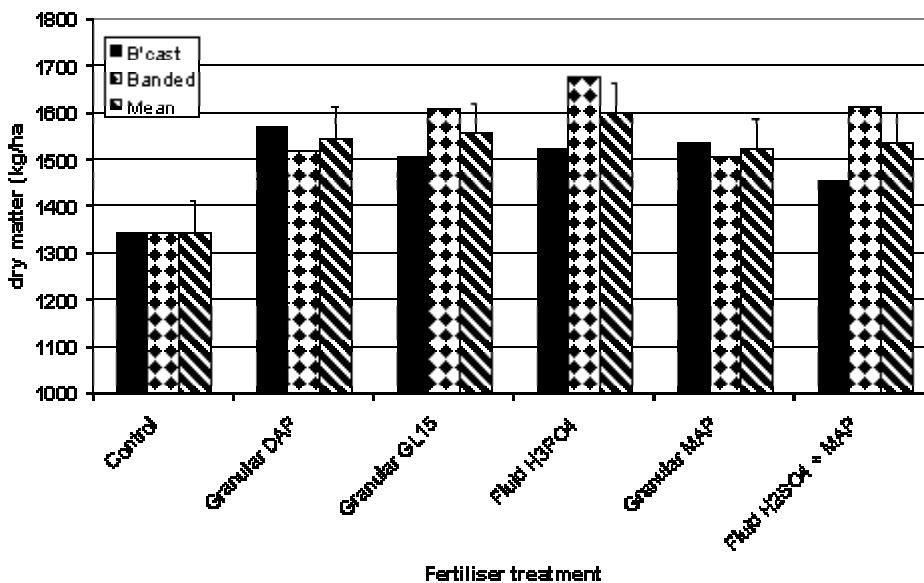
Charlie Walker, Incitec Pivot, Werribee

A pot trial on calcareous mallee sand assessed the effect of concentrating fertiliser in a narrow band vs broadcast type application, with a range of granular and fluid fertilisers with varying pH, and assessed the effectiveness of MAP digested in sulphuric acid against phosphoric acid and conventional granular fertilisers. Field trials comparing various granular and fluid starter fertilisers have also been conducted in wheat at Swan Hill and Warracknabeal in Victoria during 2000–2001.

However, due to nitrogen deficiency at both sites, the yield results achieved are inconclusive as each treatment received different amounts of nitrogen.

All phosphorus treatments gave a significant ($F_{pr} = 0.003$) dry matter response over the control although there were no significant differences between P treatments (Figure 1). Nitrogen uptake was ($F_{pr} = 0.001$) significantly improved by all P treatments except for the MAP digested in sulphuric acid. This treatment provided significantly less N uptake than all other P treatments. All P treatments gave significantly higher P uptake than the control, while phosphoric acid gave significantly higher responses compared to all other P treatments. Banding of treatments gave significant improvements in N and P uptake compared to broadcasting treatments (Walker C. 2001).

Figure 1. The effects of various granular & fluid fertilizers and application method on wheat dry matter 60 DAS



Research Report 9: Lower yields from fluid P fertilisers, Victoria

Fluid P trial at Avon Richardson Cropping Group Site.

John Stuchberry. 2001 (unpublished data)

The effect of granular (MAP) and fluid phosphorus (liquid MAP) fertiliser on wheat growth and yield was compared. Phosphorus fertiliser was delivered with the seed. The fluid P was applied using a water output of 349 L/ha.

There was significantly more wheat yield achieved with the granular fertilisers compared to fluid phosphorus fertiliser. However, there was no interaction between rate and type.

The considerable increases in yield from the first 5 kg of P applied indicated a significant response to phosphorus. Some of the additional response may have been due to additional nitrogen supplied in the fertiliser.

The reasons for a reduction in yield remain a mystery. In South Australia, best results from fluid have been obtained with fertiliser applied below the seed. However, the yields improved with the rate of fertiliser applied, suggesting the amount of fertiliser applied with the seed was not excessive.

Table 16. The effect of granular and fluid fertiliser, Avon, 2001

Wheat yield tonnes per hectare

Rate	Granular MAP	% of control	Liquid MAP	% of control
0 kg P/ha	1.2	100	1.2	100
5 kg P/ha	1.9	158	1.7	142
10 kg P/ha	2.1	175	1.9	158
20 kg P/ha	2.4	200	2.2	183

LSD granular vs fluid fertiliser = 0.1
LSD rate = 0.16
LSD overall = 0.21
LSD rate for granular fertiliser = 0.23
LSD rate for fluid fertiliser = 0.25

Research Report 10: Variable responses to fluid P, seven trials in Western Australia

Fluid phosphorus fertiliser comparisons in Western Australia, 2000–2002

Research by Stephen Loss et al., CSBP

Field experiments were conducted across the Western Australian agricultural region in 2001. Only the Salmon Gums site had any significant calcium carbonate content (1.5%). The trials compared four rates of solid MAP with three fluid products (NP1, NP2 and NP3). Urea was topdressed before seeding to even out the N application to 35–100 kg/ha depending upon the site.

At three sites there was no difference between P fertilisers. At the Salmon Gums site (pH 8) and the Williams site (pH 4.9) there was some evidence of fluid NP products being more efficient when P was applied at low rates (5 kg P/ha). The yield from 5 kg fluid P was equivalent to 10 kg P/ha applied as MAP, but was no different when 10 kg P was applied.

In 2002, useful experiments were conducted at Northampton, Gnowangerup and Frankland. Other similar trials sown at Kununoppin, Lake Grace and Salmon Gums were severely affected by drought. Urea was topdressed to provide basal N and muriate of potash was also topdressed at Gnowangerup and Frankland. At two sites (Northampton and Gnowangerup) there was a significant increase in yield from solid fertilisers, while at Frankland there was no difference in yield between fertilisers.

Table 17. Comparison of fluid fertilisers and granular forms

Salmon Gums, 2001 and Northampton, Gnowangerup and Frankland, 2002

Trials by Stephen Loss and others

Fertiliser	kg P	Grain yields in t/ha			
		Salmon Gums 2001	Northampton 2002	Frankland 2002	Gnowangerup 2002
Nil	0	2.65	2.9	2.6	1.15
MAP 22 kg	5	3.0	3.25	3.4	1.42
MAP 44 kg	10	3.25	3.42	3.7	1.42
MAP 88 kg	20	3.6	3.35	3.6	1.55
Fluid P*	5	3.2	3.15	3.5	1.2
Fluid P*	10	3.3	3.14	3.75	1.26
Fluid P*	20		3.18	3.7	1.25
LSD		0.3	0.1	n/a	0.18

* Fluid P: In 2001 fluid NP products were used at two rates, while ammonium polyphosphate 14–21–0 was used at three rates in 2002.

Research Report 11: One response to fluid P from three trials in Western Australia

Fluid phosphorus fertiliser comparisons in Western Australia, 2001–2002

Research by Sandy Alexander, Summit Fertilisers, Kwinana

A trial conducted in 2002, north of Narrogin on the property of M T and C A Potts, compared the response from MAP and APP, at rates up to 40 kg P/ha. Even though the response to P was nearly 2 t/ha, there was no difference between the fluid and granular source of P. The soil type at Cuballing had a pH of 4.9 and a PRI of 111.

This result supports other work at Holt Rock in 2001, where there was also a good response to P, but no difference between fluid and granular P. However, at New Norcia in 2001, fluid P performed better than granular P. The soil type at New Norcia was a high fixing soil, with a PRI of 213 and pH 5.5, while at Holt Rock it is lighter sand over clays soils with a pH of 4.8 and lower PRI of 5.

2001 was very dry at New Norcia until the end of July. While nominally in a 600 mm rainfall area, the trial yielded less than at Holt Rock, which would normally have half the rainfall. In 2001 Holt Rock had good early rains.

The extra response from fluid P in the New Norcia trial was not significant at 10 kg of P, and increased with rate of application of P.

Table 18. Comparison of fluid fertilisers and granular forms

Holt Rock and New Norcia, 2001 and Cuballing, 2002

Trials by Sandy Alexander and others – Summit Fertilisers

Fertiliser	kg P	Grain yields in t/ha		
		Holt Rock 2001	New Norcia 2001	Cuballing 2002
Nil	0	2.6	2.0	1.5
MAP 45 kg	10	3.3	2.6	2.5
MAP 91 kg	20	3.6	2.65	2.8
MAP 182 kg	40	3.8	2.7	3.3
Fluid APP*	10	3.2	2.7	2.5
Fluid APP*	20	3.5	2.95	2.8
Fluid APP*	40	3.7	3.25	3.2
LSD 5%		0.15	0.2	0.236

* Fluid P was ammonium polyphosphate 14–21–0.

Research Report 12: No response to fluid P in Western Australia, urea >UAN

Fluid phosphorus and nitrogen fertiliser comparisons in Western Australia, 2001

WANTFA (WA No-Till Farming Association) trial

A complete factorial trial was conducted in 2001, on an acidic, duplex sandplain soil to evaluate fluid N and P fertilisers. Five P rates by granular (double superphosphate) or fluid (LMAP) forms were used with two carriers at seeding (urea topdressed or Flexi-N injected). Starter N rates were made to total 27 kg for all treatments, to duplicate the amount of N in the 40 kg P/ha LMAP treatment. A further 51 kg N/ha was applied 25 days after sowing over all treatments.

Applied P improved grain yield, with 20 kg P/ha giving the highest response of 20% more grain yield than no applied P. Starter N produced more grain yield when it was applied as urea in the furrow rather than as Flexi-N placed with the P. Flexi-N gave more grain yield if it was applied with the fluid P rather than the granular P (but only at the 6.5% p-value). At the 5 kg P/ha rate of applied P, the fluid seemed to be producing more grain than the granular P (although not significant), which was consistent with both N carriers. At the optimum yield levels with 20 kg P there was no difference between P fertilisers, but better yields from urea, than UAN.

It is difficult to explain why the Flexi-N (UAN) starter did not perform as well as urea. The urea starter N was topdressed directly into the furrow at seeding. The Flexi-N was sprayed in a 1 mm wide band, 4 cm below the bottom of the furrow, between the two bands of seed and P application.

Table 19. Comparison of fluid fertilisers and granular forms

WANTFA trials, 2001

Trials by Bill Crabtree and others

Fertiliser	kg P	Grain yields in t/ha	
		Flexi-N at planting	Urea at planting
Nil	0	2.83	3.0
Granular	5	3.03	3.46
Fluid	5	3.57	3.62
Granular	10	3.01	3.55
Fluid	10	3.31	3.52
Granular	20	3.34	3.78
Fluid	20	3.43	3.87
LSD 5%		0.43	0.43
* Fluid P was LMAP (ammonium polyphosphate 14-21-0).			

Research Report 13: No response in trials with fluid P in Queensland

Consolidated Fertilisers Ltd Research Report 1982

A series of trials was conducted in the 1980s evaluating the form and placement of phosphate fertiliser, in conjunction with nitrogen. The results from four trials on summer crop (sorghum) grown on the Darling Downs are shown in Table 20.

Trial 1: a black earth, pH 7.2, P (bicarb) 17, organic carbon 0.72%

Trial 2: a black earth, pH 8.6, P (bicarb) 14, organic carbon 0.9%

Trial 3: a red-brown earth, pH 7.3, P (bicarb) 30 mg/kg, organic carbon 1.35%

Trial 4: a grey-brown clay, pH 8.0, P (bicarb) 8, organic carbon 0.63%

Table 20. Comparison of fluid and granular fertiliser and placement methods

Sorghum trials by Incitec Ltd, 1982

Fertiliser	kg N-P	Grain yields in t/ha			
		Trial 1	Trial 2	Trial 3	Trial 4
Nil	0	1.89	3.46	3.34	3.46
NH3 *	80-0	1.88	3.84	3.88	3.18
MAP *	7-12	2.43	3.7	3.68	3.32
Phos acid *	0-12	2.79	3.84	3.63	3.14
NH3 + MAP *	80-12	2.35	4.08	3.96	3.34
NH3 + Phos acid *	80-12	3.4	4.09	3.58	3.13
NH3 + MAP #	80-12	2.11	4.53	4.68	3.25
LSD 5%		0.62	0.51	0.85	1.93
* Treatments were pre-plant deep banded. # NH3 was applied 1 month prior to planting at 10 cm, with MAP applied in a band with the seed.					

In one trial (Trial 1), the yield of sorghum was significantly higher with phosphoric acid than all other treatments. This is reported as being due to a reduction in lodging, rather than an increase in total grain produced.

In Trial 2, the application of fertiliser in bands (15-20 cm deep, 30 cm between bands) yielded less than when fertiliser was applied at normal depths and the P fertiliser with the seed. Note the yield of NH3 + MAP#. The lower yields were attributed to the disruptive effects of fertiliser application, which may have resulted in less favourable moisture and seedbed conditions. When deep banded, there was no advantage of fluid P over granular P. Unfortunately there was no comparison between fluid P and granular P applied at sowing with the seed. Another trial compared the use of phosphoric acid with MAP on wheat.

Wheat yields were low (around 2 t/ha) due to a dry winter, with 181 mm of rain between planting and harvest. No significant differences were observed between the methods of fertiliser application or between phosphorus sources.

Research Report 14: No response to foliar N in two trials, Victoria and South Australia

Trials by Charlie Walker at Incitec Pivot show comparisons of fluid fertilisers on wheat at flowering, resulting in no yield response even at high rates.

At Geelong in 2001 four rates of N were applied as diluted UAN, which resulted in a significant drop in yield where UAN was applied. However, there was an increase in grain protein with up to 26 kg N/ha as UAN. Treatments were applied at flowering under cool conditions with a little rain two weeks after application. Foliar urea gave no response, even at high rates, suggesting significant volatilisation losses.

Table 21. The effect of anthesis foliar N treatments on grain yield

C. Walker, Incitec, Geelong 2000

Treatment	Grain yield t/ha
Control	3.03
17 kg/ha urea in 100 L water	2.77
34 kg/ha urea in 200 L water	2.89
40 kg/ha urea in 100 L water	2.88
75 kg/ha urea in 100 L water	2.89
80 kg/ha urea in 200 L water	2.94
150 kg/ha urea in 200 L water	3.12
18 kg/ha urea + 18 kg Nitram in 100 L water	3.18
36 kg/ha urea + 36 kg Nitram in 100 L water	3.53

Similar results were achieved on the Central Yorke Peninsula in 2001 where, at three growth stages (tillered, boot and flowering), granular urea and ammonium nitrate were compared to UAN applied neat using streaming nozzles. In most cases significant rain (>15mm) fell within one week of application. Yield depression from the foliar effects of UAN resulting in protein concentration was recorded.

Table 22. Foliar N at flowering at Gnarwarre, SA, 2001

C. Walker, Incitec

Treatments of UAN	Yield t/ha	Protein %
0	6.25	11.1
13 kg/ha N	5	11.9
26 kg/ha N	4.8	12.4
39 kg/ha N	4.6	12.3

Research Report 15: One response to foliar N in three trials, Victoria

‘What is the best product for topdressing nitrogen?’ Southern Mallee and Northern Wimmera Crop and Pasture Production Manual 1999–2000. BCG Trial Results

In the 1999 season the Birchip Cropping Group compared five nitrogen products at three sites. Urea, urea + Agrotain, calcium ammonium nitrate (CAN), and ammonium sulphate were all applied in granular form at 25 kg N/ha and Pivot Green N (UAN 42.2% N) as a foliar spray at 12.5 kg N/ha (lower rate for Green N so as not to burn the crop).

The three sites were Birchip, Charlton and Sea Lake, Victoria.

Urea, urea + Agrotain and CAN all performed equally well as topdressing products.

At the Charlton site Pivot Green N significantly improved yield when there was adequate rainfall after the application (>13mm). There were no yield differences between the granular forms of nitrogen at the Charlton site.

Research Report 16: No response to foliar urea and UAN, New South Wales

Trial report on N323 in wheat: Agrichem

The effectiveness of Nitrohumus 323 (urea ammonium nitrate N 32%, humic acid 3%) was compared to urea (N 46%) on wheat at Dunedoo in New South Wales by Greg Hennessy, New South Wales Department of Agriculture, Mudgee. The trial found 20 L/ha of Nitrohumus 323 (6.4 kg N/ha) resulted in the same increase in yield as 63 kg/ha of urea (29 kg N/ha).

Table 23: Yield responses of wheat to Nitrohumus and urea

Treatments	Yield tonnes/hectare	Cost \$ per hectare
Nil	3.15	0
20 L/ha N323	3.3	20
63 kg/ha urea	3.28	20

Research Report 17: Variable yield increases from late nitrogen, South Australia

Trials by Jon Hancock and Nigel Wilhelm, SARDI

A trial at Wharminda (on the Eyre Peninsula) in 2002 by Jon Hancock found no response to nitrogen fertiliser, either at sowing or when split between seeding and later applications. The 60 kg N/ha required for crop growth, for a grain yield of 1.3 t/ha, was met by soil reserves.

Three trials by Nigel Wilhelm were grown at Minlaton, at Sandilands and at Port Rickaby in 2002 to evaluate the use of broadcast and foliar N at flowering time. Five different treatments included seeding N only, seeding N plus tillering N, seeding N plus tillering N plus 8, 16 or 32 kg N/ha as a foliar spray of UAN at flowering.

Under the very dry conditions of 2002, the 15–20 kg N/ha supplied at seeding were more than adequate for the final yields achieved. In fact, yields were slightly depressed by the combined applications of N at seeding, tillering and flowering at Minlaton and Port Rickaby.

Another trial at Cleve Hills in 2002 was also low-yielding and the crop had little demand for extra N. Differences between foliar and broadcast urea could not be discerned.

Trials in South Australia during 1999 and 2000 provided more response with much higher grain yields. Urea applied at flowering, either as broadcast or foliar, increased grain protein levels in most trials. It was expected that foliar application would be more effective and reliable than broadcast urea, but in these trials it was found to be no more effective.

Application of 16 kg N/ha at flowering increased protein at three of the four sites by 0.3–0.9%. Because there was no difference between foliar and broadcast application, the cheapest treatment was broadcast urea. The maximum practical rate of application of N is 16 kg N/ha because this is the maximum amount of urea that can be dissolved in typical boomspray output rates.

Based on the yield and protein levels that occurred in this set of four trials, no N treatments of any type were justified economically unless they improved the grade of grain N at flowering and this was rarely profitable. Durum wheat was generally the most profitable wheat to apply late nitrogen. At two sites, the control produced durum 1 grain, so any protein increases with additional N only attracted a premium based on the extra protein. At the other two sites, N treatments increased the grade of wheat and in some instances returned up to eight times the cost of the application.

Good yields were necessary for N applications to be profitable. At Mintaro, where yields were approximately 6 t/ha, returns from added N varied from 1.9 to 8 times.

Research Report 18: Fluid nitrogen responds in a similar way to urea in Western Australia

Comparisons of fluid fertiliser use in WA by CSBP

Flexi-N is now the most commonly used broadacre fluid fertiliser in Western Australia. Over the past six years Flexi-N has been compared to urea in 35 trials from as far north as Yuna to Dumbleyung in the south.

In each of these trials, top-dressing was compared with Flexi-N applied by boomspray. Early plant growth and N uptake were measured, as were grain yield and protein at the end of each season. The results suggest there is no significant difference between using urea and Flexi-N, with 32 of the trials producing similar yields, and no trend towards either product. In the remaining three trials, Flexi-N produced a significantly higher yield at both east Pingelly and east Mullewa, while urea produced significantly more grain yield at Beverley.

Flexi-N banded near the seed has also been compared to Flexi-N applied through the boom and urea banded and/or topdressed in 10 trials conducted over three years. In 7 of the 10 trials there was no significant difference in yield between either product when topdressed or banded, although early nutrient uptake and growth were improved with banding. The early benefits of banding did not translate into a yield advantage due to the dry seasonal conditions. The remaining three trials showed Flexi-N to give a significant yield advantage when banded, as opposed to being applied by boomspray.

The results suggest that Flexi-N is safer to band than urea, but that it can be toxic if placed too close to the seed at high rates (>100L/ha). The risk of toxicity is increased with Flexi-N banded on wide row spacings (>22cm). There appears to be an advantage in banding Flexi-N in weedy situations on wide rows. However, more work is needed to quantify this theory.

The conclusion, therefore, is that while there does not appear to be any yield advantage associated with using Flexi-N through the boom, as opposed to urea topdressed prior to sowing, there does appear to be an advantage when it is banded.

Flexi-NS and Liqui-NS have been tested over the past three years, and the results suggest that they perform in a similar manner to granular forms of nitrogen and sulphur.

For more information, contact Mr Eddy Pol (CSBP) on 08 9411 8683 or Dr Stephen Loss (CSBP) on 08 9411 8437

Research Report 19: Variable yield increases from late nitrogen, Western Australia

Trials by Darren Hughes, Muresk and CSBP

A trial at Northam in 2002 showed application of Flexi-N increased grain protein levels, but resulted in a small (non-significant) loss in yield.

Table 24. Effect of nitrogen on yield and grain protein

Trial by Hughes and others, Northam, WA, 2002

	Rate of N (kg/ha)				
	0	30	30/30	30/30/30	45/45
Grain yield	3.06	3.06	3.06	2.89	2.88
Protein	9	9.7	11.5	13	12.9
N treatments: 30 kg N at seeding, 30/30 at seeding and tillering, 30/30/30 seeding, tillering and booting and 45/45 at seeding and tillering					

CSBP has also included Flexi-N in trace element and pesticide mixes, and late applications for protein boosting. Results indicate that Flexi-N can be mixed with trace elements and pesticides (e.g. fungicides) and applied through the boom, or banded at seeding with few problems, although leaf scorch is an issue, particularly with late applications.

CSBP trials have shown a boost to protein in wheat with late applications of 30–60 L/ha of Flexi-N, in high yielding situations, where yields were 3 t/ha or more.

At York, in a dry year with yields of 1.4 t/ha, applications of Flexi-N at flowering increased protein, but reduced yields by 8% and increased screenings significantly. A yield reduction of 18% was also recorded at Yuna in the same year (2000), when Flexi-N was applied at the flag leaf stage. Yield levels of 2.4 t/ha were limited by dry conditions during grain filling. Leaf scorching occurred at the time of application.

Research Report 20: No difference between nitrogen forms in Western Australia

Trials by Summit Fertilisers, WA

Summit Fertilisers has been conducting nitrogen source and application method trials since 1997. Urea, calcium ammonium nitrate (CAN), plastic-coated urea, agrotain-coated urea and fluid nitrogen (MAXamFLO) have all been compared, to determine which source of N is most likely to give the best return. In addition, each source has been applied in a number of ways, including with the seed, incorporated by sowing (IBS), incorporated after sowing (IAS), banded to the side and below the seed, behind the press wheel, or as a foliar application.

In almost all cases (including comparisons with MAXamFLO) there was no agronomic benefit associated with using an alternative source of N by the methods listed above. Urea topdressed and incorporated by sowing still appears to give the best dollar return.

Limited data suggest there may be a yield advantage associated with VigourFLO as opposed to Summit's granular NPK equivalent, Vigour. In a trial conducted in Northam in 2002, in which rates of Vigour and VigourFLO were compared, VigourFLO @ 100 L/ha produced the highest yield, although the difference was not significant. There were, however, visual differences between the treatments at emergence, with the plants in the VigourFLO plots emerging more evenly and 'vigorously' than those in the granular plots. More data may be available in the near future, as VigourFLO has now been commercially available for a season.

In 2003, Summit Fertilisers conducted fluid N, P and K trials, fluid vs granular potassium placement trials, protein boosting trials and fluid N herbicide tolerance trials across the state. The outcomes of these trials, which are being run in conjunction with Nufarm over a three-year period, should provide more information on the application of these various forms.

For more information, contact Mr Justin Fuery (Summit) on 08 9439 1844

Research Report 21: Fluid nitrogen has placement benefits in Western Australia

WANTFA trials by Bill Crabtree: 1999–2001

In 1999, a trial was conducted using several nitrogen fertilisers (including UAN, or Flexi-N) to determine placement and formulation options for avoiding fertiliser toxicity. The results indicated there was potential for UAN within no-till farming systems in Western Australia. UAN gave significantly better wheat grain yield than all other drilled N fertilisers (with the exception of urea topdressed IBS) at the highest rate tested (100kg/ha). The trial showed that banding UAN was as effective as spraying it out, or topdressing urea.

Trials in 2001, in conjunction with CSBP, included two Flexi-N vs urea rates and timing in wheat trials near Meckering. Grain yield increased by 190 kg/ha where Flexi-N was used over urea at the first site. However, this was not repeated at the second site. Splitting the timing of N also increased wheat grain yield at site 1. This trend was more evident with Flexi-N than with urea. Unfortunately the first site was not randomised, so the results cannot be considered reliable.

Flexi-N rates and timing were also trialed on *Stirling* barley, to determine the effects on malting standards. As expected, grain yield increased with increasing rates of N. However, there was no increase in either yield or protein when the application was split, which suggests that farmers can dribble all N at seeding without having an adverse effect on protein levels.

Fluid phosphorus was also tested in 2001, to determine if it is more effective than granular fertiliser in the acidic, duplex sandplain soils of Western Australia. The aim was to determine whether fluid P is more efficient when applied in a Flexi-N mix than in granular form, so a full range of both solid and fluid N and P carriers were tested. Flexi-N gave more grain yield if it was applied with fluid P, rather than granular P. Starter N gave more grain yield when applied as urea topdressed into the press wheel furrow immediately after seeding, than as Flexi-N placed with P. This result is puzzling, as the urea was placed on the furrow just before a dry period. A Flexi-N placement trial was conducted to determine the best dribbling location of Flexi-N at seeding for wheat. The results suggest that up to 60 kg N/ha of Flexi-N can be safely banded, provided there is good separation between the seed and Flexi-N (3–4 cm).

In 2002 a trial was conducted of Flexi-N placement and its effect on weeds in canola. The results suggest there is a limited relationship between weed growth and the application of N, which may have been due to the dry season. However, there was a 17% increase in canola yield where the Flexi-N was banded, as opposed to broadcast.

For more information, contact Mr Bill Crabtree (private consultant) on 08 9622 8815 or Ms Tracey Gillam (WANTFA) on 08 9622 3395

Research Report 22: No response to K or S in Western Australia

Trials by farmer groups in Western Australia

Replicated trials have been conducted by groups such as the Liebe Group, the Corrigin Farm Improvement Group, the Mingenew–Irwin Group, and the Kellerberrin Group.

In 2002, David Leake undertook a Flexi-N vs Flexi-NS + zinc and copper trial, and a fluid potassium and sulphur trial. In the first trial, he applied nine different treatments, replicated three times, and measured plant weight and grain yield. There were no significant yield differences between using Flexi-N and Flexi-NS, although there did seem to be a negative interaction between the addition of zinc and copper to Flexi-NS. There were no responses to the addition of sulphur.

In the fluid K and S trial, he applied five different treatments of fluid K and KS, replicated three times, and measured plant weight, protein, screenings and grain yield. There were no significant differences in yield between any of the treatments, although there was a trend towards increasing yields as the amount of potassium and sulphur increased. A response was expected, however the dry season and high efficiency of utilisation (EU) may have led the plants to draw all they needed from the soil.

In 2003 he conducted a potassium type by rate trial, comparing Flexi-N, Flexi-NK and muriate of potash, the results of which are yet to be seen. So far, there do not appear to be any differences between any of the treatments, which is unusual, as the site should be highly K responsive. The Kellerberrin Group intends to continue with the fluid fertiliser work in 2004.

For more information, contact Mr Geoff Fosbery (Farm Focus Consultants) on 08 9622 5095

Research Report 23: No response to zinc in Victoria

'Zinc Nutrition Trial', Southern Mallee and Northern Wimmera Crop and Pasture Production Manual 1997. BCG Trial Results

Four different zinc products were applied to a wheat crop. There were no significant differences in yield obtained between the control (no zinc applied) and the four different zinc treatments.

Table 25. Yield responses to different zinc treatments on wheat

Trials by Birchip Cropping Group

Treatment	Yield (t/ha)
Control — no zinc (MAP 75 kg/ha)	4.82
Teprosyn Zn (seed treated) (MAP 75 kg/ha)	5.08
Mallee Mix 1 (Zn fert) at 90 kg/ha	4.82
Zincsol, soil applied (MAP 75 kg/ha)	5.02
Zincsol, foliar applied (MAP 75 kg/ha)	4.98
Significant difference	NS

Research Report 24: No response to zinc, Victorian Mallee

Zinc and Sulphur Nutrition Trial (Barley): Minyip, Wimmera Victoria, 1998.

Robert Christie, Pivot (not published)

Zinc was applied as zinc sulphate to the soil before sowing at 10L/ha (1.7 kg/ha Zn), as a seed dressing (Teprosyn 6L/tonne grain), at sowing as confos zinc (Mallee Mix 1 at 2.1kg/ha Zn) and zinc sulphate as a foliar application at 1.5L/ha (0.25kg/ha Zn) at tillering to a wheat crop. The site was alkaline calcareous clay, with the potential for responses to zinc.

Table 26. Zinc treatments, yield and protein achieved

Robert Christie, Pivot (unpublished)

	Treatment	Yield t/ha	Protein %
1	MAP @ 20 kg/ha P	0.64	15.6
2	MAP @ 20 kg/ha P + ZnSO ₄ soil applied	0.66	15.6
3	MAP @ 20 kg/ha P + Teprosyn	0.73	14.9
4	MAP @ 20 kg/ha P + ZnSO ₄ foliar	0.75	15
5	MAP @ 20 kg/ha P + Teprosyn + ZnSO ₄ soil applied	0.74	15.3
6	MAP @ 20 kg/ha P + Teprosyn + ZnSO ₄ foliar applied	0.83	15
7	MAP @ 20 kg/ha P + ZnSO ₄ + Teprosyn + ZnSO ₄ foliar applied	0.75	15.7
8	MM1 @ 20 kg/ha P	0.98	14.9
9	MM1 @ 20 kg/ha P + ZnSO ₄ soil applied	0.97	15.1
10	MM1 @ 20 kg/ha P + Teprosyn	0.95	14.9
11	MM1 @ 20 kg/ha P + ZnSO ₄ foliar applied	0.91	15.3
12	MM1 @ 20 kg/ha P + Teprosyn + ZnSO ₄ soil	0.99	15.3
13	MM1 @ 20 kg/ha P + Teprosyn + ZnSO ₄ foliar	0.89	15.3
14	MM1 @ 20 kg/ha P + ZnSO ₄ soil applied + Teprosyn + ZnSO ₄	0.92	15.1
15	MAP 4.5% Zn	0.90	15
16	MAP 8% Zn	0.94	14.7
CV = 23.5% LSD (p 0.05) = 0.23 t/ha			
MM1 — Mallee Mix 1			

Treatments 8 and 16 were significantly different from treatment 1. There were no significant differences between each type of zinc treatment.

Appendix 2: Farmer case studies

Case study 1. Wayne & Megan Smart, Toodyay, Western Australia

Property and farming system

Wayne and Megan Smart farm in the Toodyay region of Western Australia, about 120 km north-east of Perth. Toodyay is in a high rainfall area, receiving approximately 450 mm per annum, most of it in winter (May–September).

Soils consist mainly of the red-brown loams and sandy loams typical of the river plains and valleys of the region. Also known as York Gum and Jam country (local vegetation), the area's soils are highly productive with the potential to produce 5 t/ha wheat crops in an average season.

The farm is 2500 ha in size, and supports both a mixed cropping and sheep enterprise, and a small cattle enterprise — 70% is cropped each year, while 25% is allocated to sheep and 5% to cattle. A minimum tillage system (one pass with knife points) is used to sow the crop.

Use of fluid fertiliser

Wayne Smart first used liquids in 2002, when he purchased 270 tonnes of MAXamFLO from Summit Fertilisers. This was then split between three applications, all of which were applied through the boomspray using fan jets at intervals throughout the season. There was no provision for application through the seeder in either 2002 or 2003.

The first application was mixed with a knockdown herbicide (Roundup MAX®, Sprayseed 250®) and sprayed out prior to sowing at a rate of MAXamFLO @ 70 L/ha + water @ 30 L/ha. A second application of MAXamFLO was made at 50 L/ha + 20 L/ha water + a broadleaf herbicide mix (Tigrex + LVE MCPA) at early post-emergence. A third application of MAXamFLO @ 30–50 L/ha + water @ 30 L/ha was made later in the season.

In 2003, fluid fertiliser was used in a similar way, however the fan jets were replaced with dribble jets for post-emergent application, in an attempt to reduce the leaf burn associated with mixing fluid fertiliser with herbicides. While this approach helped to reduce leaf burn, Wayne feels the damage is too great, and does not intend to mix the two again.

In 2004, UAN will be added to the list as a source of nitrogen, as Wayne feels he is not getting enough N from the MAXamFLO. Both products will be applied by boomspray until the seeder is upgraded, at which time he would like to start splitting the application of fluid fertiliser between the seeder and the boomspray.

Reasons for using fluid fertiliser

- Timing of application is faster and more flexible.
- There is reduced dependence on spreading contractors (for granular fertiliser).
- Fluids have increased nutrient availability and there is more rapid uptake by plants.

Drawbacks of using fluid fertiliser

- Corrosion of equipment and increased requirement for daily maintenance/cleaning of not only the boom, but also the tractor, all engine components, electrical components, tyres, etc
- Need for better quality plumbing in both tanks and boom, stainless steel taps, etc
- Reliance on truck contractors and the need to forward plan for fertiliser delivery, so you don't run short
- Crop damage as a result of leaf burn when mixing liquids with herbicides
- Reduced efficacy of grass selectives when mixed with fluid fertilisers

Table 1. Equipment / Machinery & Cost / Value of Liquid Fertiliser Set-Up

Equipment	Brand	Capacity	Cost	Comments
Boomspray	Hydra Boom	7000 L (100 ft)	\$62,000	
Storage tank	Tanks West	43,000 L	\$6,100	Currently 2" fill. Need 3" fill to match truck capacity and for faster filling
Storage tank	Tanks West	23,000 L	\$3,300	As above
Transfer pump	Unknown (found at local rubbish tip!)	500 L/min	Free!	Must flush with water after every use. Likely to need replacing regularly
Dribble jets (x 60)	Spraying Systems	No 3	\$690 (\$11.50 ea)	Would need No 4 jets, or two sets of No 2 jets (twin spray lines) for larger volumes
Total Cost / Value of Liquid Fertiliser Set-Up = \$72,090				

Table 2 MAXamFLO + Herbicide Mixes Used in 2002 and 2003

Timing	Products mixed with MAXamFLO	Comments
Pre-sowing MAXamFLO @ 70 L/ha + water @ 30 L/ha	Roundup Max Credit & Bonus Sprayseed 250 Hammer Dual Gold Goal CT Glean	All products mix well and perform as expected. Weed control is good (with the possible exception of Roundup MAX in some instances?). Leaf burn is not an issue, as the fertiliser is going out with the knockdown prior to sowing.
*Post-emergent Broadleaf MAXamFLO @ 50 L/ha + water @ 20 L/ha	LVE MCPA Tigrex / Giant Glean Bromoxynil MA LV Ester 60% LVE MCPA + Tigrex + Glean	Mixes and performs well, some leaf burn Mixes and performs well but severe leaf burn can occur Mixes and performs well Does not mix or perform as well as expected Mixes and performs well, slight leaf burn Mixes and performs well but severe leaf burn can occur
Potential problem herbicides	Simazine, Atrazine Diuron, Trifluralin Avadex, Stomp Amines Grass Selectives	Physical compatibility problems with mixing and performance on target weeds. Grass weed (ryegrass) efficacy appears to be reduced by up to 50%.

*The addition of oils and wetters causes more leaf burn damage when used post-emergent.



Wayne Smart in a 2003 wheat crop treated with MAXamFLO



Wayne's dribble jets (No. 3)



Wayne's Hydra boom displaying dribble jets as opposed to fan jets (middle of boom)

Case Study 2: Trevor & Carol Fowler, Trayning, Western Australia

Property and farming system

Trevor and Carol Fowler farm in the Trayning region of Western Australia, about 300 km north-east of Perth. Trayning is in a low rainfall area, receiving approximately 315 mm per annum, most of it in winter (May–September).

Soil type varies greatly and includes most of the major soils associated with the eastern wheatbelt. Generally speaking, these soils are relatively infertile, with a wheat yield potential of 1.5–3 t/ha in an average season. The farm is 5800 ha in size, and consists of cropping with no stock; 100% of the property is cropped each year using a minimum-tillage sowing system (one pass with knife points).

Use of fluid fertiliser

Trevor Fowler was one of the first to use liquids in 1999, when CSBP released Flexi-N. He purchased 100 tonnes, and applied it post-emergent through the boomspray (after the weeds were removed) to top up nitrogen and boost protein. In 2001 he replaced the urea component of the program with Flexi-N applied down the tube at seeding, and continued to top up later in the season with the boom where necessary.

Table 3. Equipment / Machinery & Cost / Value of Liquid Fertiliser Set-Up

Equipment	Brand	Capacity	Cost	Comments
Storage tanks (x 7)	Freedom Tanks	43,000 L	\$35,000	Total cost has been averaged. Received good discounts
Liquid cart	Auspray	10,000 L (2 x 5000 L)	\$28,000	Cost of cart only
Plumbing (seeder & cart)			\$10,000	Plumbing on seeder & cart, pumps, cables etc
Variable rate technology (seeder & cart)			\$16,500	Monitor, software program, cables etc
Pump (boomspray)	Hypro		\$1,600	May need replacing regularly
Nurse truck & tank	IH Truck & Rotor Moulding Poly Tank	5000 L	\$5,000	Includes truck, tank, pump, plumbing
Total Cost / Value of Liquid Fertiliser Set-Up = \$96,100				

On average, Trevor uses a rate of 50 L/ha down the tube at seeding, then another 30 L/ha at early post-emergence then 30–40 L/ha at late post-emergence, on first and second-year wheat. The rate is increased to 70 L/ha at early post-emergence for third-year wheat.

In 2003, 470 tonnes of Flexi-N was used as well as 100 tonnes of Flexi-NK and 50 tonnes of Flexi-NS. A trial of Flexi-NPK (1.3 t) was also conducted. In future, Trevor would like to trial liquid phosphorus on his Morrell soils, and use liquid potassium if/when it is sold as a stand-alone product (no N).

Benefits of using fluid fertiliser

- Timing of application more flexible
- Increased nutrient availability and more rapid uptake by plants
- Ability to use N as a means of protein boosting late in the season
- Improved time management due to ability to mix liquids with herbicides for one pass over paddock
- Risk spread of N across a number of applications throughout the year
- Ability to apply N when it's too windy to spread urea or spray weeds
- Cheap, easy method of storage which does not deteriorate in the same way as a shed
- No need for storage sheds or front-end loaders, or to clean out sheds and trucks
- Storage tanks are saleable assets, whereas sheds are fixed assets.



Trevor Fowler in his 2003 canola crop treated with Flexi-NS @ 80 L/ha



Trevor's liquid cart, seeder and three-bin box



Trevor's boomspray

Drawbacks of using fluid fertiliser

- Corrosion of mechanical and electrical equipment and increased requirement for cleaning and maintenance
- Extra cost of freight (35% more than granules) due to payment in tonnes, but spraying in litres (e.g. need to freight approx 35% more Flexi-N to get an equivalent amount of N compared with urea)
- Reduced efficacy of grass herbicides when mixed with fluid fertiliser
- Potential danger to operator of using a liquid (splash etc) as opposed to a granular fertiliser

Case Study 3: Andrew & Jennifer Polkinghorne, Lock, South Australia

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Property and farming system

This farm is in the Lock region of the central Eyre Peninsula, South Australia, about 600 km north-west of Adelaide. The annual rainfall is approximately 340 mm per annum, with 250 mm received during the growing season.

Soil types are mostly grey calcareous sand with a pH of 8.7 (water) and CaCO₃ content in the soil of 20–60%. The farm has 2200 hectares of cropping, generally planting 1500 ha wheat, 400 ha barley, 100 ha canola, 200 ha peas, plus 300 ha medic pasture.

The aim is for more consecutive cereals in the rotation using wheat, wheat, barley, break crop instead of wheat, barley, medic pasture or wheat, medic pasture. Break crops are risky in this environment and therefore are used only to clear up an agronomic problem such as weeds or disease. Wheat grain yields have improved from 1 t/ha to 2 t/ha, with 3 t/ha being the highest yield. A water use efficiency model indicates 2.7 t/ha potential.

Use of fluid fertiliser

Normal fertiliser applications made in the past have included 60–70 kg/ha DAP + 30–50 kg/ha urea to give 12–14 units of P, followed by manganese, zinc and copper trace element foliar sprays.

2002 was the first year in which fluid fertilisers were used. Phosphorus, a small amount of nitrogen and trace elements were applied in fluid form. Granular urea at seeding provided 18–24 units of nitrogen for cereal on cereal, plus post-sowing N.

The liquid included phosphoric acid base (not a dangerous good) and urea (not UAN) as well as trace elements (TEs) (1.8 kg Mn, 650 g Zn, 200 g Cu (kg/ha)) to provide a 8:12:0 mix + TEs. pH of the mix was 1.38. This was applied @ 50 L/ha product + 70 L/ha water.

The (Fertisol) product was supplied by Omnia Fertilisers in South Africa and delivered by Collivers in bulk from Adelaide. Some APP was used to supply 6 units P or 26–27 L/ha of 16:23 to finish the season.

Reasons for using fluid fertiliser

In 1997–98, trials on the farm conducted by Bob Holloway showed a 7% yield increase in wheat yield. Other sites in the area had shown a 5–38% yield increase, with an average of 19%.

Other benefits from using fluid fertilisers

- Improved yield due to increased early vigour helping with weed competition and soil-holding ability.
- A hidden benefit not demonstrated in SARDI trials on crop performance is how much more uniform the crop is with poorer areas responding and root disease minimised.
- Barley after wheat is doing much better.
- Yellow leaf spot is normally bad early in the season with a wheat-on-wheat rotation, but in 2002 the early vigour of the second wheat crop was much greater and YLS was kept at a lower level or the crop was able to keep ahead of it.
- Trace element deficiencies are on a much lower area, except where APP was used; a Mn foliar may still be used on the barley.
- Instantaneous feed to airseeder, so no gaps when taking off.

Types of equipment

A Burando Hill cart (WA company) with a Bertolini plastic pump from Peter Burgess of Liquid Systems SA, instead of a stainless steel 316 pump, is pulled behind a Morris airseeder. This machine can sow 56 ha on one tank.

Good quality fittings and hoses are important and equipment from Pattison Liquid Systems in Canada is used. Banjo fittings are good quality fittings.

A fluid distribution manifold is mounted at the front of the bar for easy access, with non-drip nozzles and a stainless steel orifice.

A single stream is shot into the furrow through a 0.8 mm outlet. Very little trouble has occurred with blocked hoses. Only five blockages were experienced last season. The nozzles will be lifted next season, as the stream can be directed more accurately. Three tanks are mounted on a flat-top semi-trailer pulled by a prime mover for carting the fertiliser around the farm. This holds enough for 2–3 fills.

The fluid fertiliser is pumped into the tank by graduation through the lower inlet and then the water is added to push up through the solution to mix it.

Fertiliser liquid is stored in high-density plastic tanks with 29,500 L capacity. Extra tanks were purchased for water availability.

Drawbacks

Obtaining knowledge for the set-up and confidence to make the change was difficult, but is very important. It is hard to pull it all together and implement the change, e.g. the range of pipe fittings required.

There is a need to identify if you will get a response to cover costs. A 10% increase in yield is needed to cover costs. \$70,000 has been invested in a prime mover, transport tanks, transfer pump, fittings and hoses, fertiliser storage tanks, a water storage tank and a distribution cart.

Product costs are such that the fluid fertiliser is applied at the same financial rate. This means 4–5 kg P/ha compared with 9–10 kg P/ha. An application of 6 kg P/ha was used, meaning that fertiliser costs for phosphorus were around 20% higher than for the fertiliser normally used.

There are ongoing costs. Extra fittings have been bought and replaced over the entire machine. One fitting leaked and dripped acid onto a hose clamp, which ate through the metal. The original John Blue pump on the Burando Hill cart lasted only one week and was replaced with a stainless steel John Blue pump.

The logistics and storing of fertilisers remain a problem, particularly to ensure a continual supply during seeding.

Future

Andrew is very keen to see research continue, particularly into the responses in different soil types, including:

- research into APP and its P releasing properties
- research for mixing trace elements with APP.

Suspensions sound good, but are not simple to achieve. The technique means fungicides in furrow may now be an option.

The price of the P fertiliser product is a big issue. Local manufacturers need to build a plant or establish a volume market to get the price of freight down. Fluid fertiliser is expensive in containers (bladders) coming from South Africa. There is not a big enough industry to fill a hold on a ship.

Andrew feels that liquids are the future and that there are plenty of potential entries into using the technology, given a reduction in price.

Case Study 4: Carolyn & Darren Mudge, Eyre Peninsula, South Australia

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Property and farming system

The farm on the Eyre Peninsula in South Australia comprises 4000 hectares (10,000 acres) with approximately 1500 ha of wheat, 500 ha of feed barley, 80 ha of oaten hay and 200 ha of canola. The remainder is pasture for a Poll Hereford stud.

Soils have high CaCO_3 levels of approximately 65–80%. The Cowell P readings are around 40 ppm, but soils have minimal response to solid P fertiliser. The soil pH is 8.4 (water).

The farm has a 300 mm average annual rainfall (250 mm in growing season), producing an average wheat yield of 1.0 t/ha. The rotation is generally wheat, wheat, barley, pasture, but it really depends on the paddock. Nitrogen has not been shown to give a response in trials on this farm and therefore no nitrogen is applied at seeding.

Use of fluid fertiliser

The main reason for using fluid fertiliser is to improve wheat yields and/or achieve a more efficient result from application of phosphate fertiliser. In 1999 in the first SARDI fluid trial on the property, the fluid fertiliser-treated wheat yielded 0.6 t/ha (3 bags/ac) compared with 0.2 t/ha (1 bag/ac) with granular fertiliser.

Fluid fertiliser, in the form of phosphoric acid, was first used in 2000. Prior to this granular fertiliser was used, either 40–50 kg/ha MAP or 50–60 kg DAP.

The phosphoric acid was obtained in 200 L drums from Albright & Wilson in Melbourne, with each drum weighing 330 kg (1.654 w/v). In 2003, Redox phosphoric acid was used.

In 2001, Zn, Mn and Cu were applied at 1 kg, 2.5 kg and 250 g/ha respectively at seeding in fluid form. In 2002 these rates were cut to 1 kg:1 kg:125 g and mixed with the acid. In 2003, Zn was used at a rate of 3.5 kg/ha zinc sulphate mixing in a 2000 L aqua tank with agitation.

The 3.5 kg/ha sulphate with fluid fertiliser + 1 kg/ha foliar @ 2–3 leaf showed up well in tissue tests with up to 100 mg/kg Zn.

The other advantage of fluid fertilisers is that they provide time-saving benefits at planting time. A bigger seed box now means fewer stops. A major constraint has been severe rhizoctonia, which is the main reason for the emphasis on zinc.

Types of equipment

A fluid cart has been built to tow behind the seeder, while a flat-top truck is used to cart water and fluid fertiliser.



The fluid cart has a 3000 L trailing tank with a ground-driven Bertolini (Croplands) pump, which is acid-resistant, has an acid-proof flow meter and KEE spray controller.

The planter was originally a chisel plough with 30 cm (12 inch) spacing and narrow planting points. It is now a 15 metre (42 ft) Forward bar with 20 cm (8") row spacing, Agmore boots, knife points and swivel walking press wheels.

The Mudges started with poly pipe, dripper tube and garden nozzles but found acid needs stainless steel distributor heads and/or PVC fittings. The method they use is to shoot as deep as possible in a single stream @ 5–10 psi. 60 L/ha is applied using 0.8 mm nozzles with two inline filters.

Disadvantages of fluid fertiliser

The main disadvantage is the high cost of nutrients. It has been possible to obtain Fertisol APP in bladders from South Africa (although it now seems they are not practical). This has some N but at \$1400/t it is expensive, with an approximate cost of P of \$5.80/kg. In 2003, Redox phosphoric acid (26% P) was the cheapest fluid P fertiliser — at a cost of \$860/tonne delivered from Adelaide to farm, which is approximately \$3.26/kg P.



Zinc is added to the water first before adding phosphoric acid.

The trial work has shown 4 kg P in a fluid form will yield similarly to 20 kg P applied in a granular form. To apply 4 kg P as phosphoric acid would cost \$13/ha compared to \$17/ha for 8 kg P/ha (using 40 kg DAP/ha). Trials have indicated that, in order to achieve the same yield as 4 kg P fluid, the cost of granular fertilisers would be \$38/ha.

Comparative costs for phosphoric acid and DAP

	Phosphoric acid @ \$890/t		DAP @ \$425/t	
Rate P/ha	4	6	8	10
Per kg P	3.26	3.26	2.13	2.13
Per ha	13.03	19.55	17.04	21.25

The safety of phosphoric acid is an issue, but should not be a major one when the correct materials are used. The left-over 200 L drums are also a problem, but dealing in bulk (if possible) would be more efficient. Initially phosphoric acid ate through the delivery hose, requiring it to be changed 2–3 times. The flow rate controller was eaten out and needed replacing.

Set-up costs included \$3000 for tanks, with six distributor heads costing \$150/head, and a spray trailer. The total cost was around \$15,000 including pumps.

Future

The improved response of P fertiliser on calcareous soils means the Mudges will continue with fluid fertilisers. The price of products will be important. Phosphoric acid has a higher concentration of P compared to APP, which means less need for storage. They are not really concerned with the corrosiveness of PA as their system allows for minimal handling. APP is an option, especially if they need to start applying N again, but it needs to be cheaper. Mixing trace elements with APP is an issue for the Mudges.

There are still problems with set-up and nozzle design that need to be sorted out, along with rates and forms of trace elements.

Case Study 5: Peter Kuhlmann, Eyre Peninsula, South Australia

Property and farming system

The farm is at Mudamuckla on the Eyre Peninsula in South Australia. The soils are mostly grey calcareous sandy loams with a pH of 8.6. Average rainfall is 300 mm, with wheat yields around 1 t/ha.

Around 5000 ha of wheat are grown in a rotation of wheat, wheat, pasture or wheat, wheat, barley/oats/wheat, pasture. No-till and minimum tillage are used.

Use of fluid fertiliser

The main reason for changing to fluid fertiliser was research that showed additional yield from less P fertiliser on calcareous soils in the district.

In the past, normal fertiliser use was 50 kg DAP. In 2002, Peter changed to fluid fertilisers using APP (14:21:0) at 20–25 L/ha. This provided 4–5 units of P at the same cost as 50 kg of DAP. Although the DAP contains 10 kg of P, research has indicated better responses from the lower rates of P applied in a liquid form.

In 2003, APP was used with urea @ 30 kg/ha on third-year wheat crops, together with 200 g/ha of zinc heptahydrate added to solution.

Fluid fertiliser equipment

Five 27,000 L heavy-duty poly tanks are used for storage, with field transport using a 17,000 L milk tanker. The liquid is filtered into the tank, out of the tanker, with two filters fitted on the cart.

Non-drip spray nozzles with a metering orifice are used for distribution. A 4 mm dripper line runs down seed tubes and a microjet in the end gives a single stream.

Two planting machines have been set up for fluids. For minimal-till paddocks, sweeps are used with fluid applied at 100 L/ha through 0.28 mm orifices during the working-up process. On the no-till machine, which has Harrington knife points, fluid is metered through 0.22 mm orifices and is applied at 70 L/ha at seeding. The orifices in the nozzles are stainless steel, costing \$6 per orifice. They are used in the non-drip nozzle to maintain an even flow. The system works at 2 bar pressure.

The fluid cart is a 7000 L Burando Hill tank using a ground-driven John Blue single piston, double-acting variable-stroke pump.

The best quality equipment was used for the change-over to fluids. This was for safety reasons and to minimise the risk of down-time at seeding due to equipment failure. Although APP is being used, the equipment is high quality and could handle phosphoric acid-type products in the future.

Benefits

An average yield increase in the order of 10 % is anticipated from changing to fluid fertilisers. Fluid fertilisers appear to give the best yield increases in drier years when any yield increase is critical.

In 2002 a trial was set up on wheat using 15 and 30 L/ha APP, with added zinc. On paddock, the yield without fertiliser was 0.8 t/ha, the average of three strips with 15 L/ha APP was 1 t/ha, while 30 L/ha APP yielded 1.25 t/ha.

The south side of the paddock received 30 kg of DAP (18:20), which yielded 0.57 t/ha. The addition of 15 L/ha APP + zinc increased yield to 0.76 t/ha, while the yield from 30 kg of DAP and 30 L/ha of APP + zinc was 0.85 t/ha.

Using APP, the residual P benefit and the ability to unlock soil phosphorus will have a significant impact on the farming system in the future.

The much greater vigour of wheat plants during the seedling and tillering stage reduces the risk of wind erosion as well as the risk of root disease and nematode damage.

The other benefit is greater efficiency in paddock logistics. With granular fertiliser, fills were at each 65 ha, taking half an hour to fill. With liquids, the seeder will do 100 ha in the same filling time.

Drawbacks

The major drawback is the price of APP. The price of APP is 2.85 times more per kg of P than granular products. The cost has been kept down to a little over the cost of 50 kg DAP/ha by using much less P. There is a need for a cheaper product so that higher P rates can be used.

Mixing zinc sulphate with APP forms a precipitate and requires good agitation to allow the APP to sequester the zinc. A fire-fighting pump provides good agitation.

There are set-up costs and extra tanks are needed to store water. The costs of conversion include a liquid cart (\$26,000), a milk tanker (\$18,000), storage tanks (\$16,000), and hoses, pumps, filters and distributors (\$11,000), giving a total of \$71,000.

Future

The farming system, sustainability and productivity are expected to improve in the future along with lowered drought and erosion risks. Residual benefits are expected from fluid fertilisers, whereas granular fertilisers appear to become totally fixed.

In the longer term, Peter expects to move to variable rate application of fertiliser and the use of more nitrogen. Fungicides and herbicides might be used in the solution, along with trace elements such as zinc, copper and manganese.

There is a need to get the package right to maximise benefits, which may or may not include extra yield.



Fertiliser cart used on Peter Kuhlmann's farm



Injector tube directs fluids ahead of the seed

Case Study 6: Tim van Loon, Warramboo, South Australia

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Property and farming system

The farm owned by Tim van Loon is at Warramboo on the Upper Eyre Peninsula in a 350 mm rainfall area with average wheat yields of 1–1.2 t/ha. Around 1600 ha of crop are grown each year. Soils are grey calcareous loams with a CaCO₃ content of 60% and a pH of 8.5.

Use of fluid fertiliser

The switch to fluid fertiliser has been made in response to trials in the region showing extra yield and more efficient responses to liquid P fertiliser, compared to the standard application in the past of 50 kg/ha DAP. Trials showed fluid fertilisers produced a 12% increase in yield over normal district practice.

The other major reason for changing is to allow application of trace elements into the root zone along with P. Over the past three years, phosphoric acid and APP have been used with nitrogen and trace elements. In 2001, phosphoric acid was applied with nitrogen and Cu, Mn and Zn. In 2002, APP was applied and found very simple to use with no hassles. In 2003, phosphoric acid was used as a P fertiliser.

Fertiliser equipment

A Conner Shea airseeder has been fitted with a trailing liquid tank. Liquid P fertiliser is handled and stored in 200 L drums or shuttles.

Fertiliser is applied using 120 L/ha of fluid delivered at the tine through a 0.9 mm nozzle at 10 psi pressure. PVC has been used, as it is acid-resistant, with poly fittings across the machine.

Benefits and comparisons

In 2001 a 40% increase in dry matter and a 12–15% increase in grain yield were achieved over the whole farm. Fluid fertiliser was shown to be 3–4 times more efficient than granular fertiliser in terms of applied P.

Improved early vigour and growth are major advantages, as the crop is more competitive with weeds and more protected against wind erosion.

Fluids provide more options with mixes, due to their ease of mixing.

In the mid-1990s plant tissue zinc levels were in the range of 20–35 ppm, but are now up around 45–65 ppm with zinc applied.

Dry matter of wheat grown in strips of Paddock A, Tim van Loon's 13.8. 2001

	Dry matter (kg/ha)	% of granular
6 P liquid + 3.6 P granular	385	142
11 P granular	270	100
6 P liquid	383	141
3.6 P granular	189	70

Drawbacks of fluid fertiliser

The main drawback is the cost, with APP costing \$5.50 per kg of P in 2001, technical grade MAP \$3.08/kg P and phosphoric acid \$3.27/ kg P compared with DAP at \$2.15/ kg P unit. Some prices have come down a little since then, but it is hoped they will come down further as the use of fluid P fertiliser increases.

In 2002, it was difficult to dissolve enough trace elements into the APP. Phosphoric acid is easier to mix, but has a problem with user-friendliness and the need for neoprene seals on pumps for protection.

The conversion to fluid fertilisers costs money but doesn't need to be expensive. When fertiliser is used from shuttles or drums, it can be done for under \$10,000.

Future

The future use of fluid fertiliser will depend upon prices and availability of fertiliser. The price per unit of P is expected to come down with greater use.

Future developments include the fine-tuning of application equipment and mixing of trace elements with fluid fertiliser. Variable rate technology is a likely improvement of the fertiliser system.

Study tour

Tim van Loon undertook a study tour of North America in 2001, looking at the use of fluid fertilisers. Key features of this study from his Nuffield Scholars report are:

1. The use of liquid P fertiliser occurs after and on the back of liquid nitrogen use.
2. The biggest challenge facing the Australian industry is price.
3. The need to import products from North America, South Africa or Russia creates a freight component that is almost equivalent to the price of the product.
4. High temperatures in autumn can compromise the quality of polyphosphates.
5. Finding a cost-effective N, P and trace element mix is still a big challenge.

Case Study 7: Brian Hedt, Dimboola, Victoria

Property and farming system

The farm, at Dimboola in the Wimmera district of Victoria, consists of 1482 hectares of alkaline Wimmera grey clay loams and some red-brown earths. The annual rainfall is 410 mm.

The farming system is a continuous cereal legume rotation, with broad beans, wheat, lentils and barley. Fluid fertiliser used on the farm at sowing is phosphoric acid (81% P) applied at 16 L/ha (7 kg P/ha) blended with 24 L/ha of water, with a total application rate of 40 L/ha. It is delivered to the farm in 200 L drums and is purchased from Deltrex Chemicals.

Application equipment

- Second-hand saddle tanks are fitted to the tractor, two 900 L tanks plus a tank at the front of the tractor with fresh water for flushing the lines and safety.
- Filters, pumps and hoses were purchased from Peter Burgess, Liquid Systems, Adelaide.
- The distribution system at each tine was custom-built by the Hedts using purpose-built blunt hypodermic needles and fittings sourced from a surgical supplier. This allowed for a low rate (40 L/ha) to be applied and to still achieve a continuous stream of product (cost approx. \$5/tine).
- Product was mixed with water in the yard and carted to the paddock in an old milk tanker (up to 9000 litres at a time).
- A Raven controller is used to control flow rate.
- The airseeder is 8 metres wide with 45 tines at 180 mm row spacings.

Reasons for using fluid phosphorus

- Brian Hedt had been following research work in South Australia for a number of years and was impressed with the results.
- He hopes to achieve the same yield increases as those achieved in South Australia, of 10–15%.
- He hopes the fluid fertiliser will assist in making available to the plant any phosphorus “locked” in the soil.
- He understands that phosphorus is not very mobile in alkaline soils and believes that fluid P should be more accessible to the plant.
- He could not see crop responses to phosphorus from solid fertilisers used (Mallee Mix 4 — N 11.6, P 14.7, S 7.7, Zn 1.5)

Benefits

- Ease of handling product compared to solid fertiliser
- Ease of mixing additional nutrients if required, e.g. zinc, molybdenum, sulphur
- Accuracy of application using the flow rate controllers
- Fluid fertiliser does not settle out and will sit mixed in the tanker until required, unlike solid fertiliser which can deteriorate if left in augers or seeding equipment overnight.

Drawbacks

- A change in the ratio of water or adding new products would mean recalibrating the flow rate meter, which would take time
- Dripping nozzles
- Care when handling corrosive product to avoid spillages
- Transfer of product out of drums is slow, because the product is heavy.

Costs

- Total cost to set up for seeding including the cost of the milk tanker was \$20,500
- Using phosphoric acid (81% P) cost \$1.65/L (\$3.77/kg P) on-farm, compared to using Mallee Mix 4 (N 11.6, P 14.7, S 7.7, Zn 1.5) at \$4.76/kg (\$3.23/kg P) on-farm (costs exclude GST)
- Extra filters
- Wasted money on equipment that didn't work or deteriorated, e.g. Hardi controller worth \$3,000
- Setting up distribution to additional tines would cost less than \$20 per tine
- Product was delivered in 200 L drums on pallets. As a result, the freight was approximately \$40/tonne, compared to solid fertiliser delivered bulk, which is approximately \$20/tonne.

Future use

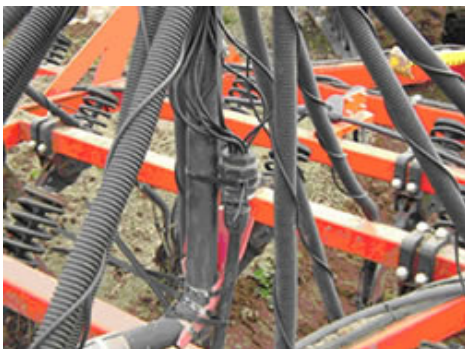
- Will continue to use phosphoric acid on pulses
- Will mix with trace element liquid products
- Will try ammonium polyphosphate next season on cereals
- Variable rate and dual distribution systems to apply extra nutrients, e.g. sulphur, to particular areas of the paddock a real possibility
- Bulk product rather than 200 L drums
- Replacement of nozzles with non-drip system.



Moving seed and fertiliser



Filling the tanks for seeding



Fertiliser distribution hoses wound around seed delivery hoses



Fertiliser injection set-up at each tine



Fertiliser being injected

Case Study 8: Dean Johns, Horsham, Victoria

Property and farming system

The property of 1600 ha is near Horsham in the Victorian Wimmera. It comprises alkaline soil, Wimmera grey clay loams and some red-brown earth.

The farming system is a continuous crop rotation of wheat, barley, canola, chickpeas, lentils, broad beans, with around 10% of fallow.

Fluid fertiliser applied to the crop during the growing season is urea ammonium nitrate (UAN), sold as Easy N 42.5%. Nitrogen is applied as a foliar spray at less than 20 L/ha and applied direct onto the soil at rates in the range of 20–100 L/ha. In the first eight months of 2003, Dean had already used 100 tonnes.

Application of UAN

- Boomspray – all plastic and stainless steel
- Soil application
 - streaming nozzles with T-bar
 - rates of up to 100 L/ha of UAN applied neat or mixed with up to 20 L/ha of water depending on the weather (mix with water if warm, sunny and windy to avoid crop damage)
- Foliar application
 - coarse nozzles, e.g. Turbo T, to provide a droplet size of greater than 250 micron
 - rates of less than 20 L/ha of UAN mixed with 20 litres of water — too much water results in increased crop damage
- Apply after 4pm, particularly if warm, to avoid crop damage
- Timing of application and equipment is critical for success and to reduce crop damage

Reasons for using fluid fertiliser

- Timing of application is flexible
- Ease of application
- Type of nitrogen applied is more stable and more available than urea with less chance of volatilisation
- Availability of nitrogen to the plant is improved.

Costs

- * UAN costs double that of urea per kilogram of nitrogen on-farm (\$1.80/kg N in UAN and \$0.85/kg N in urea)
- * Freight from Brisbane is the biggest expense issue
- * Setting up with non-corrosive equipment on boomspray, e.g. taps, fittings and pumps should be stainless steel and plastic. Any metal components deteriorate quickly.

Issues

- Handling issues when using a hazardous chemical
- The corrosiveness of the product resulting in equipment damage
- Mixing with herbicides needs good agitation, otherwise the product will settle out.

Future

- It would be good to see tanks of product delivered in bulk on-farm similar to fuel.
- A manufacturing plant in Victoria would reduce freight costs.
- In the past dissolved urea was used. However, this will not be used again due to issues with the time needed to dissolve the product. To dissolve 1 tonne of urea in 6000 litres of water takes 40 minutes.



Dean Johns applying UAN to wheat at growth stage Z31

A survey of farmer experience with fluid fertilisers in Western Australia

A survey of farmers working with Farm Focus in Western Australia provided the following information on the use of fluid fertiliser. Of a total of 80 farmers, approximately 25% are now using fluid fertilisers for part of the cropping program. Of these, nine farmers agreed to take part in a survey, the results of which are outlined below.

Most of the farmers are using Flexi-N applied using a boomspray, both prior to and after seeding. The fertiliser is often used at the same time as a herbicide spray, either with a knockdown before planting, or a post-emergent weedicide during tillering.

On average, the farmers spent \$67,000 (range of \$33,000–\$81,900) on the equipment required to convert to fluid fertiliser use. This includes the cost of the boomspray of approximately \$45,000, which is also used to apply pesticides. Most have invested in storage tanks, a truck and tanks for on-farm cartage, pumps and boomspray parts (nozzles, replacement parts, etc).

The main benefits cited are increased flexibility in regard to timing and number of applications and the reduced need for labour or spreading contractors. The main drawbacks are questions regarding the compatibility of the fluid fertilisers with pesticides (herbicides, insecticides and fungicides), the level of crop damage that occurs when liquids are applied post-emergence, and the corrosive nature of the products.

Most of the farmers surveyed indicated that they will continue to use, and indeed increase the use of, fluid fertilisers in the future. Most predict they will be applying liquids via variable rate technology through the seeder, and in mixes with trace elements, in the not too distant future.

Farmers surveyed on fluid fertiliser use			
Farm no	Farm size (arable ha)	Liquid fertilisers used	Approx cost of converting to liquid
1	3380	Flexi-N, BSN 10 (seed dressing)	\$51,080
2	3400	Flexi-N	\$81,740
3	5000	Flexi-N	\$78,000
4	3600	Flexi-N	\$76,500
5	3600	Flexi-N	\$56,600
6	1750	Flexi-N	\$77,800
7	5800	Flexi-N	\$81,900
8	5000	Flexi-N, Flexi NS	\$67,900
9	2400	Flexi-N	\$33,000

Benefits of fluid fertiliser on survey farms

1. Mid to late applications of N for correcting nitrogen deficiency and boosting protein
2. Speed, accuracy and timeliness of application; reduced labour requirement
3. Accuracy of placement; ability to apply with fungicides and herbicides; no need for spreader
4. Convenience at seeding (no need for spreader); reduced volatilisation; ability to boost protein late in season
5. Greater efficiency; ability to top up in wet, windy conditions; liquid can be used as a carrier for herbicides
6. Ease of storage; ease and speed of application; no need for spreader or spreading contractor
7. Ease of storage; ability to improve N levels while spraying out knockdown; rapid nutrient uptake by plant
8. Flexibility of application timing; accurate coverage; elimination of need for spreading contractor
9. Better nutrient uptake; increased number of spraying hours/days due to ability to spray in rain and wind

Drawbacks of using fluid fertiliser on survey farms

1. Questionable compatibility with herbicides, insecticides and fungicides; corrosion of tractor and boomspray
2. Incompatibility with some chemicals (in particular ECs); corrosive nature of products
3. Extra cost of investing in infrastructure; down-time during seeding and increased risk of breakdown
4. Incompatibility with chemicals; cost of converting seeder; corrosion on machinery; timely delivery of product
5. Not a good carrier for chemicals; too much leaf burn when used post-emergence; highly corrosive to machinery
6. Corrosion of machinery; incompatibility with herbicides and fungicides; leaf scorch when applied post-emergence
7. Leaf scorch when mixed with herbicides; corrosion of equipment, especially electrical and mechanical parts
8. Corrosion of all parts of the machine as a result of drift when spraying
9. Corrosion of machinery; second-hand boomsprays and tractors are likely to be worth very little in the future.

Future plans/trends for fluid fertiliser use on survey farms

1. Liquid cart and application through the airseeder; mixing liquids with trace elements
2. Liquid cart and application through the airseeder; mixing liquids with trace elements
3. Application via variable rate technology
4. Liquid cart and application through the airseeder; increased rates of Flexi-N
5. Application via variable rate technology; total liquid use (no granules); blending on-farm
6. Multiple tanks applying a number of products at once
7. Increase usage; mix with trace elements
8. At this stage, will continue to use liquids in the same way they are currently being used
9. Increase use of trace elements in mixtures.

Research needs: areas identified by farmers for future GRDC funding

1. Correcting nutrient deficiencies with foliar sprays
2. Time of spraying and effect on yield; compatibility of Flexi-N etc with trace elements (Boron etc)
3. Efficacy and safety of mixtures (herbicides, fungicides, insecticides and liquid fertilisers) on the crop
4. Compatibility of liquids with pesticides; timing of application for boosting protein; fertiliser placement
5. Effect of fluid fertiliser mixes with herbicides and fungicides applied post-emergence on crops, crop damage etc
6. Effect of late nitrogen applications on protein and yield in cereals
7. Effect of banding vs spraying on crop yield; effect of liquid vs granules on crop yield
8. Efficacy and safety of mixtures (herbicides, fungicides, insecticides and liquid fertilisers) on the crop
9. Efficacy and safety of mixtures (herbicides, fungicides, insecticides and liquid fertilisers) on the crop

Farmer experiences with fluid fertiliser in Queensland and northern New South Wales

There are no farmers in Queensland and northern New South Wales using fluid fertiliser on a regular basis (note that use of anhydrous ammonia is not included in this report). Liquid forms of nitrogen and phosphorus have been available at times, and many farmers have compared the performance of liquids against solid fertilisers, but have not found any consistent advantage.

Manufactured in Brisbane until the mid-1980s, phosphoric acid was marginally cheaper per kilogram of P than MAP or DAP, especially during the early 1980s.

A number of farmers tried using phosphoric acid, but found it difficult to manage with respect to pumps, handling equipment and operator safety. They found no significant yield responses and most gave up its use, even before the Brisbane plant ceased manufacture.

During the late 1980s and early 1990s farmers became interested in water injection, where they dribbled around 400–1000 litres of water per hectare onto the bottom of the seed trench at planting time to increase the potential results of planting under marginal moisture conditions, several weeks after rain.

Many of these farmers tried MAP and zinc fertilisers added to water injected into the soil at sowing. The MAP available at that time was a reasonably pure product with good solubility. The water injection was conducted on soils with a high clay content (50–70% clay) and high pH (8.0–9.0), but no significant response to the liquid form of P was recorded.

Liquid nitrogen use has also been trialed by farmers over the years. Farmers are not averse to investing in storage and handling equipment, as evidenced by the common use of anhydrous ammonia in southern Queensland as a nitrogen fertiliser. Most farmers have invested in storage tanks and have special applicators to apply anhydrous ammonia.

The attraction of anhydrous ammonia has been the price. It has consistently been the cheapest source of nitrogen. With farmers on the Darling Downs using more than 100 kg N/ha on summer crop, a difference of 20% in price constitutes a significant impact on fertiliser costs.

Liquid nitrogen fertilisers have not proven popular, despite the construction of a liquid urea and UAN facility in Dalby. During the 1980s, agronomists employed by Consolidated Fertilisers Ltd conducted numerous farmer observation trials on the use of liquid nitrogen, boomsprayed onto soil at planting time, dribbled on at planting and during tillering stages of winter cereals, and in foliar applications.

The general conclusions of this work and other trials conducted by the Department of Primary Industries in Queensland were that liquid forms of nitrogen fertiliser did not provide any advantages to solid forms of nitrogen applied at or prior to planting and that they were at times subject to some volatilisation loss.

Foliar applications sometimes provided a response in terms of yield and/or grain protein, but the response was unreliable and dependent upon rainfall to activate the nitrogen before the cut-off time for response. Late tillering was regarded as the cut-off time for a yield response and flowering for a protein response.

Post-planting applications of urea and UAN sprays were used in 1998, when the yield potential of wheat was enhanced by a good season. However, in a year when everything looked right for yield responses, there was a negative reaction from using fertiliser, due to the nitrogen enhancing the effect of yellow spot disease, and making the wheat more attractive to army worm and subsequently suffering more damage from this pest.

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