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THE CONTRIBUTION OF FERTILIZERS TO AGRICULTURAL PRODUCTION IN AUSTRALIA

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Abstract

The paper provides estimates of Australian N, P and K fertilizer use by the Australian farm sector in terms of volume and value. The estimates show the increasing use of fertilizer over time as well as some information on the proportions used by, and importance of fertilizer in the cost structure of, different agricultural sectors. Some factors driving past trends and those likely to affect future fertilizer use in Australia are identified.

The second part of the paper identifies how fertilizer has enhanced agricultural production and provides an estimate of the value that fertilizer has contributed. The difficulties in estimating this contribution are explored and areas identified where the value of fertilizer can be enhanced in the future.

Introduction and Background

The objective of this paper is to assess the contribution of the value of fertilizer to Australian agricultural production. Agricultural production is defined as including livestock production, broadacre cropping, and horticulture.

Linkages with other papers at this conference are important, especially with Doug Reuter's paper on nutrient balance and Derek Quirke's paper on the value of the fertilizer industry to the Australian economy. The present paper can be seen as a link between the other two as nutrient balance is critical to fertilizer use and value, and the value of fertilizer to agriculture is a key driver in its broader role in the economy.

Fertilizer Use by the Farm Sector

Value of Agricultural Outputs

In order to gain an understanding of the volume and value of fertilizer use by the farm sector, it is useful to consider the value of industries to which this use relates. Data in Table 1 presents the value (in nominal dollar terms) of Australian agricultural outputs for cropping, pastures and horticulture. This information is also presented graphically in Figure 1.

Table 1: Value of Australian Agricultural Outputs ($million)

Year	Cropping[ab]	Pastures[bc]	Horticulture[de]	Total
1989/90	5,969	11,401	2,743	20,113
1990/91	5,316	9,762	2,737	17,815
1991/92	5,399	8,433	3,131	16,963
1992/93	6,394	8,823	3,047	18,264
1993/94	6,431	9,414	3,015	18,860
1994/95	5,948	10,386	3,429	19,763
1995/96	9,449	9,423	3,829	22,701
1996/97	10,338	8,932	4,052	23,322
1997/98	9,059	9,639	4,393	23,091
1998/99	9,176	9,558	4,780	23,514
1999/2000	9,947	9,383	4,780[f]	24,110

[a] Farm-gate value; includes coarse grains, wheat, rice, cotton, pulses, oilseeds, sugarcane

[b] Source: Australian Commodity Statistics – various years

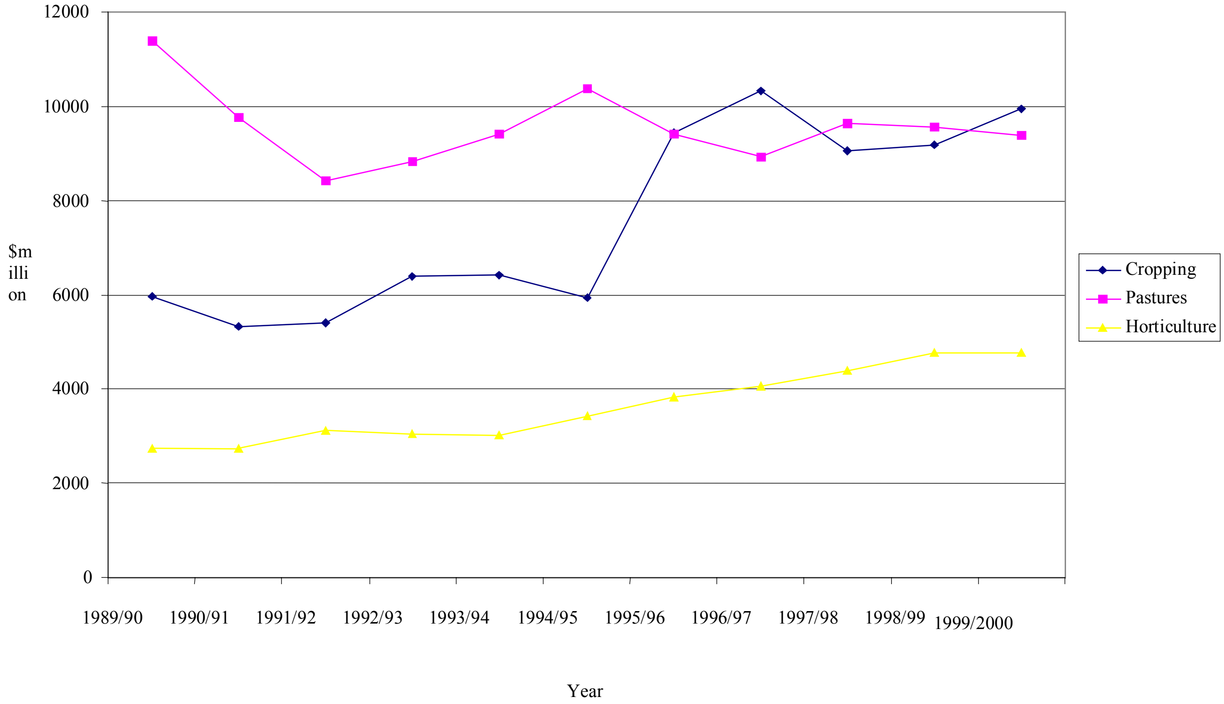
[c] Farm-gate value; includes dairy products, beef and veal, lamb and mutton, wool

[d] Gross value; includes fruit, nuts and vegetables, but not nursery production which is significant at $600 million in 1994/95.

[e] Source: ABS Value of Agriculture (7503.0) 1994; ABS Value of Agricultural Commodities Produced (7503.0) 1996-97; ABS Value of Principal Agricultural Commodities Produced (7501.0) 1998-99

[f] 1998/99 value used due to unavailability of 1999/2000 data

Figure 1: Value of Australian Agricultural Outputs



The data above shows that while the value of cropping has increased steadily over the period 1989/90 to 1999/2000, the value of (products from) pasture has remained relatively constant, so that the value of cropping and pasture production is approximately equal. The value of horticultural production has increased steadily over the same period, but is still only about half of the value of either of the other two sectors.

Volume of Fertilizer Use

A first step in assessing the contribution of fertilizers is to establish their on-farm usage in both volume and value terms. Only the principal fertilizer elements of nitrogen (N), phosphorus (P) and potassium (K) are considered. These make up the bulk of nutrients applied as fertilizer in Australian agriculture.

Secondary nutrients include calcium (Ca), magnesium (Mg) and sulfur (S). Data on the volume and value of these nutrients consumed is not presented in this paper. Also important to plant nutrition, are the micro-nutrients, or trace elements. These include boron (B), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn). No data on volume and value are provided for these trace elements. Other soil additives such as lime and gypsum are also excluded.

Table 2 presents the annual Australian consumption of elemental N, P and K fertilizers for the years 1989/90 to 1999/2000. Fertilizer quantities are reported here in elemental terms (N, P and K), except where specified. It is recognised that many in the industry report P and K in terms of quantities of P_2O_5, and K_2O. (A conversion factor of 0.4364 was used to convert P_2O_5 into elemental P and a conversion factor of 0.8302 was used to convert K_2O into elemental K.) The table shows that Australian consumption of nitrogen has increased by around 150% from 1989/90 to 1999/2000. Phosphorus consumption has increased by about 80% and potassium has increased by about 30%. The average annual increase in consumption is 10% for N; 6% for P and 3% for K.

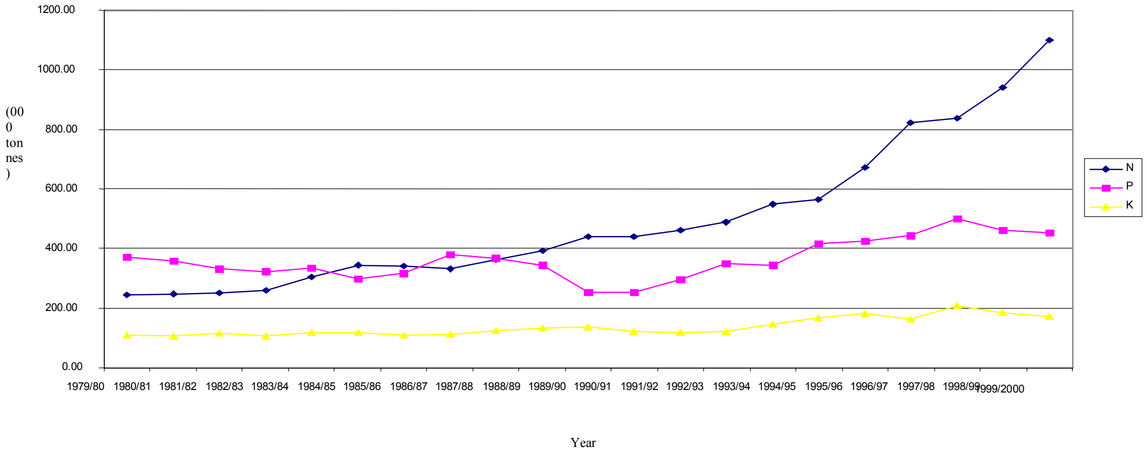
Table 2: Annual Australian Fertilizer Consumption (000 tonnes)

Year	Elemental N	Elemental P	Elemental K	Total
1989/90	440.3	252.6	135.0	827.9
1990/91	439.4	253.1	120.7	813.2
1991/92	462.4	296.8	118.0	877.2
1992/93	488.0	349.7	120.6	958.3
1993/94	548.0	345.0	143.3	1,036.3
1994/95	564.5	414.6	167.0	1,146.1
1995/96	671.3	426.6	181.8	1,279.7
1996/97	824.6	443.4	163.1	1,431.1
1997/98	839.4	501.0	206.7	1,547.1
1998/99	940.7	462.0	185.1	1,587.8
1999/2000	1,099.4	451.6	171.8	1,722.8

Source: Derived from ABARE Commodity Statistics, 2000

Figure 2 below shows the increase in Australian consumption of N, P and K over the past 21 years. This clearly shows the static consumption in the 1980's with an increase in fertilizer use in the 1990's, particularly for nitrogen.

Figure 2: Annual Fertilizer Consumption Since 1979/80



Source: ABARE Commodity Statistics, 2000

A paper prepared by Gordon Davis of Incitec Fertilizers for the IFA Regional Conference for Asia and the Pacific in December 2000 provides several reasons for the large increase in fertilizer consumption in Australia over recent decades. These include:

- There is a scarcity of highly productive soils in Australia, and in recent decades farming practices have developed to allow the extension of agricultural activity to lands considered marginal for production previously.
- There has been a trend for growth in intensive activities such as cropping and a relative decline in extensive activities such as livestock enterprises.
- Production of cotton has increased, which has contributed to the increase in use of N fertilizers.

- Horticulture production has increased, and the amount of fertilizer inputs being used for dairy production has increased.

In terms of nitrogen which has experienced the most rapid growth in recent years, some of the reasons provided by Davis (2000) include:

- Changed pricing structure in both the wheat and barley industries which now base payment on protein content.
- Introduction of new crops offering high returns but requiring greater nitrogen inputs.
- Long term depletion of nitrogen in local soils.
- Increased availability of nitrogen fertilizers and more reliable supply.
- The need to achieve higher yields from areas already developed and farmed.

Other factors affecting the increase in fertilizer use over recent decades include declining soil fertility on lands that have been cropped for some time and improved yield potential (resulting in more N use) due to improving other aspects of our production systems (McGuffog, 2001).

McGuffog (2001) reasonably assumes that the demand for cropping fertilizers will continue to increase as the total area planted to crops is projected to increase in the medium term, accompanied by continuing improvements in farm productivity. McGuffog also contends that significant increase in the prices and demand for Australian livestock products should lead to a recovery in demand for pasture fertilizers in the immediate future.

Other factors affecting the level of fertilizer use in the future include:

- continued horticultural expansion
- intensification of cropping
- contraction of cropping to most reliable rainfall areas
- increasing use of other organic materials and wastes (e.g. effluent and mill mud) may result in a reduced demand for fertilizers

Table 3 below presents the Australian use of elemental N, P and K by crop for the years 1996 and 1999/2000. These are the only years for which data was available by agricultural sector.

Table 3: Total Australian Fertilizer Use by Sector (1996 and 1999/2000)

Crop segment	000 tonnes of nutrient applied							
	1996 (source: NLWRA)				1999/2000 (source: FIFA)			
	N	P	K	Total	N	P	K	Total
Cereals	613	196	4	813	701	214	27.5	942.5
Pulses/Oilseed	14	32	3	49	55	43	6	104
Cotton	48	2	0	50	56	4	2.5	62.5
Pasture	59	161	95	315	76	158	63	297
Horticulture	50	22	42	114	71	37	45	153
Sugar cane	100	7	37	144	96	12	30	138
Total	884	420	181	1,485	1,055	468	174	1,697

Source: Fertilizer Industry Federation of Australia (FIFA) and National Land and Water Resources Audit (NLWRA)

The estimate of total fertilizer consumption presented in Table 3 is different to the total presented for the same years in Table 2. The reason for these differences is not entirely clear, but is most likely due to reporting differences between sources. Quantity data presented other than in Table 3 is sourced from ABARE Commodity Statistics, and it is likely that the data is actually based on volumes of fertilizer manufactured and imported. This data is used a proxy for use and consumption. However it is recognised that in reality 'import and manufacture' does not strictly equal 'use'.

A paper by McGuffog (2001) also draws on the data in Table 3 and shows that from 1966 to 1996 there has been a steady increase in the use of nitrogen fertilizers in all sectors, however the major increases have occurred in the cropping sector (particularly the cereal grain sector and the irrigated cotton industry). It is also shown that their has been a decline in the use of phosphorus fertilizers on pastures, however there has been a steady increase in its use on sugarcane, horticulture and crops (McGuffog, 2001).

Value of Fertilizer Use

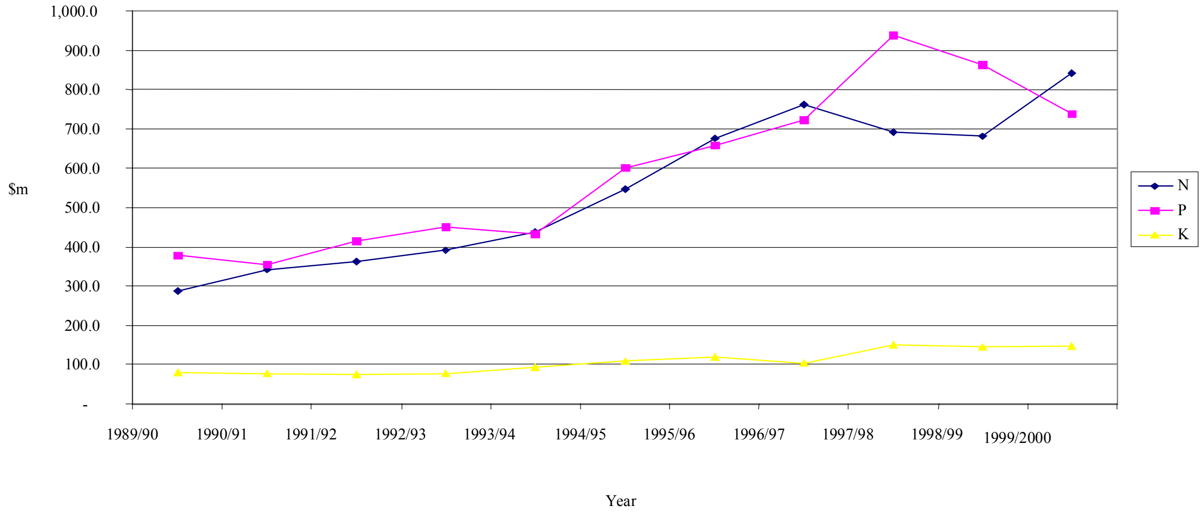
Table 4 below presents the value of elemental N, P and K used in Australia over the years 1989/90 to 1999/2000. The information contained in the table was derived using the consumption data already reported plus unit price data derived from ABARE's Australian Commodity Statistics. The unit (per tonne) value of fertilizer products including urea, ammonium sulphate, triple superphosphate, single superphosphate, diammonium phospate and potassium chloride were sourced for each year, converted to a per unit of element value, and then applied to quantities in Table 2 to derive a total value for N, P and K. FIFA supplied data relating to the percentage of N, P and K content in each fertilizer product, as well as the % of total N, P and K being supplied by each product.

Table 4: Value of Fertilizer Use in Australia (nominal dollars)

Year	Elemental N		Elemental P		Elemental K	
	$/kg	Total ($m)	$/kg	Total ($m)	$/kg	Total ($m)
1989/90	0.65	287	1.50	378	0.59	80
1990/91	0.78	343	1.41	356	0.63	77
1991/92	0.78	362	1.40	416	0.65	76
1992/93	0.80	392	1.29	450	0.65	78
1993/94	0.80	438	1.25	432	0.66	94
1994/95	0.97	546	1.45	601	0.65	109
1995/96	1.01	677	1.55	659	0.65	118
1996/97	0.92	761	1.63	722	0.64	104
1997/98	0.82	692	1.87	939	0.73	151
1998/99	0.72	680	1.87	862	0.79	145
1999/2000	0.77	842	1.64	739	0.86	148

Source: Prices derived from Australian Commodity Statistics 2000 and FIFA (pers comm)

Figure 3: Total nominal value of Australian fertilizer consumption



In contrasting Figure 3 and Figure 2 presenting quantity data, two conclusions can be drawn:

a) the higher value of P per tonne compared to N per tonne results in the total values of these two nutrients being approximately equal over time.

b) the relative directions of unit price trends in P and N over the past five years has contributed to the gap in total value evident in Figure 3 over this period.

Figure 4 presents the real price from 1989/90 to 1999/2000 of several common fertilizers (in 1999/2000 dollars).

Figure 4: Real price of fertilizer 1990 to 2000

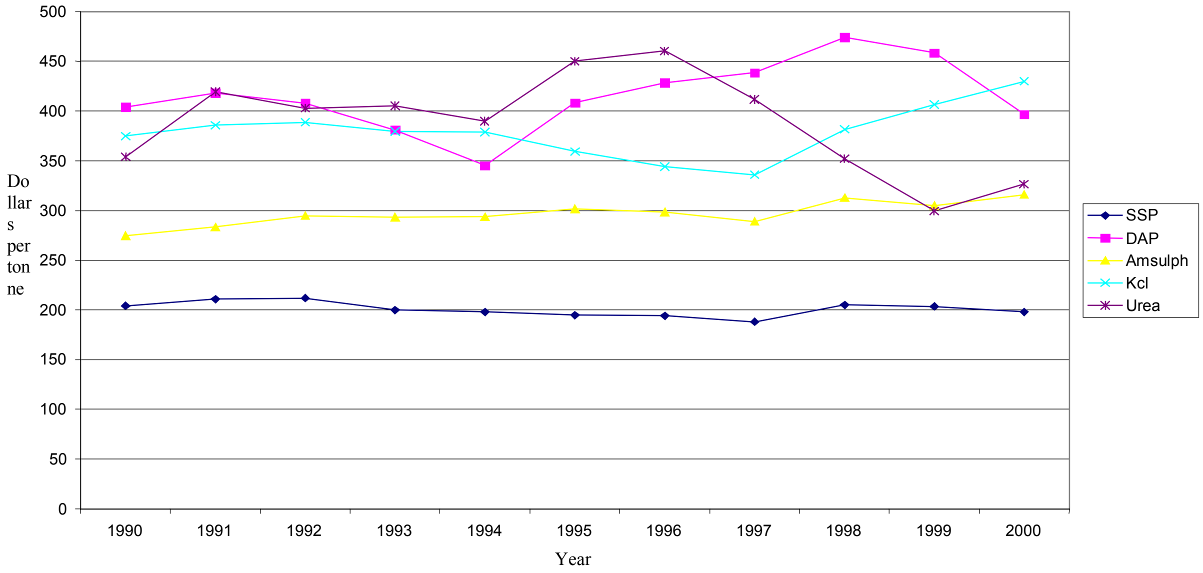


Table 5 presents the value of fertilizer use by crop for 1996 and 1999/2000. This data is derived by applying elemental price data for the years 1995/96 and 1999/2000 to the tonnes of each element used in that year as reported in Table 3. Please note that the values presented differ slightly from the total value presented in Table 4. This is due to different sources of volume data, as well as different assumptions relating to bagged and bulk unit prices of fertilizer.

Table 5: Value of Fertilizer Use by Crop (Australia, 1996 and 1999/2000)

Crop segment	Value of nutrient applied ($m)							
	1996 (source: NLWRA)				1999/2000 (source: FIFA)			
	N	P	K	Total	N	P	K	Total
Cereals	602	257	3	862	561	315	27	903
Pulses/Oilseeds	14	62	2	78	45	86	6	137
Cotton	47	2	0	49	58	7	1	66
Pasture	58	309	62	429	62	339	58	459
Horticulture	49	26	27	102	58	53	41	152
Sugar cane	98	8	24	130	78	17	28	123
Total	868	664	118	1650	863	817	160	1840

Table 5 shows the total value of the three elements applied in Australian agriculture in 1999/2000 approximates $1.8 billion per annum.

Table 6 provides a comparison of the value of agricultural outputs by crop, and the value of fertilizer used on those crops for 1999/2000. It shows that while cereals account for 49% of the value of total fertilizer use, they account for only 26% of total value of agricultural outputs. Conversely, pastures account for 39% of the total value of agricultural production, but only 25% of the total value of fertilizer.

Table 6: Comparison of Value of Agricultural Outputs and Value of Fertilizer Use (1999/2000)

	Value of crop ($m)	Value of fertilizer use ($m)	Value of agricultural outputs as a % of the total value of agricultural production	Value of fertilizer as a % of the total value of fertilizer
Cereals	6,329	903	26%	49%
Pasture	9,383	459	39%	25%
Horticulture	4,780	152	20%	8%
Cotton	1,459	66	6%	4%
Sugar cane	839	123	3%	7%
Oilseeds/ Pulses	1,320	137	6%	7%
Total	24,110	1,840	100%	100%

Table 6 also shows that for the 1999/2000 year the cereals and sugar cane sectors have the highest level of fertilizer use per unit of output with 14 cents of fertilizer used for every $1 of output. Pastures on the other hand require about 5 cents of fertilizer inputs for every $1 of output. Horticultural production and cotton production require about 3 cents and 4 cents of fertilizer inputs for every $1 of output respectively, while production of oilseeds/pulses requires about 10 cents of fertilizer inputs for every $1 of output.

A second source of fertilizer use data at the farm scale is ABARE's Annual Farm Survey and this data is reported in Table 7. It shows that fertilizer costs as a percentage of farm cash costs increased from 6.6% to 9.9% from 1989/90 to 1999/2000, which is further evidence of the increase in fertilizer consumption over time in Australia, and the increasing importance of fertilizer as a key farm input.

Table 7: Value of Average Fertilizer Costs as a Percentage of Average Farm Cash Costs

Year	Average fertilizer cost (per farm) ($)	Average cash costs (per farm) ($)	Fertilizer cost as a % of cash costs
1989/90	8,313	125,542	6.6%
1990/91	6,251	119,224	5.6%
1991/92	7,943	116,282	6.8%
1992/93	8,249	125,745	6.6%
1993/94	10,160	139,740	7.3%
1994/95	11,340	142,662	7.9%
1995/96	14,823	150,620	9.8%
1996/97	15,247	154,343	9.9%
1997/98	16,442	162,267	10.1%
1998/99	17,061	165,799	10.3%
1999/2000	16,440	165,970	9.9%

Source: ABARE Farm Survey, various years

Summary of Findings Relating to Volume and Value of Fertilizer Use in Australia

The following can be concluded:

1. In regards to volume of fertilizer used in Australia, nitrogen (N) currently has the highest level of use, followed by phosphorus (P) and then potassium (K). Australian consumption of N has increased by around 150% from 1989/90 to 1999/2000. P consumption has increased by about 80% and K has increased by about 30%. The average annual increase in consumption is 10% for N; 6% for P and 3% for K.
2. Some of the key reasons for the rapid increase in fertilizer consumption in recent decades include:
    - farming practices have developed to allow the extension of agricultural activity to lands previously considered marginal for production.
    - a trend for growth in more fertilizer intensive activities such as cereals and other cropping on lands previously used for livestock enterprises.
    - Suggested reasons for the rapid increase in nitrogen consumption include changed pricing structures in both the wheat and barley industries which now base payment on protein content; the introduction of new crops offering high returns but requiring greater nitrogen inputs; and the long-term depletion of nitrogen in some soils.
3. The demand for cropping fertilizers is likely to further increase as the total area planted to crops is projected to increase in the medium term, accompanied by continuing improvements in farm productivity. Other factors affecting the level of fertilizer use in the future include continued horticultural expansion, intensification of cropping, and contraction of cropping to the most reliable rainfall areas
4. While cereals account for 49% of the value of total fertilizer use, they account for only about 26% of total value of agricultural outputs, based on the year 1999/2000. Conversely, pastures account for 39% of the total value of agricultural production, but only 25% of the total value of fertilizer. In terms of value of fertilizer use, pastures is followed by horticulture (8%), sugar cane (7%), oilseeds/pulses (7%) and cotton (4%).

5. The cereals and sugar cane sectors have the highest intensity of fertilizer use per unit of output with 14 cents of fertilizer required for every $1 of output. Production of oilseeds/pulses requires about 10 cents of fertilizer inputs for every $1 of output. Pastures require about 5 cents of fertilizer inputs for every $1 of output. Horticultural production and cotton production require about 3 cents and 4 cents of fertilizer inputs for every $1 of output respectively.
6. Fertilizer costs as a percentage of total farm cash costs increased from 6.6% to 9.9% from 1989/90 to 1999/2000, which is further evidence of the increase in fertilizer consumption over time in Australia, and the increasing importance of fertilizer as a key farm input.

The Value of Fertilizer to Agricultural Production

Based on the statistics reported earlier, fertilizer is obviously a key input to Australian agricultural production. The question of the value that fertilizer contributes is difficult to answer both conceptually and practically.

A starting point is that the value of fertilizer to Australian agricultural production is at least as much as it costs agricultural producers, otherwise the existing quantities of fertilizer would not be purchased and applied. This statement assumes that users of fertilizer are economically rational and correct in perceiving that benefits are at least somewhat greater than costs. In a wider context, it also assumes that there are no negative associated impacts, on or off-farm, as a result of fertilizer use. On this basis the value of fertilizer is approaching $2 billion per annum, based on current usage of the principal three fertilizer elements of N, P and K.

Depending on the extent to which benefits exceed the costs of each tonne or kilogram of fertilizer applied, the value of fertilizer could well be many times the estimate of current fertilizer input costs to agriculture of nearly $2 billion per annum.

Decisions Regarding Fertilizer Applications

Farmers apply fertilizer with the expectation that the returns from additional or higher quality product will be greater than the costs of the fertilizer and its application. Some guidance on the level of returns in relation to different levels of nutrient application can be obtained from an understanding of response functions with which most would be familiar.

A physical response function shows how the predicted yield and other attributes of the product may be expected to change according to different levels of nutrient application. As we know, the shape of the relevant response function can vary with plant species, soil properties (including the soil status of the nutrient itself as well as other nutrients, the method and timing of application of nutrients, and the form in which the nutrient is applied). The response function is also likely to vary spatially across the paddock.

Further, the seasonal conditions experienced after fertilizer is applied can significantly influence yields, so that the actual response to fertilizer is often uncertain at the time of application.

The most commonly observed response to fertilizer application is the diminished returns response which shows an initial large increase in plant yield as the nutrient level is increased, with a lesser response per unit of nutrient applied as yield approaches the maximum yield (Peverill et al, 1999).

The economic optimal quantity of fertilizer to apply in any given situation will vary not only with the shape of the yield response function, but also with the market value of the nutrient and the value of the additional product or enhanced quality that is produced. This can make it difficult to predict the optimal amount of fertilizer to apply with a high degree of accuracy. In general terms, with the diminished response function, the economic optimal quantity of nutrient to apply will usually be somewhat less than that required for maximum yield.

Even if the optimal amount of fertilizer of a given type in a given set of circumstances could be estimated accurately, the application of the optimal is not always achievable. Some producers may be applying quantities below the economic optimal; others may be applying quantities above.

Key factors influencing divergence from the optimal would include:

- knowledge available (such as the existing nutrient status and its spatial variation, likely losses of nutrients).
- the application of available knowledge by the producer.
- financial management (cash shortages).
- attitudes to risk, and
- seasonal factors including climate that impact after fertilizer decisions are made.

The return to any given fertilizer application, and hence the value of fertilizer applied in aggregate, will therefore to a large extent depend on the decisions of individual fertilizer users within the agricultural sector, as well as factors outside the control of the users.

Examples of Fertilizer Contributions to Pastures

To assess the contribution that fertilizer makes, it is useful to view some of the experimental data that has underpinned the responses that might be obtained. Two key experiments reported here are for fertilized pastures, in turn key inputs to livestock production in Australia. The first trial is that of the long-term phosphate experiment in Western Victoria and the second is that of sulfur in northern and central NSW.

Long-Term Phosphate Experiment

This experiment ran for 20 years in Western Victoria, beginning in 1977 and finishing in 1997. The phosphate experiment provided a base for the development of productive pastures in the region and has had a major impact on the grazing industries in other parts of southern Australia. The experiment demonstrates clearly the importance of pasture quality as opposed to pasture quantity and the role that fertilizer plays in maintaining this pasture quality.

The Experiment

Six fertilizer rates at three grazing pressures were used across an area with a low fertilizer history, and sown to perennial ryegrass, phalaris and subterranean clover. Average fertilizer rates corresponded to 1, 4, 8, 15, 23, and 33 kg P/ha annually. The 1 kg/ha paddocks had fertilizer applied only twice in the 20 year period. In order to get the treatments up and running quickly, 50-100 kg P/ha were applied in 1979-80 to the 23 and 33 kg P/ha treatments. To eliminate non-P deficiencies, potassium, molybdenum and copper were applied across all paddocks on several occasions (Saul et al, 1998).

There were three initial stocking rates to provide low, medium and high stocking rates at each fertilizer treatment. Stock were managed in accordance with regional practice.

Key Findings

Pasture Growth,

- Increasing fertilizer application improved pasture growth and improved the contribution from the sown species, as well as increasing their persistence
- Annual pasture production doubled with increased P (6t/ha at 1kgP/ha compared to 12.6t/ha at 33 kgP/ha) (Saul et al, 1998).

Soil Phosphorus

- To increase soil phosphorous, at least 30kg/ha of P will be needed annually for 2-3 years, and 10-20 kg P/ha annually for maintenance.

Nutritive Value

- The nutritive value of most species increased by 3-5 units of digestibility when 15kg P/ha was applied. The 1 kg P/ha treatment produced approximately 4t/ha of digestible dry matter, and 23kg P/ha produced 9.7t/ha (Saul et al, undated).

Sheep Production

- The increased stocking rate on high fertility paddocks outperformed the ewes on the low fertility paddocks. This was seen in differences in weight change, fleece weight and strength, and weaning rate (Saul et al, 1998).

Profitability

- To make a profit from the extra application of fertilizer, the animal production systems needed to utilise the additional, higher quality pasture grown. This could be achieved by increasing the stocking rate, changing from wethers to ewes and other management changes, for example by moving to late winter-spring lambing, and use of highly productive livestock. (Saul et al, 1998).
- Higher rates of P at a higher stocking rate increases profitability. For example, for the typical district stocking rate of 7 ewes/ha and applying 7-10 kgP/ha, the gross margin was $120/ha compared to a gross margin of $250/ha with 18 kgP/ha with 18 ewes/ha (Saul et al, undated).
- At each stocking rate, the highest gross margin was achieved when 1 kgP/ha was applied for each ewe/ha (0.7 kg P/DSE). This amount of fertilizer would maintain the soil P status (Agriculture Victoria, 1999).

The Hamilton experiment has shown the increase in fertilizer application improves pasture composition, nutritive value and growth, resulting in a higher gross margin. The optimal rate under these conditions was 23kg P/ha at a stocking rate of 18 ewes/ha.

One of the significant implications of this 20 year trial is that it demonstrates that short-term grazing trials and mowing trials can be misleading as they are not undertaken in the context of an ongoing production system with implications for pasture composition and quality over time. The decline in pasture composition that occurs when fertilizer is not used has been clearly shown (Saul et al, undated).

The additional gross margin of moving from say 8 kg P to 18 kg P would be $130 per ha. At an elemental P cost as high as $2 per kg, this is estimated as an investment of an additional $20 per ha providing an extra gross margin of $130, plus the $20 (as the $250 and $120 gross margins will already reflect the difference in the cost of P). The additional capital invested with the higher stocking rate would not have been accounted for in the gross margin analysis. Allowing an annual cost of $40 per ha for additional capital, the $20 investment per annum could be returning about $110, or a benefit to cost ratio of about 5.5 to 1. It should be noted that the relevance of this experiment is restricted to particular areas of Australia.

Sulfur on North-West Slopes of NSW

Fertilizer use on the north-western Slopes and Plains has been restricted in the past, especially in comparison to the NSW Northern Tablelands. Much of this land is now of low fertility due to the conversion of heavily cropped country to pasture systems with no fertilizer program in place.

The Experiment
The establishment of a series of trials between 1987 and 1989 allowed the measurement of phosphorous and sulfur response under several pasture types. Native pastures oversown with sub-clover, and sown pastures of lucerne, phalaris, sub and white clover were used. Each site was chosen to represent soil types and fertilizer programs typical of the area.

Production was measured in the second, third and fourth year after fertilizer was applied each year, or applied in the first year only.

Key Findings
The experiment found that in excess of 80% of sites responded to at least one nutrient, most of the sites were sulfur deficient, and gave responses to sulfur of up to eight fold. The most interesting result was the dramatic drop in pasture quantity and quality with only one application of fertilizer compared to annual applications.

The findings (see Table 8 below) demonstrated a *cumulative* drop in yearly production. After the fourth year of missed fertilizer application, late winter and spring production (time of feed shortage and high animal requirement) dropped by 90%. Plant quality was also reduced, legume content declined from 78 to 5%, protein from 20.1 to 8.6% and plant P content from 0.23 to 0.19% at one site.

Table 8: The average reduction (%) in total dry matter yield from ceasing fertilizer application for 1, 2 or 3 years. (Source: Crocker, 1992)

Missing Fertilizer for:	1 year	2 years	3 years
Spring production	52	62	90
Yearly production	45	52	75
Range	6-97	6-93	60-96
Number of trials	18	12	5

In a wider context, in excess of 80 fertilizer trials (1982-1994) covering an area of 15 million hectares over a region encompassing northern and central western NSW have shown that 90% of sites responded to sulfur, with 50% responding to phosphorous. The experiments found sulfur increased dry matter production by up to eight times, consistently doubling yields and improving pasture quality. It was concluded from these trials that the increased pasture quality and quantity from modest fertilizer programs often double pasture and animal production (Watson et al, p10).

For those areas that required sulfur based nutrients, it was estimated that for every $1 invested in fertilizer, an additional $5 was generated in livestock production (Watson et al, p 21). The benefits of widespread sulfur use was potentially valued at over $200 million per annum (Crocker, G.J., undated).

Potassium Use in Increasing Livestock Production

The effects of applications of potassium over three years on the average liveweight gain over six years for weaner steers in coastal NSW ranged between 2 and 2.9 additional kg of liveweight gain per kg of K applied (Source: First Workshop on Potassium in Agriculture, 1997). With liveweight gain valued at about $1 per kg, and K at $0.8 per kg, a return to cost ratio of between 2.5 and 3.6 can be estimated.

Examples of Contribution of Fertilizers to Crops

The following provides brief descriptions of fertilizer responses from a sample of cropping trials.

Cereal yield responses in Subtropics

A series of reported grain yield responses from fertilizer trials in subtropical Australia for rainfed wheat (4 trials) averaged 15.6 kg grain per kg nitrogen used. The response for 13 trials involving rainfed sorghum was 23.4 kg sorghum per kg of N (Strong and Holford, 1997).

With grain valued at $0.15 per kg and nitrogen at $0.90 per kg, these results suggest a return of about $2.60 (wheat) to $3.90 (sorghum) for each dollar invested in nitrogen fertilizer.

Canola

A trial in Western Australia for nitrogen application to canola after a lupin crop, showed that 46 kg of N applied at five weeks after sowing gave a response of 350 kg of canola, or an additional 7.6 kg canola per kg of N (Weeks and Moreschi, 2000). At relative prices of $350 per tonne of canola and $0.90 per kg for N, this meant a $1 investment in N provided a return of $2.95.

Trials over four sites in WA in 1998 reported return to cost ratios of 2.2:1 to 4.5:1 for nitrogen applied to canola (Pluske, 1999).

Sugar Cane

Potassium has been shown to provide an increase of 29 tonnes of cane per 110 kg of K (White, 2000), equivalent to about 0.26 tonnes of additional cane per kg of K. With additional cane valued at about $20 per tonne, this is equivalent to a return of about $5.20 per kg of K. With K valued at $0.80 per kg, then the benefit to cost ratio is about 6.5.

Cotton

In some cotton growing areas (e.g. Emerald, Darling Downs and Macquarie Valley) there are areas of cotton that are responsive to potassium fertilizer. At one site, yield was improved by 8-24% from 125 kg of K per ha. With an average lint yield of 1500 kg per ha, lint valued at $2.50 per kg, and K at $0.80 per kg, the response was equivalent to 0.96-2.9 kg cotton per kg K. This is equivalent to a return of $2.4 to $7.2 per kg of K, or a return of $3 to $9 per dollar invested in K.

Interpretation for Value of Fertilizer

The above brief summary of some trial results and the corresponding estimates of returns demonstrate that there is likely to be a significant return to fertilizer investment. There are many more trials that could be assessed, but the foregoing does show that the return to cost ratios vary from about 2 to about 9 (with an average for these particular trials of 4.4).

Trial data are often not representative of what happens in a practical farming sense. Some of the trials reported account for seasonal variation across years, and those where irrigation was used have been ignored. Nevertheless, many trials reduce other sources of variation that will influence response in a commercial situation. Furthermore, management of trials is often superior than what can be effected in a mainstream farming sense, so that yield overall and hence the level of response can be higher. For this reason, it would be appropriate to apply a dilution factor to reduce the above ratio to a commercial potential ratio. A diluted average ratio from over 4 to about 3 could then represent the potential in a practical farming sense, given good information, a high level of management and where there are no budget constraints.

Hence, a ratio of about 3 to 1 could be an estimate of the return if:

- the trial responses reported are typical of all trials carried out
- fertilizer applications are made in a manner that was related to trial information which has been appropriately translated into particular situations

The actual value that current fertilizer use can claim is most likely less than what is suggested from this ratio. Some fertilizer use may not be giving these responses for various reasons of imperfect application of fertilizer knowledge in specific situations, and non-optimal management of other inputs aimed at constraints such as weeds and disease etc.

A fair estimate may be an average return ratio of between \$2 and \$3 for every \$1 invested. Assuming \$2, a simple estimate of the contribution of fertilizer to Australian agricultural production would be of the order of \$4 billion. However, such estimates ignore any substitution effects between input and potential changes in product mix.

Pulsford (1989) provided a perspective on the fertilizer industry in 1989 that is relevant to what has been attempted in this paper. He recognized the issue of fertilizer being only one of a number of inputs in the production process, so that it was difficult to attribute the specific contribution of fertilizer to production. His comments still apply. Pulsford also mentioned that at that time, fertilizer expenditure in Australia was about \$990 million. Without this fertilizer, he claimed that the value of rural production may fall by about \$3 billion, implying an investment return of \$3 was being generated for every dollar invested in fertilizer.

A Wider Approach to Valuation

The value of fertilizer used can be defined as equivalent to the difference between the costs of production using fertilizer compared with the costs of the next best option of producing the same specific set of products (quality and quantity) without fertilizer. The question then is what would it cost to produce the same set of products without fertilizer? Is it technically possible regardless of costs? Could it be technically possible in the future? Could another set of production technologies be developed that may not include inorganic fertilizer (e.g. rotations incorporating legumes or 'organic' farming methods or varieties that, for example, may utilise rock phosphate instead of superphosphate). Some may say that this is not possible; others would say that it is technically possible but not economically viable; others may say that it is already happening, albeit on a small scale.

The next question is even more difficult, that is, whether a different set of products might be produced that provides the same level of domestic satisfaction/utility and export income as that provided by our existing production mix that depends heavily on inorganic fertilizers?

In this broader context, the difficulty of placing a value on fertilizer is therefore due to the myriad of input and product substitutions, and alternative production systems that might be in place if we did not have access to fertilizer as an input.

Increasing the Value of Fertilizer

Introduction

The potential for increasing the value of fertilizer inputs to agriculture is high and multi-faceted. The challenges include:

(i) identifying situations where fertilizer may currently be over or under used

(ii) improving and packaging existing knowledge so that it is in a form more suited to decision making and which adds value to its use

(iii) developing new information and technologies where fertilizer inputs can be made more efficient and effective (e.g. R&D into placement/depth including distribution across the paddock, new forms of fertilizer, slow release, minimising losses, improving plant uptake, climate forecasting, etc)

There are considerable pressures on producers to make better decisions on fertilizer use. As reported earlier, fertilizer expenditure makes up a significant proportion of the variable cost structure of many farming systems so that it is a potential source of savings if less can be used without reducing net profits. Perhaps of even greater importance is the income that might be foregone if not enough is used. Pressures from the profitability viewpoint are sharp, but the pressures with an environmental foci are also increasing.

In general, it is likely that better and better fertilizer decisions are being made by agricultural producers. Refinement in decision making is apparent as a result of more experimental trials, producer and adviser experience, and technological advances.

Changing Behaviour

A benefit-cost analysis of a prospective extension project to reduce fertilizer input was effected by Agtrans Research for the Sugar Research and Development Corporation and the Land and Water Resources Research and Development Corporation in 1997. The analysis was in response to use by the sugar industry of rates of fertilizer (particularly N) above the recommended rates for both plant and ratoon cane. It was estimated that the net present value of the extension investment, considering only industry benefits in saved fertilizer costs was $13 million and the project would have had a B/C ratio of 33 to 1. Returns were much higher if environmental benefits were also included. It was recognised that some canegrowers would not reduce rates due to attitudes to risk (the perception that foregoing of additional profits from higher than optimal rates in a good year more than offset the losses in poor weather years).

Independent of this study, actions taken by the industry in the late 1990s included:

- the development of codes of practice for fertilizer use that were in accord with sustainable canegrowing and which encouraged soil testing, matching applications to crop needs and recognizing the potential negative impacts on the environment of fertilizer overuse, and
- an extension program demonstrating overall profitability at different application levels

Although not yet completely analysed, the results of monitoring a series of demonstration sites within the extension program are showing that the recommended rates provide long-term benefit to canegrowers. Over the past few years surveys have shown a reduction in overapplications, but it is difficult to attribute changes to different forces operating such as the code of practice, the extension program/demonstration sites, or the fall in the price of sugar.

This example demonstrates that there are benefits to producers of more careful decision making regarding fertilizer decisions and that extension efforts can be effective. This particular example also raises the issue of whether the application of climate forecasting to fertilizer decision making in the sugar industry may be of some value.

Improving the Use of Information

Soil Testing

Soil testing has been used for many years. More and more producers are utilising soil and plant tissue test results as a guide in making more informed fertilizer decisions (Fosberry, 1998; Reuter, 2001). Results of such tests are usually combined with advice from fertilizer companies regarding fertilizer type and rates of application.

In general soil testing can be useful in providing a guide to the nutritional requirements of plants in a specific situation. However, there are inadequacies in solely relying on soil testing and some of these have been defined in Rayment et al (1998), and Cook and Bramley (2000).

Decision Support Models

Decision support models or aids have been around for decades and over time have become more sophisticated. Such models attempt to take into account the likely current nutrient status of the soil through the previous paddock history and often through some form of nutrient budgeting and target yield specification.

Such aids can be used to provide an estimate of how much fertilizer to use for a given plant in a given situation. Examples are the phosphate model 'Decide' and wheat/canola models for assisting with nitrogen rate decisions in crops (Bowden, pers comm, 2000).

Use of such models by farmers has not been widespread, but many of the principles emanating from such models have been useful to advisers to assist with fertilizer advice. More sophisticated models can be used to address uncertainty emanating from spatial and temporal variation.

Managing variation

Spatial variation across paddocks and in the weather over time introduces significant uncertainty in agricultural decision making regarding fertilizer application. The introduction of control technology such as split applications, precision farming and climate forecasting are increasing the capacity of the grower to control this variation.

Precision Farming

The introduction to agriculture of information technologies highlights the significance of within paddock variation in crop performance (Cook and Bramley, 2000). Precision farming is a land management system used to provide more accurate management of inputs (such as fertilizer). This technology usually involves a Global Positioning System (GPS) and a Geographical Information System (GIS). The GPS is a locator device which communicates with orbiting satellites. The GIS is a computer-based information system that manages the data from each of the unit mapping areas (pixels), and allows interfacing of the data base with other equipment (UNIDO, 1998).

Applications of GPS include: accurate identification of soil samples taken from small areas with the GIS; harvesting equipment to monitor yields, fertilizer spreaders (in conjunction with soil fertility test data) allow variable fertilizer application, planting equipment can alter sowing rates, herbicide applications and irrigation equipment can be linked to GIS (UNIDO, 1998).

Fertilizer management as a component of precision farming offers much potential for increasing the value of fertilizer. However, the investment in cost of acquiring and applying the additional information can be high, so that the accuracy of the information and its interpretation need to be appropriate to ensure the returns are generated. The recent paper by Cook and Bramley (2000) provides interesting reading in this context.

Weather and Climate Forecasting

The use of weather and seasonal forecasts in farming is a developing tool that can add value to the use of fertilizers. Seasonal forecasts (0-6 months) allow producers to make more 'accurate' decisions regarding practices such as varietal choice and levels of fertilizer application. Although forecasts themselves are based on probabilities, they are more accurate than using historical probabilities.

For example, a study by Marshall et al (1996) estimates that the value of a seasonal forecasting system based on the Southern Oscillation Index (SOI) was applied to each of the climate patterns for a Goondiwindi wheat farm over the period 1894 to 1991. Decisions regarding the variety used and the nitrogen application rate at planting were examined, with eleven fertilizer rates and three varieties. The expected net payoff from using forecasts over the period was estimated at nearly $5 per hectare. More recently, the model 'Whopper Cropper' provides probabilistic information on the outcomes of management alternatives, including applied N alternatives. For example, the model has shown that with a positive SOI in September-October, higher and less risky yields could be achieved by sowing sorghum in Central Queensland in November-December rather than later in the season, if the soil water was available (Hammer et al, 2001).

More accurate short-term weather forecasts may be used to assist timing decisions and help reduce the risk of fertilizer applications being partly wasted by runoff as well as ameliorate environmental impacts through reduction in nutrient export.

The Role of Research and Development

The role of current and future research and development in adding even further value to fertilizer use should be acknowledged. Such investment, if successful, could push the return potential (that is, the return to fertilizer use by farmers) higher than what it may be today.

Innovations associated with such topics as different fertilizer formulations, testing techniques, timing of applications, controlled spatial applications, techniques to minimise nutrient losses, improving plant uptake, integration of use with other inputs such as liming (in an increasing acid Australian environment for cropping), and climate forecasting, will be vitally important in the future to keep adding value to the fertilizer used. Improving use of existing technology and information will also be important through further development of information packaging and decision aids that are likely to be more integrated with other input use but simpler to use than ever before.

Also, in order to minimise any cost to fertilizer use that may be incurred off-farm (and hence increase the value of fertilizer in the wider sense), other research will be important to support in the future such as:

- Research to improve understanding of nutrient movement and chemical transformations occurring as a result of deep leaching, sub-soil movement and surface soil movement.
- RD&E to improve nutrient utilisation and reduce the off-farm export of nutrient through altering farming systems, e.g. rotations with perennial pastures.
- Investigation of the value of various options to minimise nutrient export such as revegetating stream banks and gullies to minimise the movement of soil with nutrient attached, and the implementation of buffer strips in strategic locations on-farm.

Summary and Conclusion

(i) This paper has provided a status report on the Australian agricultural use of fertilizer at an aggregate level. There has been increasing use of fertilizer in Australia in the past decade, particularly of nitrogen use in the cropping sector. Nitrogen (N) currently has the highest level of use in terms of tonnage of nutrients, followed by phosphorus (P) and then potassium (K). Australian consumption of N has increased by about 150% from 1989/90 to 1999/2000. P consumption has increased by about 80% and K has increased by about 30%. The average annual increase in consumption is 10% for N; 6% for P and 3% for K.

(ii) Some of the key reasons for the rapid increase in fertilizer consumption in recent decades include:

- farming practices have developed to allow the extension of agricultural activity to lands previously considered marginal for production.
- long term depletion of N in some soils.
- expansion of horticulture and irrigated cotton and the intensification of dairying.
- a trend for growth in more fertilizer intensive enterprises such as cereals and other cropping on lands previously used for livestock enterprises.

(iii) The demand for cropping fertilizers will continue to increase as the total area planted to crops is projected to increase in the medium term, accompanied by continuing improvements in farm productivity. Other factors affecting the level of fertilizer use in the future include continued horticultural expansion, intensification of cropping, and contraction of cropping to the most reliable rainfall areas.

(iv) Fertilizer costs as a percentage of total farm cash costs increased from 6.6% to 9.9% from 1989/90 to 1999/2000, which is further evidence of the increase in fertilizer consumption over time in Australia, and the increasing importance of fertilizer as a key farm input.

(v) It is likely that these fertilizer use trends will continue in the future as Australian agriculture further intensifies and consolidates under larger production units. Environmental considerations will act as a light brake on fertilizer use but it is anticipated that improved management of fertilizer will accommodate most environmental concerns.

(vi) Estimating the value of fertilizer is difficult due to it being only one of many inputs to most agricultural production systems.

(vii) The average value of fertilizer in production systems can be safely estimated as at least its cost to the producer, a return ratio of above 1 to 1. Analysis of a range of Australian fertilizer trials has demonstrated that the potential return to fertilizer applications can be several times this return. Actual return ratios are likely to be less for a range of reasons.

(viii) It is likely that an average return ratio of between 2 to 1 and 3 to 1 applies, perhaps $2 for every $1 invested would be a reasonably conservative estimate. Based on a return ratio of 2 to 1, the annual contribution of fertilizer to Australian agricultural production would be of the order of $4 billion. However, such estimates ignore substitution effects between input and potential changes in product mix.

(ix) Decisions on fertilizer use are being sharpened with increasing information being made available to producers on the soil, the paddock and climate and weather, and being able to better deliver fertilizer in the form, type, time, location and quantity to maximise its value. This not only can increase the total added value of fertilizer in a production sense, but also can reduce any externalities that might exist from nutrient export from the farm. However, many of these aids are still imperfect, and the frontiers are still being explored.

(x) Investment by agricultural and fertilizer industries in further R&D to develop more innovative technologies and to more effectively apply existing information is likely to be rewarding.

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