LAND & WATER RESOURCES RESEARCH & DEVELOPMENT CORPORATION

&

PIVOT AGRICULTURE

Final Report

DAV12: Environmentally Sustainable Fertiliser Use Through Improved Flood Irrigation Management Techniques

PRINCIPAL INVESTIGATORS	Nicholas Austin Bernard Prendergast		Institute of Sustainable Irrigated Agriculture Ferguson Road Tatura 3616 Phone: (058) 335222 Fax: (058) 335299
PROJECT LEADERS	Belinda Bush Matthew Collins Rachel Dick Michelle Miller		
TECHNICAL SUPPORT	Brian O'Meara		
COLLABORATORS	Larry King Athol McDonald	*Pivot Agriculture* *Goulburn-Broken CALPB*	

PROJECT TITLE	Environmentally Sustainable Fertiliser Use Through Improved Flood Irrigation Management Techniques
LWRRDC PROJECT NUMBER	DAV12
REPORT PREPARED	30 January, 2004

1. OBJECTIVES

- To quantify levels of nutrient (nitrogen and phosphorus) runoff from irrigated perennial pasture bays, after fertiliser application.
- To determine and demonstrate irrigation management methods that minimise or eliminate nutrient runoff after fertiliser application, and minimise deep percolation losses of fertiliser.
- To establish penetration uniformity of fertiliser into soil on irrigation bays.
- To publish a booklet that provides guidelines for water management practices that promote efficient use of fertiliser. This will lead to higher retention of fertiliser on-farm, and reduce downstream environmental impacts of fertiliser application.

2. METHODOLOGY

2.1 Background Nutrient Levels

To establish typical (background) nutrient losses from commercial dairy farms, six district border check irrigation bays, on heavy and light soils in lengths of 100m, 300m and 500m were instrumented to record the full water budget. Water samples were collected one- and three-hourly from irrigation and rainfall induced runoff respectively. These samples were analysed for TK-N, NH_4-N, NO_2-N, NO_3-N, Total-P (TP), Total Reactive P (TRP). Bays were managed (grazed, fertilised and irrigated) by the respective farmers following their standard management practices. The data collected provided a 'benchmark' against which irrigation and fertiliser management practices could be assessed.

2.2 Irrigation Modelling

The Analytical Irrigation Model (AIM) developed at ISIA Tatura, was used to predict parameters that influence the uniformity and efficiency of irrigation (viz. irrigation discharge and duration). AIM provided a means to predict:

- irrigation duration for minimal runoff;
- uniformity of water application;
- the effect of changes in antecedent water content on irrigation advance and recession.

2.3 Typical Fertiliser Losses

To assess the impact of fertiliser application on nutrient losses in irrigation runoff, fertiliser was applied to all six district bays at 'typical' rates of 16.3 kg P ha^{-1} (1.5 bags single super per acre) and 60.8 kg N ha^{-1} (1 bag urea per acre). Using AIM to predict discharge and duration, the bays were irrigated to achieve 30% runoff. Concentrations, forms and total loads of N & P in runoff were measured hourly for the first irrigation after fertilising, and for at least two subsequent runoff events.

2.4 Irrigation Management to Minimise Fertiliser Losses

Once an irrigation bay has been laid out, the three main management variables available to farmers for regulating surface irrigation are time to cut-off, discharge rate onto the irrigation bay, and time period since previous irrigation (antecedent soil water content).

2.4.1 Time to Cut-off

The same methodology employed in Section 2.3 (above) was used once runoff concentrations returned to 'background' levels, with the exception that runoff in the first irrigation (only) was minimised. Time to cut-off for 'zero-runoff' was predicted by AIM. Subsequent irrigations reverted to standard practice, with nutrient loads and concentrations in runoff recorded as above (Section 2.3). The difference in total nutrient loads resulting from 'zero-runoff' versus '30% runoff' for the irrigation following fertilising was observed and accounted for.

2.4.2 Discharge

In the original R&D agreement, the same methodology employed in Section 2.3 (above) was to be used, with the exception that irrigation velocity (ie. discharge) would be minimised to reduce particulate transport. However, results from Sections 2.1 & 2.3 showed that 95-98% of the phosphorus in runoff was comprised of TRP (mainly orthophosphate). Since the predominant P loss mechanism was therefore dissolution not particulate transport, irrigation discharge was considered unlikely to affect runoff nutrient concentration or total fertiliser nutrient loss in runoff. Consequently, a more detailed investigation of the effects of fertiliser application rate on runoff losses was conducted in place of the irrigation velocity trials (Revised project schedule 28 July 1995 - N. Schofield). Four rates of single superphosphate (250, 500, 750, and 1000 kg.ha^{-1}) were applied to twelve 30 x 8 m flood irrigated bays in a randomised design, on a Lemnos loam (*Natric Xeralf*), at ISIA Tatura. Phosphorus forms, concentrations and loads in surface runoff for three irrigations following fertiliser application were determined.

2.4.3 Antecedent Soil Water Content

A plot scale experiment (twelve 30x8 m bays) was conducted, to assess the effect of soil water content on surface and sub-surface nutrient losses. Four antecedent soil water conditions were imposed on the bays (0, 30, 60 & 90 mm cumulative evaporation less rainfall). Granular Br^-, as a traceable surrogate for NO_3-N, was mixed with superphosphate (45 kg P ha^{-1}) and surface broadcast prior to irrigation. Concentrations of TP, FRP and Br^- were measured in runoff for two irrigations, the first directly following P & Br^- application. Soil was sampled to 0.5 m in 0.1 m increments and analysed for Br^- using HPLC.

2.5 Uniformity of Fertiliser Penetration

Lateral transport of fertiliser along bays in irrigation water was determined. Initially this was proposed using soil sampling to 0.3 m depths at intervals down the length of the bay. For the same reasons as outlined in Section 2.4.2, and because of high background soil-P concentrations and large spatial variability within bays, lateral transport was determined by quantifying P concentrations in surface water during an irrigation event (Revised project schedule 28 June 1996 - N. Schofield). Nine irrigation bays (three replicates of three lengths - 70, 140 & 210 m) were fertilised (45 kg P ha^{-1}) and flood irrigated. Samples were taken at regular intervals from the flowing water to identify the extent of lateral P transport, and further investigate impacts of irrigation bay length on nutrient losses.

2.6 Educational Manual

A short manual was written to describe Best Management Practices (BMP) to reduce fertiliser losses and improve fertiliser use efficiency.

2.7 Field Days

One major field day and several presentations were held during the project, to raise awareness of the work and to present research results. Other publications, reports and articles appear in Section 5.

3. RESULTS

3.1 Background Nutrient Levels

In total, 3,224 samples were collected and analysed. The field data (Fig.1) suggested that neither bay length nor soil type had any significant effect on nutrient loads or runoff concentrations, however effects may have been masked by high variability (fertiliser history, grazing rotations, stocking pressure) between farms. Further replicated experimental work was conducted at ISIA Tatura (see Section 3.5) to investigate possible bay length effects on nutrient transport.

Fig.1 *Scatter plot of average nutrient concentrations for the six monitored bays on commercial irrigation farms in the Shepparton Irrigation Region. Also shown are the mean (solid), 95 percentile (dotted) and "degraded" concentrations. Each point represents the average concentration from a runoff event (rainfall or irrigation).*

Other observations arising from the field program include:

- Nutrient concentrations are higher in irrigation induced runoff than in rainfall induced runoff;
- Although discharge (L/s) may vary by two orders of magnitude during a runoff event, runoff nutrient concentrations remain relatively constant, except that;
- Both N and P exhibit 'first flush' effects where concentrations at the start of runoff are higher than those later in the runoff event.

3.2 Irrigation Modelling Results

The average absolute error for predicting 'zero' and '30%' runoff using the Analytical Irrigation Model, AIM, for all irrigation trials was 6.6%. Available irrigation discharge was set by the farm layout at each site, meaning optimal discharge was not always available. AIM was therefore used to predict, *a priori,* time to cut-off for the available discharge and desired runoff percentage. The average absolute error of 6.6% may be considered good, given the limited data available to provide parameter estimates. Further work is required to better define infiltration and surface roughness parameters, and improve AIM's predictive capabilities.

3.3 Typical Fertiliser Loss Results

Average concentrations of N and P in runoff following fertiliser application (16.3 kg P ha^{-1} as single super and 60.8 kg N ha^{-1} as urea) appear in Table 1. The effect of fertiliser application rate on runoff concentrations is discussed in Section 3.4.2

Table 1 Average[a] concentrations (mg/L) of N and P in runoff following fertiliser application

Irrigation after fertilising	TK-N (mg/L)	NH_4-N	NO_3-N	NO_2-N	TOTAL-P	PO_4-P
First irrigation	12.28	7.89	0.17	0.03	5.18	4.81
Second irrigation	4.81	1.03	0.25	0.01	2.02	1.79
Third irrigation	3.49	0.55	0.10	0.01	2.08	1.76

[a] average of three bay lengths and two soil types.

3.4 Results of Irrigation Management to Minimise Fertiliser Losses

3.4.1 Effect of Time to Cut-off

Selecting time to cut-off to minimise runoff in the first irrigation following fertiliser application is an effective method for reducing nutrient losses in surface runoff. A comparison of N & P total loads in runoff when fertiliser application was followed directly by an irrigation with either 'zero' or '30%' runoff is given in Table 2. Table 2 shows the total load from three irrigations after fertilising. The relative importance of each successive irrigation in reducing runoff loads is discussed further in Section 3.4.2.

Table 2 Average total loads of N & P in runoff from the three irrigations following fertiliser application

Analyses	'30%-runoff' in first irrigation		'Zero-runoff' in first irrigation	
	(kg/ha)	(% of applied)	(kg/ha)	(% of applied)
Total Phosphorus	2.4	14.7	0.5	3.1
Total Nitrogen	4.2	6.9	1.1	1.8

3.4.2 Effect of Fertiliser Application Rate

In runoff, total-P (TP) (Fig.2), filtrable reactive P (FRP) concentrations and EC increased linearly with application rate, with initial concentrations (5-minutes) being significantly higher than those later in a runoff event ($P < 0.025$). In the irrigation directly following fertiliser application, runoff concentrations of TP and FRP reached 120 $mg.L^{-1}$, and the depth of irrigation water which infiltrated (calculated from volume balance) was in direct proportion to single superphosphate application rate ($P = 0.03$). Normalised runoff losses of single superphosphate in consecutive irrigations followed a single exponential decay (Fig.3). The primary loss mechanism for P following single superphosphate application was through dissolution, rather than sediment transport. Details are contained in the supporting documents.

Fig.2 *P concentration in runoff from the first irrigation after superphosphate application to perennial pasture.*

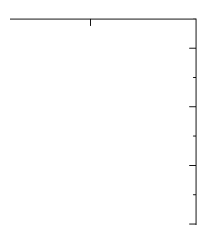

Fig.3 *Decay in runoff P loads. Normalised P loss is the loss per irrigation over the total loss from all three irrigations.*

3.4.3 Effect of Antecedent Soil Water Content

The concentration of TP in irrigation runoff for the first two irrigations following fertiliser application is shown in Fig.4. Low antecedent soil water content (dry soil) results in proportionally more water and dissolved fertiliser transmitted via macropores, with a consequent reduction in runoff concentration. Unfortunately, high variability means the Br^- data, whilst supporting this hypothesis, were not significant. When fertiliser is applied at high antecedent water content (wet soil) localised high nutrient concentrations near the soil surface result, with a consequent increase in runoff concentration. This phenomenon may be advantageous for P which is not prone to leaching, however with nitrogenous fertilisers may result in higher nitrate accessions to groundwater. Research is continuing for N, and to determine the effect of any soil-water deficit attained after fertiliser has been applied, funded under NRMS/Pivot Project I6063.

Fig.4 *Effect of soil water deficit (at time of fertiliser application) on runoff P concentration, for the two irrigation events directly following surface broadcasting of single superphosphate (45 kg P ha^{-1}).*

3.5 Fertiliser Penetration Uniformity Results

Averaged concentrations of TP in irrigation water on the 80, 160, and 240m bays are shown in Fig.5. Also shown are irrigation advance and recession. Concentrations at the wetting front (advance) are significantly higher than those behind the front, signifying rapid dissolution and vertical transport into the soil. However, behind the advance, there is also a significant increase in concentration with distance along the bay, signifying lateral transport of fertiliser. The relative magnitude of each of these processes will depend on the solubility of the fertiliser: more slowly soluble fertilisers will be more susceptible to lateral transport along a bay, whilst more rapidly soluble fertilisers will dissolve and infiltrate locally. Therefore, the extent of lateral transport and consequently the uniformity of fertiliser penetration, will depend on the solubility of the fertiliser applied. Further modelling of these data is proposed.

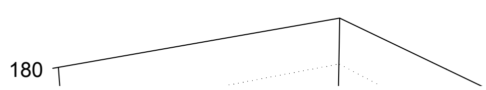

Fig.5 *Concentration of total P in irrigation water flowing over perennial pasture following application of 45 kg P ha^{-1}. Also shown (solid lines) are irrigation advance and recession. Bay lengths (80, 160 and 240 m) have been non-dimensionalised.*

3.6 Resulting Education Manual

A draft of the education manual appears in Appendix 1, as specified in Milestone 3e on Page 5 of the Project Schedule. While the 'Best Management Practices' identified in the manual are supported by this research, some (particularly 3.3-Timing and 3.5 Buffer Zones) are not conclusive. Fertiliser trials to be conducted under NRMS/Pivot Project I6063 this 1996/97 season will further investigate these aspects. Consequently, it is felt that delaying publication of the manual until these trials are complete would be beneficial. It is anticipated that the manual will be distributed to farmers with Pivot fertiliser, and will be used by AV Extension Officers in promoting environmentally sustainable fertiliser use.

3.7 Results of Field Days

A major field day to present results from Project DAV12 was held on Tuesday 4 June 1996 at ISIA Tatura, attracting approximately 80 dairy farmers. The day was reported on ABC Radio and Win TV News. Despite the good attendance, feedback received after the day indicated that the day was not entirely successful. A number of reasons were reported, however a main reason was that the day reported research "in progress", rather than providing take-home messages. The education manual (Section 3.6) should effectively address this issue. Other communications, outlined under Section 4.1, were considered more successful in transferring technology arising from this project.

3.8 Interpretation and Practical Significance of Results

DAV12 has shown that irrigated dairy farms in the Shepparton Irrigation Region contribute significant loads of both N & P to irrigation drainage. Typical concentrations of N and P are shown in Fig.1. Export rates of N & P from irrigated dairy pastures (Table 3), are directly proportional to runoff volume; the constant of proportionality being nutrient concentration. Table 3 is based on 15% irrigation runoff and 20% rainfall runoff.

Table 3. Estimated[a] N & P loads from irrigated dairy farms in the Shepparton Irrigation Region.

Form of runoff	TP		TN	
	(kg/ha)	% of total	(kg/ha)	% of total
Winter Rainfall	0.3	4.3	4.1	27.9
Three Irrigations following Fertilising	5.0	72.5	4.6	31.3
Remainder of Irrigation Season	1.6	23.2	6.0	40.8
TOTAL	**6.9**	**100**	**14.7**	**100**

[a] Assumptions made in arriving at figures in Table 3 appear in First Milestone Report - DAV12.

Appropriate water and fertiliser management have the potential to greatly reduce these loads, decreasing environmental impacts and increasing productivity of irrigated dairy farming. Since nutrient loads in runoff depend on the volume of runoff and the concentration of nutrients therein, effective management strategies will tackle either or both the runoff volume or nutrient concentration. Several farm-level management strategies arising from this research are summarised in the attached education manual (Appendix 1).

4. ADOPTION

Close linkage with the fertiliser industry has been assured through financial support and active involvement from Pivot Agriculture. Project outcomes have been presented in Pivot Technical Bulletins and in "Pivot Points" with wide distribution throughout the southern Murray-Darling Basin. Presentations by DAV12 project officers at Pivot functions (Fertiliser nights, Prescription Farming Expos etc) have provided wider exposure than normally achieved through conventional extension channels (eg Target 10, Landcare and Waterwatch). A Nutrient Extension Officer based at Kyabram (a component of NLP project DAV2551) has provided direct and effective transfer of outcomes from DAV12 to the irrigation farming community. Results have fed directly into the draft Goulburn Broken Water Quality Strategy (1996) thereby finding rapid incorporation into policy. Numerous oral presentations have been made under DAV12; a summary appears below.

4.1 Summary of communications to date

4.1.1 Oral Communications 1993/94

- Society for Engineering in Agriculture/NSW Agriculture. AIM - A model for improved border irrigation management, Yanco.

4.1.2 Oral Communications 1994/95

- GV Fertilisers Farmer Night - Kyabram Club, 19 July 1994. Environmentally sustainable fertiliser use through improved flood irrigation management techniques.
- Goulburn Murray Water, Kerang, 8 September 1994. Review of nutrient research in northern Victoria.

- Echuca Waterwatch Group meeting. 19 October 1994. Managing fertiliser to reduce nutrient losses.
- Ardmona Dairy Discussion Group, Ardmona. 24 January 1995. Fertiliser nutrient losses from dairy pastures.
- Target-10 Extension officers, 9 February 1995. Research update - Fertilisers and Irrigation. Shepparton.
- Girgarre/Stanhope Landcare Group, 9 March 1995. Best management practices for fertiliser use in irrigated dairying.

4.1.3 Oral Communications 1995/96

- Dairy Horizons - Developing Extension Skills LaTrobe University Bundoora, November 1995. Fertiliser movement on dairy farms: a nutrient audit.
- G&C Fertilisers Cobram, 27 February 1996. Getting more from your fertiliser dollar.
- Toolamba Target 10 Discussion Group, ISIA Tatura, 20 March 1996. Environmentally sound water and fertiliser management.
- Reedy Creek Irrigation Management and Monitoring Group SA, ISIA Tatura, 27-28 March 1996. Review of current irrigation and nutrient research for perennial pastures.
- Wimmera Landcare Group Community Workshop, Horsham, 1 April 1996. Drainage in the Wimmera Area.
- Pivot Prescription Farming, Kialla, 1 May 1996. Fertilisers and dairy farms: Environmental considerations.
- Hydrologic Research Group Field Day, ISIA Tatura, 4 June 1994. Nutrient Project Progress.
- Irrigation Surveyors and Designers Group, Echuca, 14 June 1996. Irrigation management using AIM.
- GV Fertiliser Farmer Night, Kyabram Club, Kyabram, 18 June 1996. Environmentally sustainable fertiliser use through improved flood irrigation management techniques - Research update.
- North Central Waterwatch, Rochester, 25 June 1996. Nutrient Management Day - Driving your water and fertiliser dollar further.
- Target-10 and Salinity Extension officers, ISIA Tatura, 30 July 1996. Research update, Fertilisers & Irrigation.

4.2 Suggested technology transfer/adoption activities

Project DAV12 has provided background information and identified areas for new research. Some of these areas, specifically timing of application (Section 3.4.3) and solubility of fertiliser (Section 3.5), have been addressed in the recently funded NRMS/Pivot Project I6063. Others, such as the effects of surface roughness and antecedent water content on flood irrigation performance (Section 3.2), have been proposed for funding. A continued R&D program on farm-scale water and fertiliser management for irrigated pastures is essential for successful transfer/adoption of existing and emerging outcomes. Continuity of staff is key to ensuring successful technology transfer/adoption, since the implications of a significant proportion of project results cannot be determined within the project timeframe.

A series of presentations to farmer groups, highlighting BMP's identified in Projects DAV12 and I6063, is seen to be an effective technology transfer activity that should be pursued.

The number of educational manuals printed (Appendix 1) will be limited by budget. Depending on the reception of the booklet by the farming community, printing of additional copies may be necessary to ensure adequate circulation and improve transfer/adoption.

5. PUBLICATION TITLES

A summary of written communications appears below. Copies of these publications have been submitted with the Final Report.

5.1.1 Written Communications 1993/94

- Austin, N.R., Prendergast, J.B., & Collins, M.D. (1994) Reducing fertiliser nutrient losses through improved flood irrigation management. Water Down Under '94. Proc. Int. Conf. IEAust. Adelaide Nov. 1994 Vol 1:543-546.
- Austin, N.R., & Prendergast, J.B., (1993) Using an analytical model of border irrigation to improve water management in the Murray Basin. Proc. Hydrol & Water Resour. Symp. IEAust. Newcastle 1993.
- Austin, N.R. (1994) AIM for improved flood irrigation management. The Northern Irrigation Cropper. No.17 Autumn '94.
- Country News (1994) Joint Tatura research project reveals: Fertiliser is going down the drain. Country News, p.7, Aug 29 - Sept 4, 1994.
- Pivot Points (1994) Irrigation run-off study. Science in Agriculture. Pivot Points No.14 May, 1994. Pivot Fertilisers.
- Weekly Times (1994) Dairy Loss. Weekly Times, p.9 Aug 17, 1994.

5.1.2 Written Communications 1994/95

- Austin NR (1995) Minimising phosphorus runoff. Research Round Up. Target 10 Newsletter. April 1995

- Austin NR, Prendergast JB, Collins MD (1995) Optimising superphosphate application rates on perennial pastures to reduce surface P losses. Proc. Downstream Effects of Land Use, National Conf., Rockhampton. 26-28 April 1995.
- Austin NR, Prendergast JB, Collins MD (1996) Phosphorus losses in irrigation tailwater from fertilised pasture. J. Env. Qual. 25 (1).
- Austin NR, Prendergast JB, Dick R (1995) Towards environmentally sound fertiliser management on irrigated pastures. Proc. Nutrient Management in Irrigated Agriculture - Research and Implementation. Echuca-Moama 19-20 June 1995.p.55-61.
- Dick R, Austin NR, Prendergast JB (1995) Nutrient loads from irrigated pastures in northern Victoria. Proc. Downstream Effects of Land Use, National Conf., Rockhampton. 26-28 April 1995.

5.1.3 Written Communications 1995/96

- Austin NR (1995) Fertiliser movement on dairy farms: a nutrient audit. Proc. Dairy Horizons Conf. LaTrobe University Bundoora
- Austin NR, Bush BJ (1995) Plant and soil response to superphosphate application rates on flood irrigated perennial pastures. ASSSI-First National Soil Phosphate Conf, Nov 17-18. CSU Wagga Wagga.
- Austin NR, Prendergast JB (1995) Infiltration characteristics of a cracking soil and the implications for an analytical kinematic wave model of border irrigation. Irrig Sci (in review).
- Austin NR, Prendergast JB (1995) Managing nutrients from irrigation drainage in south eastern Australia. Proc. Managing Environmental Changes due to Irrigation and Drainage. 16th Congress of the International Commission on Irrigation and Drainage, September 1996. Cairo, Egypt.
- Berridge S. Interim report: Towards reduced fertiliser loss in irrigated pasture. Research Report - WaterWheel 3. LWRRDC
- Berridge S. Towards reduced fertiliser loss in irrigated pasture. Irrigation Australia, Spring 1996 11(2). Irrigation Association of Australia.
- Pivot (1996) Fertiliser management on irrigated pastures. Technical Bulletin P:006, Pivot Limited Melbourne. February 1996
- Pivot (1996) Dairy Farming: Nutrient audits to determine fertiliser movements. Technical Bulletin P:007, Pivot Limited Melbourne. February 1996

6. ADDITIONAL INFORMATION

Additional information, or copies of any of the above written communications, can be obtained from either the principal investigator or from:

The Publicity Officer, Agriculture Victoria
Institute of Sustainable Irrigated Agriculture, Tatura Ph (058) 335 222
Private Bag 1, Ferguson Rd, Tatura Vic 3616 Fax (058) 335 299

7. ACKNOWLEDGMENTS

7.1 Funding

Funding for this three year research program was provided by the Land and Water Resources Research and Development Corporation (LWRRDC), Pivot Agriculture and the Victorian State Salinity Program. The assistance of these bodies is gratefully acknowledged.

7.2 Landholders

Much of the research in DAV12 was conducted on commercial irrigation farms in the Shepparton Irrigation Region. The support, assistance and contribution from the farmers concerned is greatly appreciated. Particular thanks to:

- Gary Campbell, formerly of Ardmona
- John Matthewson, Ardmona
- Les Bently, Mooroopna
- Bill Dunlop, Tongala
- Chris and Gwen Jensen, Mooroopna
- Charlie Phelan, formerly of Harston.