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Rural Industries Research and Development Corporation

Using Raised Beds on Rice Farms

– sustainable cropping systems on rice farms –

A report for the Rural Industries Research and Development Corporation

By

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Foreword

The Australian rice industry has a long record of striving to improve water productivity (t/ML) both for the rice crop and for other crops grown as part of the rice based farming system. This is achieved by selecting suitable soils for rice production and by improving irrigation layouts and irrigation management.

Crops such as soybeans, maize, canola, faba beans, wheat, barley and vegetables clearly have potential within rice based farming systems. However, several of these crops cannot handle waterlogged soil conditions and therefore cannot be grown in rotation with rice using conventional rice layouts. To be economic, many of these crops need to be grown on raised beds. This project has compared the performance and productivity of a number of crops in the rice based farming system

Project findings indicate that we can successfully grow rice on raised beds and achieve rice yields equivalent to those of conventional flat irrigation layouts. We can also successfully grow other crops in rotation with rice on raised beds. The project findings emphasise the need to apply deep water during the early pollen microspore stage of rice plant development regardless of the irrigation layout being utilised. This highlights the importance of projects funded by RIRDC to incorporate increased tolerance of cold temperature conditions into the genetics of Australian rice varieties. When cold tolerant varieties become available further improvements in rice water productivity are likely.

This report provides information on crop performance in a side by side comparison of irrigation layouts and systems. Irrigation layouts can be modified to allow for a close rotation of rice and other crops, without the need to change irrigation layouts to satisfy the different crops needs. The report will be a useful basis for those growers and advisers (agronomists and irrigation system designers) contemplating changes in irrigation layouts.

This project was primarily funded from rice and grains industry revenue by two R&D Corporations — Rural Industries Research and Development Corporation (RIRDC) and Grains Research and Development Corporation (GRDC) which is matched by funds provided by the Australian Government and Australian Centre for International Agricultural Research (ACIAR) who is funded principally by the Australian Government to conduct collaborative research projects concurrently in Australia and in developing nations.

This report, an addition to RIRDC's diverse range of over 1600 research publications, forms part of our Rice R&D program, which aims to improve the profitability and sustainability of the Australian rice industry.

Most of our publications are available for viewing, downloading or purchasing online through our website:

- downloads at www.rirdc.gov.au/fullreports/index.html
- purchases at www.rirdc.gov.au/eshop

Peter O'Brien
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Keiran O'Keeffe, District Agronomist, NSW DPI, Griffith provided us grower feedback through regular grower visits to the Coleambally Demonstration Farm site.

Our thanks are due to the Murrumbidgee Shire Community Experimental Demonstration Farm Management Committee for access and advice in utilising the demonstration farm resource.

We acknowledge support from the Cooperative Research Centre for Sustainable Rice Production, Coleambally Irrigation Cooperative Limited, Murray Irrigation Limited, Grains Research and Development Corporation (GRDC) and the Australian Centre for International Agricultural Research (ACIAR).

The project steering committee including Dr Liz Humphreys and Dr Jagadish Timsina CSIRO Land and Water and input from members of the RIRDC Rice Research and Development Committee contributed to the success of the project.

Abbreviations

ASW	Australian Standard Wheat
CDF	Coleambally Demonstration Farm
cv.	cultivar
CIA	Coleambally Irrigation Area
DAP	diammonium phosphate
DLWC	Department of Land and Water Conservation
DM	dry matter
DSE	dry sheep equivalent
ECa	apparent electrical conductivity
EM31	Geonics EM31 Electro-magnetic Instrument
EPM	early pollen microspore
ESP	exchangeable sodium percentage
ESPe	exchangeable sodium percentage derived from saturated soil paste extracts
ET	evapotranspiration
ETo	adjusting reference evapotranspiration
GM	gross margin
GPS	Geographical Positioning System
HI	harvest index
l.s.d.	least significant difference
MIA	Murrumbidgee Irrigation Areas
ML	megalitres
MDBC	Murray Darling Basin Commission
MDBMC	Murray Darling Basin Ministerial Council
MSD	mid season drained
MSN	mid season nitrogen application
n.s.	not significant
N	nitrogen
NDVI	Normalised Difference Vegetation Index
NPV	net present value
PI	panicle initiation
PIN	panicle initiation nitrogen application
PM	physiological maturity
PRB	permanent raised beds
PV	present value
WP	water productivity

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Executive Summary

Importance of this research
This report contains the results of an experiment evaluating a new irrigation layout for rice and other crops. It involved the side by side comparison of the agronomic and irrigation performance of rice, and crops in rotation with rice. Three layouts / irrigation treatments inside a bankless channel were used – flat, permanent beds and permanent beds with sub-surface drip irrigation. Beneficiaries of the research will include rice and grain growers within rice based farming systems, advisory and commercial agronomists, irrigation surveyors and designers, irrigation distribution companies and, land and water management plan implementers operating in these areas.

Background
To remain financially viable and environmentally sustainable, rice growers in southern New South Wales need to be able to readily respond to market opportunities, increase crop productivity, increase water productivity and manage watertables. Improved irrigation layouts may allow an increased range of cropping opportunities and productivity increases, whilst reducing environmental impacts.

Aims
The aim of this project is to increase the sustainability, resource use efficiency, yield and profitability of rice-based cropping systems through improved soil, water and nutrient management using permanent raised bed systems.

Methods used
A large replicated field experiment was conducted at Coleambally Demonstration Farm, NSW. The project investigated the performance of several crop sequences with rice in the rotation, including double cropping with side-by-side demonstration of permanent raised beds (including sub surface drip irrigation) and traditional 'flat' layouts. Three broad types of crop sequence were selected to include both traditional and novel crop sequences (double cropping with both winter and summer crops each year). Different crop options were included within each broad sequence.

This study also estimated the potential benefits and costs involved in switching over to permanent raised beds over common irrigation layouts of rice based farming systems within a benefit cost framework.

Results
Rice can be grown in close rotation with winter cereals and other summer crops on raised beds where irrigation supplies are of sufficient volume. The results of this project demonstrate that the adoption of raised beds in terraced, bankless channel layouts provides an opportunity for this to occur. Barley/soybean double cropping was successful on raised beds in rotation with rice.

The results of the benefit cost analysis revealed that there are significant benefits in switching to permanent raised beds in terraced, bankless channel layouts. Furthermore, the technology available is viable from a financial perspective.

Implications
The increased cropping choice, flexibility and significantly reduced labour requirement made possible by this layout suggests the on-going adoption of terraced, zero graded bankless channel layouts for rice growing, including raised beds, appears likely. In the MIA, CIA, Murray Valley and by riparian and groundwater irrigators a range of crops is being grown under variations this layout style including rice, wheat, maize, cotton, faba beans, chickpeas, barley and sunflowers.

The area of adoption is not great at this stage but considerable attention is being applied to the performance of these layouts in commercial fields by other irrigators. Some growers are using relatively expensive designs, in terms of structures and piping, to achieve terraces/steps between bays in commercial situations.

Surveyors and designers are generating and installing irrigation designs based on these concepts in the rice growing areas of southern New South Wales. It is likely that when water availability and financial conditions improve, there will be an increased rate of adoption of this type of irrigation layout. Growers who have adopted these designs consider the life style and labour saving benefits worth the investment. Further work needs to be undertaken to explore the distribution uniformity of irrigations and the water saving possibilities of these designs on a commercial scale.

The use of these layouts will be confined to locations where existing land grades allow creation of zero-graded layouts with appropriate terrace widths and steps to allow adequate drainage at acceptable landforming cost. They will also be confined to locations where access to large irrigation flows is available to allow short duration watering times for crops other than rice. There may be significant improvements to be made where pastures are grown in rotation with rice on flat layouts by increasing irrigation flow rates and reducing water on/ water off times.

The potential of these irrigation layouts fits with grower and grains industry desires to increase the crop range and yield of crops e.g. crops after and in rotation with rice such as chickpeas, faba beans, soybeans, canola, wheat and barley. The layouts link to precision agriculture concepts – compaction control, tramlining, machinery efficiencies and uniform or varied input application –which will help improve the sustainability of irrigation farming.

Recommendations

Rice can be grown in close rotation with winter cereals and other summer crops on raised beds where irrigation supplies are of sufficient volume to allow the adoption of raised beds in terraced, bankless channel layouts.

Adoption of zero-graded, bankless, terraced rice field irrigation designs (basin layout) incorporating raised beds (lateral beds) should be promoted to rice growers in appropriate locations, with regard to existing slopes and access to high irrigation flows.

If this style of layout adopted by increased number of growers within irrigation areas and districts, consideration needs to given for installation of on-farm storages to facilitate the high irrigation delivery rates required. Irrigators and surveyor/designers need to consider the field size in relation to potential water flows and implications for access to adequate flow.

The current experiment was undertaken during very dry (drought) climatic conditions. Monitoring of the performance of the irrigation layouts in farmers' fields during higher rainfall and potentially waterlogging conditions needs to be undertaken when the opportunity arises.

1. Introduction

To remain profitable and environmentally sustainable, farmers need to be able to readily respond to market opportunities, increase productivity, increase water use efficiency and manage watertables (and thereby soil salinisation and drainage water salinity).

Our hypothesis is that increases in profitability, water productivity, sustainability, and ease of management can be achieved through changing from cropping systems where rice is grown on the flat to permanent bed cropping systems. Switching to a permanent bed system will offer advantages including:

1. Increased cropping flexibility – opportunity to grow crops in rotation with rice that can't be grown profitably on the flat, and the possibility of rapid response to market opportunities (due to existence of bed layout).
2. Higher yields of crops traditionally grown on the flat in rotation with rice due to improved drainage and soil structure.
3. Increased opportunity of double-cropping because of quicker turn around (maximise use of land resource).
4. Reduced cost of earthworks – same layout used for all crops, whereas at present beds are constructed after the rice phase, and destroyed to return to rice on contour layout on the flat.
5. Better disease, weed and pest control - through increased diversity in rotation possibilities.

In addition, water productivity will be increased through higher yields and increased opportunity for establishing crops immediately after rice. The latter will also assist watertable management.

This project addressed the key R&D issue of improving the sustainability of the rice farming system - especially improved and effective water use (RIRDC Research Priorities 2002-03). Irrigated cropping industries in the rice growing areas of southern NSW will be the primary beneficiaries of this research. Irrigated agriculture of the Murrumbidgee and Murray Valleys in southern NSW has access to allocations of 4,560 gigalitres of which about 3,650 gigalitres are used annually. NSW rice growers who use ~150,000 hectares of land and two gigalitres of irrigation water to produce around 1.5 million tonnes of rice annually will be significant beneficiaries of this research in that other parts of the rice based farming system will operate more productively and efficiently, and through increasing their cropping options.

Crops such as soybeans, maize, canola, faba beans, wheat, barley and vegetables clearly have potential within rice based irrigated farming systems. However, several of these crops cannot handle waterlogged soil conditions and therefore cannot be grown in rotation with rice using conventional rice layouts. Furthermore, establishment and productivity of crops grown on traditional rice layouts is impaired due to poor drainage and soil structure. To be economic, many of these crops need to be grown on beds.

The main economic benefits of permanent bed layouts will be: (i) reduced cost of landforming when changing between rice and crops normally grown on beds (e.g. soybeans, faba beans, maize, cotton), (ii) increased productivity of crops traditionally grown on contour layouts in rotation with rice (such as winter cereals) through improved drainage and soil structure, (iii) increased cropping flexibility and ability to respond to market opportunities, and (iv) increased possibility of double cropping through using the same layout for all crops. If the rice on beds is grown using intermittent irrigation for the first couple of months, there may also be cost savings through reduction in water use compared with aerial sown rice. However, it should be noted there are some areas where the development of permanent bed cropping systems may be undesirable or unachievable with present technology and economics. These are areas with shallow saline watertables, areas with highly sodic soils, areas with restricted water supply and areas with very flat land grades.

The main environmental benefits of the permanent bed system for Australia would be from reduced fuel requirement (reduced greenhouse gases from burning diesel) due to no longer shifting between contour and bed layouts. Other benefits would include improved soil structure and drainage for crops traditionally grown in rotation with rice. There could also be a reduction in the amount of water needed for rice production and recharge depending on the water management adopted. The permanent bed system should also increase the ability to establish winter crops immediately after rice, resulting in increased irrigation water use efficiency (t/ML) and reduced net recharge through use of stored soil water, capture of winter rain, and crop water use from upflow from the watertable. The project will also demonstrate that the Rice Industry is proactively examining alternative management systems to improve water use efficiency.

This project seeks to improve the productivity, profitability and sustainability of the cropping systems in the rice-growing areas of southern Australia by incorporating rice growing on beds into cropping systems. Rice grown on permanent beds is a radical change from conventional flooded rice systems on the flat.

Irrigated agriculture in general, and the rice industry in particular, face the problem of reduced availability of irrigation water largely due to allocation of water for the environment, through the implementation of the MDBC Cap (MDBMC, 2000) limiting the level of surface water extraction and the river flow rules (DLWC, 1998) limiting the seasonal availability of irrigation water and to the current low rainfall environment in which we find ourselves. Furthermore, the price of irrigation water is increasing, as is the uncertainty in the amount of water available for irrigation each year. Added to this are uncertainty and fluctuations in the prices of all irrigated agricultural commodities, including rice.

The environmental sustainability of irrigated agriculture in the rice-growing areas of southern Australia is also threatened by salinisation as a result of rising watertables due to clearing of native perennial vegetation and the introduction of irrigation. Now large portions of the irrigation areas and districts have watertables within 2 m of the surface, and often these shallow groundwaters are highly saline (Hoey, 1992; van der Lely, 1992). Forty to fifty per cent of the rise in watertables has been attributed to ponded rice culture (GHD, 1985; Dwyer Leslie, 1992), with significant contributions from other irrigated crops, channels and rainfall. Saline drainage from irrigation areas, due to high saline watertables, is now a major challenge for irrigation area managers.

The irrigation areas were developed on soils dominated by heavy textured clay soils, often with high levels of surface and/or subsoil sodicity. While these soils are well-suited to ponded rice culture, there are often severe limitations to the growth of upland crops under irrigated conditions (Muirhead and Humphreys, 1984). The limitations include physical conditions such as poor tilth, inadequate infiltration, shallow hard-setting surface horizons, crusting surface soils, dense sub soils, waterlogging, and soil compaction (Beecher et al., 1998). The current rice cropping practices of ponded (4-6 months) rice culture on contour layouts (Figure 1) lead to problems of soil degradation during the rice phase and during harvest (especially in wet years), poor water management and waterlogging for crops grown in rotation with rice using the rice layout, and limited cropping flexibility. Conversion from poorly drained contour layouts to better drained border check or bed layouts is inconvenient and expensive, and is not normally practised where rice is grown regularly in the “rotation”. This essentially limits the non-rice part of the rotation to relatively waterlogging tolerant, low value crops (winter cereals) and annual pastures.

Improved soil and water management are needed to increase water use efficiency, manage watertables, increase cropping flexibility, and improve the productivity of crops grown in rotation with rice in Australia, and maintain or increase profitability (Figure 1).

This project proposal builds on the findings of John Thompson’s (NSW DPI, Deniliquin) Rice CRC research on rice on beds, and Liz Humphreys’ (CSIRO, Griffith) Rice CRC research on wheat after rice. The project idea was developed through numerous discussions with RIRDC Rice R&D Committee members, bed farmers, researchers from CSIRO, NSW DPI, Charles Sturt University and the Director of the Rice CRC. These discussions identified permanent beds as a potential area of research for improving the water-use efficiency, productivity and sustainability of cropping systems in the rice growing areas of southern NSW.

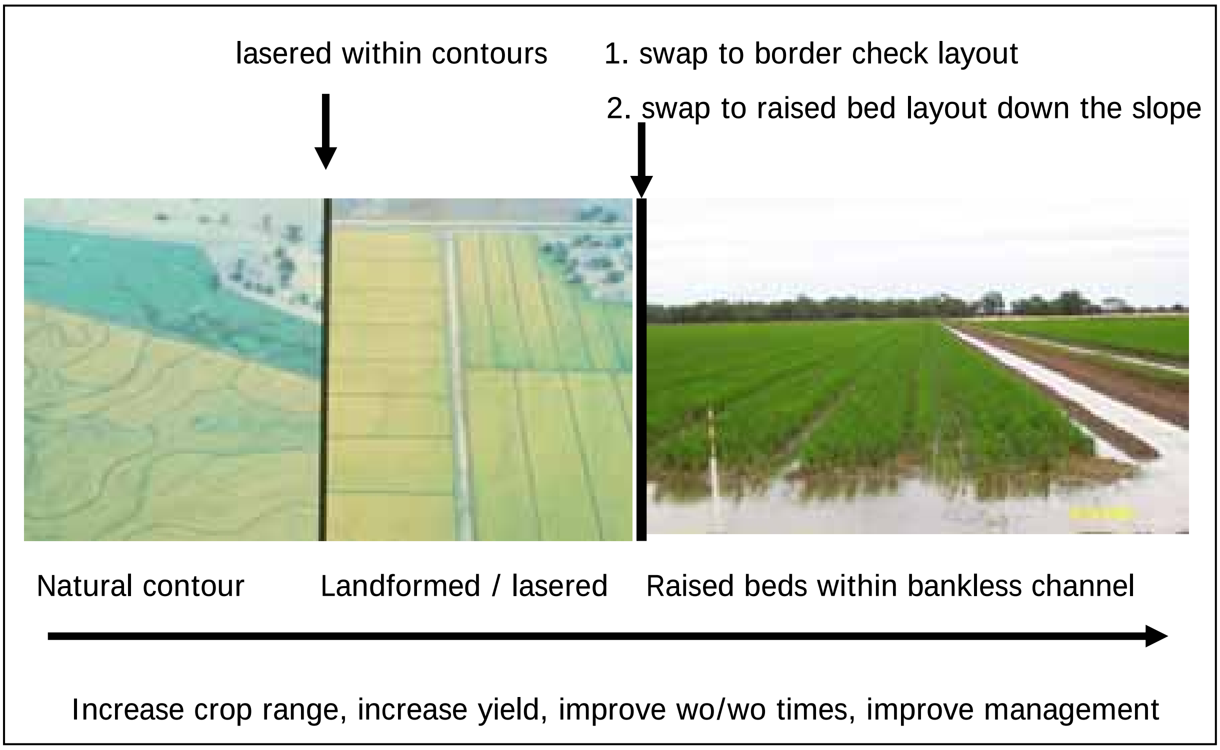


Figure 1. Potential progressive or step wise development of field layouts

Various names are applied to the same concept – level basins, beds in bays, zero grade terraced bays/basins.

Bankless channel irrigation designs are commonly used within the Murrumbidgee and Murray Valleys. Bankless channel layouts improve supply and drainage compared to other layouts, the bankless channel acting as both supply channel and drain for each bay and with fewer irrigation structures compared to other layouts. These designs usually do not have a level basin within the bays but have a grade that is constant across the entire field (Figure 2 section B-B). However the use of terraced zero grade bays is increasing in the Murrumbidgee Valley (Figure 2 Section B'-B').

Raised beds are increasingly being used for production of both winter and summer crops in the Murrumbidgee Valley with beds traditionally formed running down the slope of the field. The possibility of incorporating permanent lateral raised-beds within a bankless channel field design (Figure 2) for use in rice-based cropping systems potentially negates the need to convert irrigation layouts between different phases of the cropping rotation. In this layout the beds are formed across the slope within the bays. With this layout it should be possible to grow an increased range of high yielding crops in rotation with rice.

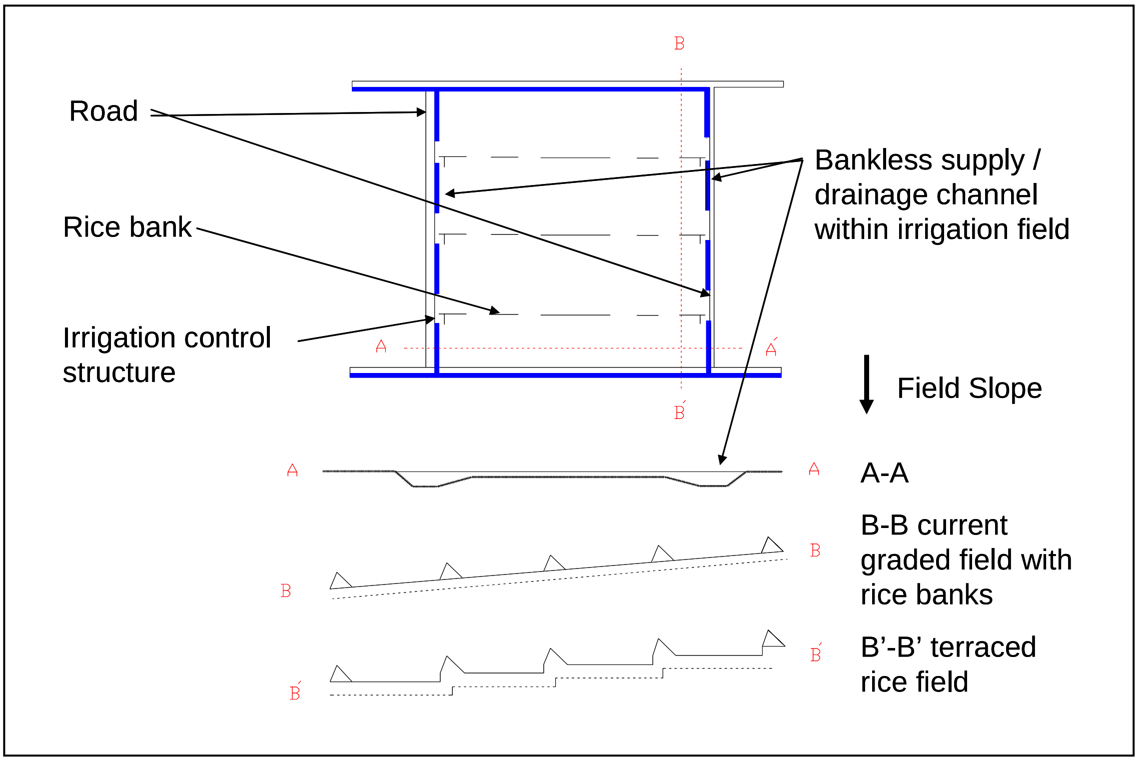


Figure 2. Terraced zero grade layout design

Some maize producers are using raised beds within bankless channel field designs citing advantages of decreased labour requirement (no syphons) and faster water on/ water off periods, suggesting reduced waterlogging, decreased intake opportunity time restricting infiltration and reduced costs.

Overall, permanent lateral bed farming may give rice growers the opportunity for a more diverse, profitable and sustainable cropping system.

2. Objectives

The goal of this project is to increase the sustainability, resource use efficiency, yield and profitability of rice-based cropping systems through improved soil, water and nutrient management using permanent beds.

The project investigated:

Side-by-side demonstration of permanent bed (including sub surface drip irrigation) and traditional layouts for a range a crop sequences with rice in the rotation, including double cropping.

Producing:

Data on the performance of the layouts, crop sequences and irrigation methods, including irrigation and total water use efficiency, net recharge, profitability, soil condition, cropping flexibility.

Which will allow development of:

Guidelines for improving the profitability, water use efficiency and sustainability of rice-based cropping systems.

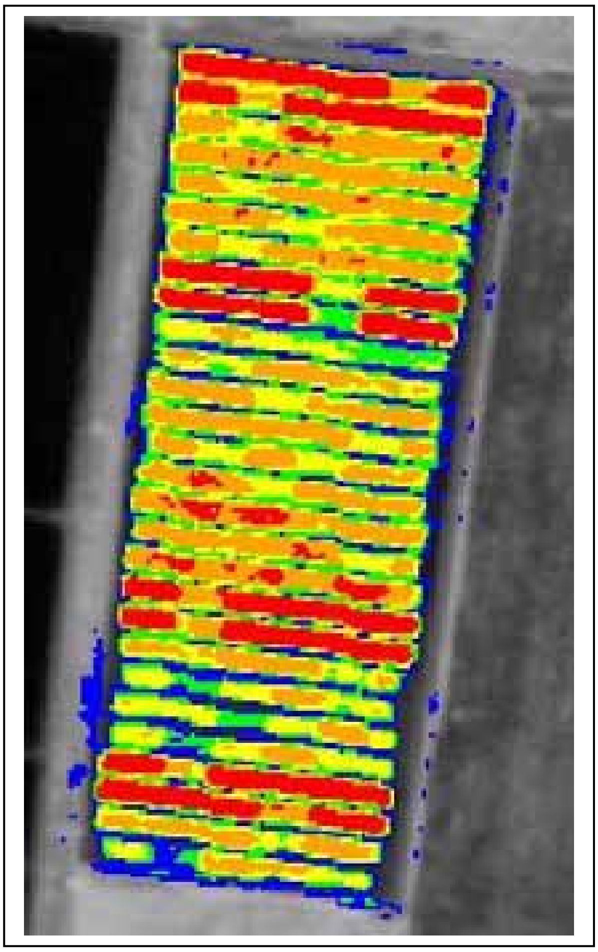


Figure 3. NDVI image of experimental site during 2002-03 rice growing season

3. Methodology

A replicated field experiment (Figure 3) was initiated at the Murrumbidgee Shire Community Experimental Demonstration Farm (also referred to as Coleambally Demonstration Farm or CDF) (34^o44'S, 145^o 56'E) in the Coleambally Irrigation Area, south-eastern Australia in September 2002. The experiment consists of three irrigation treatments – flat layout, permanent beds and permanent beds with sub-surface drip irrigation – all inside a bankless channel type layout. A range of cropping sequences have since been applied (see Table 1).

The north-west corner of a 30 ha field was chosen as the experimental site, based on a Geonics EM31 vertical dipole (apparent electrical conductivity, ECa) survey, soil exchangeable sodium percentage (ESP) and the rice soil suitability criteria (Beecher et al., 2002). The soil at the site is typical of ricegrowing soils in this region – an association of Wilbriggie clay loam and Yooroobla clay (Stannard, 1970), a transitional red-brown earth and self-mulching clay, respectively. Soil properties of the experimental site (0 to 15 cm) were: 0.10% OC, 1.15% N, 11.2 ug/g ammonium N, 2.5 ug/g nitrate N, pH ($CaCl_2$) 5.0, ESP 2.7, ECe (dS/m) 0.67 and particle size distribution: clay 36, silt 21 and sand 43 percent, respectively.

The 6 ha experimental site had an ECa range of 125 to 185 mS/m using an EM31 mounted on the front carrier of a 4WD motorbike, ESP (0 to 60 cm depth) of 5 to 9 and ESP (60 to 150 cm depth) of 11 to 14.

Since laser levelling in 1999, the field had grown one irrigated canola and two irrigated wheat crops, with the second wheat crop harvested in December 2001. The stubble from this crop was burnt and the field lay fallow until July 2002, when 44 kg P/ha (as 500 kg/ha single superphosphate) was applied to the soil surface to ensure that P was not limiting during the experimental period.

In August 2002, a GPS guidance system (Beeline) was used to guide a tractor with furrowing equipment to create 1.83 m wide raised beds (centre to centre) east/west across the site. The beds ran at right angles to the 1:1500 slope of the field.

The bays which were to become the flat treatments were scarified several times to remove the beds and levelled with a field grader.

An excavator and road grader were used to construct a supply channel at the eastern end and a drain at the western end, to measure irrigation and drainage volumes. Banks were constructed parallel to the beds to create 28 bays (each with six raised beds), resulting in an effective bay size of 140 by 14.7 m. All bays (Flat and Bed) could be ponded with water to a depth of about 20 cm, if and when required.

In eight of the bed bays, two drip lines were installed into each bed, 17 cm below the bed surface. The drip lines ran parallel to the bed, one quarter of the way onto the bed from the bed shoulder, giving a drip line spacing of 70 cm within the bed. The drip tape emitters were spaced at 35 cm intervals and were capable of 0.80 L/h output at a pressure head of 10 m.

A soil association map of the farm was available (Figure 4), as was an EM31 electrical conductivity survey of the site. The site chosen was the western side of Field 4 where the higher EM31 values were recorded (Figure 5) and where higher soil sodicity values 0-60 and 60-150 cm were observed (Figure 6).

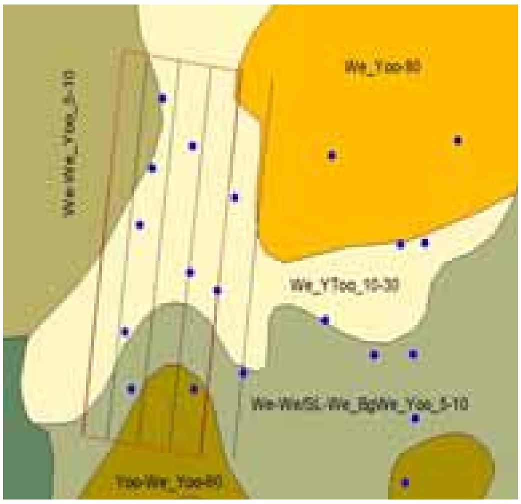


Figure 4. Extract of a digitised soil association map of Field 4, CDF. Showing the presence of transitional red brown earths (We) and self mulching clays (Yoo) across the site.

The experiment location is highlighted.

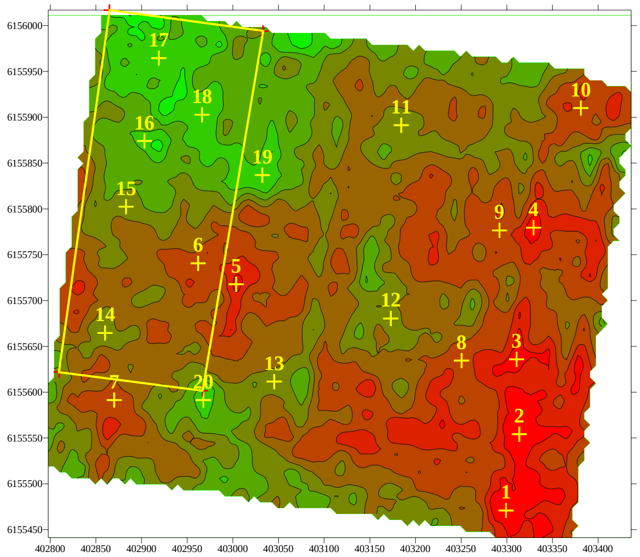


Figure 5. Electromagnetic (EM31) survey of Field 4, CDF including the area of the experiment (highlighted)

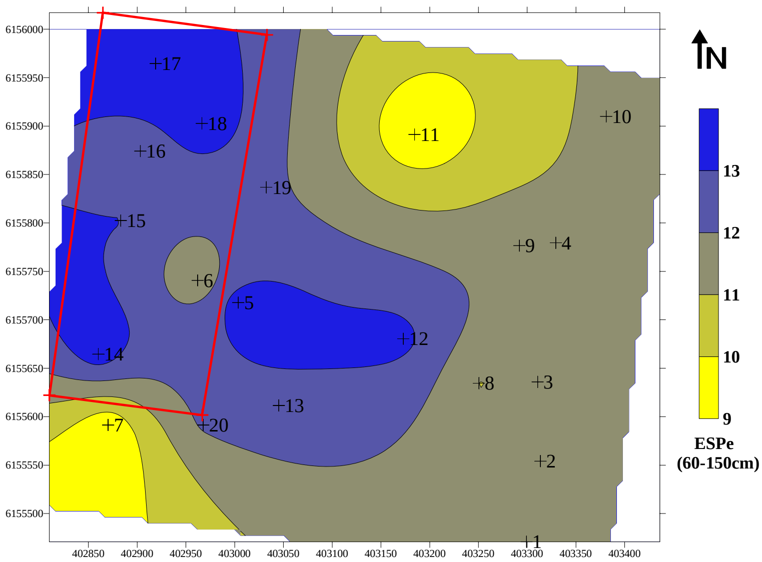


Figure 6. Interpolated map of soil ESPe based on the indicated sampling points across Field 4

3.1 Experimental design

The replicated experiment compared a permanent bed layout with the traditional "flat" layout. Several major crop sequences were examined (Table 1). Three broad types of crop sequence were selected to include both traditional and novel crop sequences (double cropping with both winter and summer crops each year). Within each broad sequence different crop options were included. The details were finalised in consultation with the project steering committee.

Sub-surface drip irrigation was also evaluated for the bed farming sequences. This treatment was installed as part of the main experimental design, being randomised among the flood and furrow irrigated treatments.

Plots were six beds or approximately 11 m wide by 150 m long. Crop sequence nitrogen fertiliser subplots were at least 25 m long. Beds were 1.83 m wide (mid-furrow to mid-furrow), as commonly adopted by adjacent commercial growers.

Main plots – soil x water management

1. Flood irrigated, flat layout - crop sequences a & b
2. Flood (furrow) irrigated beds - crop sequences b & c
3. Subsurface drip irrigated beds - crop sequence c

The experiment was not a complete factorial design but included adequate overlap of treatments to allow comparisons to be made. Crop sequences were confined to appropriate soil x water management treatments (irrigation bays) (see Table 1). For example, there is little point in growing a rice–fallow–wheat sequence on beds, with or without drip irrigation.

Table 1. Crop sequences grown at CDF from 2002-03 to 2006

Bay	RRISYS	Summer 02/03	Winter 03	Summer 03/4		Winter 04		Summer 04/5	Winter 05	Summer 05/6	WINTER 06
1	F	Rice	Stubble	Stubble	Cult/Graded	Wheat		Wheat Stub	Wheat Fallow	Rice	Happyseeder
2	F	Rice	Wheat	Wheat/Stub	Cult/Graded	Wheat		Wheat Stub	Wheat	Wheat Stub	Wheat Stub
3	B	Rice	Wheat	Wheat/Stub	RH/sweep/BS	Wheat		Wheat Stub	Wheat	Wheat Stub	Wheat Stub
4	B	Rice	Barley	Soybean IRC	RH/sweep/BS	Barley		Soybean IRC	Soy stubble	Rice	WHEAT
5	D	Rice	Barley	Soybean IRC	RH/sweep/BS	Barley		Soybean IRC	Soy stubble	Rice - mid drain	WHEAT
6	B	Rice	Stubble	Rice		Rice stubble	RH/sweep/BS	Rice	Rice stubble	Rice	WHEAT
7	D	Rice	Stubble	Rice		Rice stubble	RH/sweep/BS	Rice	Rice stubble	Rice - drip	WHEAT

Bay	RRISYS	Rice	Winter 03	Summer 03/4		Winter 04		Summer 04/5	Winter 05	Summer 05/6	
8	F	Rice	Stubble	Stubble	Cult/Graded	Wheat		Wheat Stub	Wheat Fallow	Rice	Happyseeder
9	F	Rice	Wheat	Wheat/Stub	Cult/Graded	Wheat		Wheat Stub	Wheat	Wheat Stub	Wheat Stub
10	B	Rice	Wheat	Wheat/Stub	RH/sweep/BS	Wheat		Wheat Stub	Wheat	Wheat Stub	Wheat Stub
11	D	Rice	Barley	Soybean	RH/sweep/BS	Barley		Soybean	Soy stubble	Rice - mid drain	WHEAT
12	B	Rice	Barley	Soybean	RH/sweep/BS	Barley		Soybean	Soy stubble	Rice	WHEAT
13	B	Rice	Stubble	Rice		Rice stubble	RH/sweep/BS	Rice	Rice stubble	Rice	WHEAT
14	D	Rice	Stubble	Rice		Rice stubble	RH/sweep/BS	Rice	Rice stubble	Rice - drip	WHEAT

Bay	RRISYS	Rice	Winter 03	Summer 03/4		Winter 04		Summer 04/5	Winter 05	Summer 05/6	
15	D	Rice	Stubble	Rice		Rice stubble	RH/sweep/BS	Rice	Rice stubble	Rice - drip	WHEAT
16	B	Rice	Barley	Soybean	RH/sweep/BS	Barley		Soybean	Soy stubble	Rice	WHEAT
17	D	Rice	Barley	Soybean	RH/sweep/BS	Barley		Soybean	Soy stubble	Rice - mid drain	WHEAT
18	B	Rice	Wheat	Wheat/Stub	RH/sweep/BS	Wheat		Wheat Stub	Wheat	Wheat Stub	Wheat Stub
19	F	Rice	Wheat	Wheat/Stub	Cult/Graded	Wheat		Wheat Stub	Wheat	Wheat Stub	Wheat Stub
20	F	Rice	Stubble	Stubble	Cult/Graded	Wheat		Wheat Stub	Wheat Fallow	Rice	Happyseeder
21	B	Rice	Stubble	Rice		Rice stubble	RH/sweep/BS	Rice	Rice stubble	Rice	WHEAT

Bay	RRISYS	Rice	Winter 03	Summer 03/4		Winter 04		Summer 04/5	Winter 05	Summer 05/6	
22	D	Rice	Stubble	Rice		Rice stubble	RH/sweep/BS	Rice	Rice stubble	Rice - drip	WHEAT
23	B	Rice	Stubble	Rice		Rice stubble	RH/sweep/BS	Rice	Rice stubble	Rice	WHEAT
24	B	Rice	Barley	Soybean	RH/sweep/BS	Barley		Soybean	Soy stubble	Rice	WHEAT
25	F	Rice	Stubble	Stubble	Cult/Graded	Wheat		Wheat Stub	Wheat Fallow	Rice	Happyseeder
26	F	Rice	Wheat	Wheat/Stub	Cult/Graded	Wheat		Wheat Stub	Wheat	Wheat Stub	Wheat Stub
27	B	Rice	Wheat	Wheat/Stub	RH/sweep/BS	Wheat		Wheat Stub	Wheat	Wheat Stub	Wheat Stub
28	D	Rice	Barley	Soybean	RH/sweep/BS	Barley		Soybean	Soy stubble	Rice - mid drain	WHEAT

F = Flat, B = Beds, D = drip in beds, IRC =inter row cultivated
RH = rotary hoed, sweep = furrows cleaned, BS = beds shaped

3.2 Rice 2002-03

During 2002-03 five water management/field layout treatments were evaluated:

- flooded rice on flat layout
- flooded rice on raised beds (flooded (15 cm depth)from 14 days before panicle initiation)
- flooded rice on raised beds (flooded (5 cm depth) from 14 days before panicle initiation)
- furrow irrigated rice on raised beds
- sub surface drip irrigated rice on raised beds.

Table 2. Allocation of irrigation layouts, methods and nitrogen fertiliser applications for the 2002-03 rice crop, distribution of N fertiliser subplots and flooded water depths during early pollen microspore period of the rice crop

Coly Demo Farm - Rice on Beds Trial, Total of all Urea N fertiliser applied to Rice 2002

N

Rep 1 — Nrates

Bay	IRRSYS	CROP	Buffer	plot 4	plot 3	plot 2	plot 1	Buffer	Water Depth
1	F	A	120	180	120	60	0	120	15cm
2	F	B	120	0	60	120	180	120	15cm
3	B	B	120	0	180	120	60	120	15cm
4	B	D	120	180	120	60	0	120	Furrow
5	D	D	120	0	60	180	120	120	Drip
6	B	C	120	120	0	60	180	120	5cm
7	D	C	120	0	60	180	120	120	5cm

Rep 2 — Nrates

Bay	IRRSYS	CROP	Buffer	plot 4	plot 3	plot 2	plot 1	Buffer	Water Depth
8	F	A	120	60	180	0	120	120	15cm
9	F	B	120	60	120	0	180	120	15cm
10	B	B	120	180	120	60	0	120	15cm
11	D	D	120	0	120	180	60	120	Drip
12	B	D	120	120	0	60	180	120	Furrow
13	B	C	120	120	60	180	0	120	5cm
14	D	C	120	0	180	60	120	120	5cm

Rep 3 — Nrates

Bay	IRRSYS	CROP	Buffer	plot 4	plot 3	plot 2	plot 1	Buffer	Water Depth
15	D	C	120	180	0	120	60	120	5cm
16	B	D	120	120	180	0	60	120	Furrow
17	D	D	120	60	120	180	0	120	Drip
18	B	C	120	60	120	0	180	120	5cm
19	F	A	120	0	120	60	180	120	15cm
20	F	B	120	0	180	60	120	120	15cm
21	B	B	120	60	180	120	0	120	15cm

Rep 4 — Nrates

Bay	IRRSYS	CROP	Buffer	plot 4	plot 3	plot 2	plot 1	Buffer	Water Depth
22	D	C	120	0	60	180	120	120	5cm
23	B	C	120	120	0	60	180	120	5cm
24	B	B	120	0	120	180	60	120	15cm
25	F	B	120	0	180	60	120	120	15cm
26	F	A	120	180	120	0	60	120	15cm
27	B	D	120	60	120	0	180	120	Furrow
28	D	D	120	0	180	120	60	120	Drip

Rice (cv. Amaroo) was sown at 140 kg/ha into a cultivated seedbed using a Connor Shea twin disc drill. Eight rows were sown on top of the beds and two rows were allowed to drop into the furrows. All plots had DAP (150 kg/ha) sown with the seed. Establishment on the shoulder of the beds and in the furrow was poor and variable. To enable valid comparisons between water management treatments on the raised beds, all plants in the furrows were removed. This resulted in a wide gap (60 cm) between edge rows on adjoining beds.

Figure 7. Sowing rice into a raised bed treatment in 2002-03

Note: the level sowing undercarriage meant seed was surface sown in furrows and drill wheels ran on adjacent beds.

All treatments received the same herbicide applications. Gramoxone® was applied to control barnyard grass at 1 L/ha just prior to rice emergence. Magister® was applied at 500 mL/ha between the third and fourth flushing and molinate (5 L/ha) was applied into the permanent floodwater.

Urea was broadcast prior to permanent flood at the indicated rates for the rice on flat layout. A split nitrogen application was made to the rice on beds (1/3 pre-permanent flood and 2/3 pre-panicle initiation) which aimed to minimise nitrogen losses through denitrification during intermittent irrigations early in the season.

The first irrigation occurred on 21st October 2002. The rice was flushed four times prior to permanent flood. When the permanent flood was applied to the flat layout, the raised bed treatments were flooded to 10 cm above the surface of the bed to assist with nitrogen use efficiency. Once this water was used, further intermittent irrigations were applied to the beds up to 14 days before panicle initiation. Two weeks prior to panicle initiation the beds were allowed to dry for a second urea application. Water (10cm depth) was again applied to the bed treatments and the water was allowed to be used by the rice. One bed treatment remained flooded, whilst sub surface drip and furrow irrigated treatments began on the other beds. Between panicle initiation and flowering, the flooded treatments maintained a minimum water depth of 15 cm, whilst the furrow and sub surface drip irrigated rice had no deep water treatment.

Water applications were measured on and off each bay using RBC and circular flumes, respectively. Crop sampling occurred at various stages from establishment through to harvest.

3.3 Wheat/Barley 2003

Winter crops of barley (Gairdner) and wheat (H45) were sown at 100 kg/ha into slashed and burnt rice stubble using a Connor Shea twin disc drill on May 23. Eight rows were sown on top of the beds and two rows (one each side) were allowed to drop into the furrows. All plots had diammonium phosphate (DAP) sown with the seed at 185 kg/ha. The winter crop germinated on soil moisture with 5mm of rain on 1 June aiding emergence. Rainfall (38 mm) on 28 June – 1 July continued the good early growth of the crop.

All winter crop treatments received herbicide applications. Tigrex® was applied to control broadleaf weeds at 1 L/ha at growth stage Z22 to both wheat and barley. Hostage® was applied at 1 L/ha to wheat only at about growth stage Z27.

Urea (85 kg N/ha) was broadcast at the Z31/32 growth stage to both wheat and barley in early September 2003.

Commencing 18 September, irrigations were applied throughout spring at 60 mm ETo-rainfall, for surface irrigated treatments to the wheat (5) and barley (4) crops.

3.4 Rice 2003-04

Rice was grown on two bed treatments (see Table 1) where we compared furrow and drip irrigated beds. Rice (cv. Quest) was sown at 140 kg/ha into an un-cultivated seedbed using a cone seeder equipped with Barton disc openers. Six rows were sown on top of the beds and two rows were sown into the furrows at a spacing of 20 cm. All plots had DAP sown with the seed at 180 kg/ha.

Both irrigation treatments received the same herbicide applications. A post sowing/ pre emergence application of Glyphosate at 2 L/ha was applied. Gramoxone® was applied to control barnyard grass at 1.3 L/ha just prior to rice emergence. An additional Gramoxone® was applied to control barnyard grass at 1.0 L/ha on Replicate 1. Molinate at 5L/ha and Lorsban (150ml/ha) were applied, followed by Londax (85g/ha) for dirty dora control.

Urea was broadcast prior to permanent flood at 150 kg N/ha. An application of 100 kg N/ha was made to sub plots in all treatments after PI.

The first irrigation occurred on 22nd October, 2003. The rice was flushed five times prior to permanent flood. Permanent flood was applied to both furrow and drip irrigated treatments after nitrogen application. Both treatments were flooded to 12 cm above the surface of the bed to assist with nitrogen entry into the soil. Once this water was used, further intermittent irrigations were applied to the beds up to 14 days before panicle initiation. Two weeks prior to panicle initiation the beds were allowed to dry for a second urea application after which they were flooded to two cm depth. After this the furrow irrigated and the sub surface drip treatments were supplied with water to keep the drip beds saturated. There was **NO** deep water treatment between panicle initiation and flowering (ie. no deep water at early pollen microspore).

3.5 Soybeans 2003-04

Soybeans (cv. Djakal) were direct drilled into the burnt barley stubble on furrow and drip irrigated beds on 9 December 2003. The soybeans were sown at 100 kg/ha in 4 rows sited to be either side of the two drip lines using the Connor Shea twin disc drill. No fertiliser was applied with the soybean seed.

The water was maintained in the furrow of the furrow irrigated beds in order to allow improved subbing of water to the seed line – a tactic possible due to the zero grade nature of beds in bays. The drip irrigated beds were drip irrigated until the beds blacked out (moisture reached the soil surface in the centre of the beds).To encourage emergence of soybean of the furrow irrigated treatment, the beds were topped (flooded) at the next irrigation to ensure that water infiltrated into the centre of the beds. The seeds had already imbibed and commenced germination.

The soybeans were sprayed using Fusilade (30 December) and Verdict (28 January) for barnyard grass control. An inter row cultivation was applied on 22 January for Bathurst Burr and thistle control.

3.6 Wheat/barley 2004

Wheat (cv. Chara) was grown on bed and flat treatments and barley (cv. Gairdner) was grown on bed treatments following soybeans (furrow and drip irrigated). The irrigation plots had the stubble (wheat or soybean) burnt prior to being cultivated (and reshaped in the case of the beds) prior to being sown dry on 13th May, 2004. The wheat and barley were sown at 100 kg seed per ha and were fertilised with 185 kg DAP.

A germinating rainfall of 16 mm about 10 days later allowed the crop to establish. And a total of about 115 mm of rainfall was received prior to anthesis.

The Connor Shea twin disc drill was modified to allow the capability to sow into the bed shoulders. Adequate depth of seed placement was achieved on the reworked and reshaped beds and seed was successfully sown into the bed shoulders and furrows. Nine rows were sown on the top of the bed and 1 row in each of the bed shoulders.

The crops were top-dressed with 100 kg N/ ha at Z31/32 stage and irrigated throughout spring (four irrigations) to maturity at 70 mm cumulative ETo-rainfall for surface irrigated treatments. The drip irrigated bays were irrigated when soil moisture tension reached about -50kPa at 30m cm depth, as indicated by the Gbug gypsum blocks.

3.7 Rice 2004-05

Rice (cv. Quest) was grown on raised bed treatments only, where we compared furrow and drip irrigated treatments as in 2003-04. (see Table 1). Rice was sown using the Stubble King no-till drill which allowed successful sowing of seed into the shoulder/furrow with eight rows on top of the beds and one row on each bed shoulder (see Figure 8).

The subsurface drip treatment was maintained with no ponded water, whilst the furrow treatment was maintained at close to 15 cm ponded water depth during the rice growing season.

Urea was surface applied at permanent flood (100 kg N/ha). Further nitrogen (80 kg N/ha) was surface applied to dry soil in both the furrow and drip irrigated treatments prior to panicle initiation as the crop appeared to be deficient in nitrogen. The beds were flooded to 12 cm after N application and once this was used, saturated soil was maintained in the drip bays. During EPM deep water was applied to the furrow bed treatments but was difficult to maintain due to leaking banks. Irrigation water delivery measurements were confounded by leaking banks which made maintaining deep water through EPM a major issue

Barnyard grass and Dirty Dora required multiple treatments for reasonable weed control. Problems with Dirty Dora in the crop occurred to some extent due to adjacent location of soybean crops restricting the opportunity to undertake desired chemical weed control.

Figure 8. Stubble King No Till Drill sowing rice into bed layout

Seed was successfully sown into the shoulder/furrows of the beds without trafficking the bed tops.

3.8 Soybeans 2004-05

Soybeans (cv. Djakal) were direct drilled into the burnt barley stubble on furrow and drip irrigated beds on 15 December 2004. The soybeans were sown at 100 kg/ha in four rows sited to be either side of the drip line using the Stubble King no-till drill. No fertiliser was applied with the soybean seed.

The water was maintained in the furrow of the furrow irrigated beds in order to allow improved subbing of water to the seed line – a tactic possible due to the zero grade nature of beds in bays. The drip irrigated beds were drip irrigated until the beds blacked out (moisture reached the soil surface in the centre of the beds). Once soybeans on the furrow irrigated bed treatment showed sign of swelling and germinating, the beds were topped by water at the next irrigation to ensure that water infiltrated to the centre of the beds

The soybeans were sprayed post sowing and pre-emergence using glyphosate (17 December 2004) and post emergence using Verdict (17 January 2005) for barnyard grass control. An application of endosulfan was made for insect control.

3.9 Wheat 2005

The wheat (cv. Chara) bed and flat treatments were direct drilled (at 115 kg/ha) along with 150 kg DAP/ha on 13th May, 2005 following a pre-sowing irrigation (5 May). Eight rows were sown on the top of the beds and one row in each of the bed shoulder/furrows using the Stubble King drill. Germination and establishment of the wheat crop was excellent with 218 and 228 plants/m^2 in the bed and flat treatments. Grazing of the plots by kangaroos until the break of season rains was a concern, requiring electric fencing to be installed at the experimental site.

Nitrogen top dressing (125 kg N/ha) was applied either all at growth stage Z31 or split, with 65 kg N/ha applied at Z31 and 60 kg N/ha at late heading.

Stripe rust was rife throughout the district during 2005 and although the seed had been treated with Jockey (fluquinconazole), the crop became infected with stripe rust. Two aerial applications of Bumper (propiconazole 250 g/L) applied at 500mL/ha on 19 September and 12 October appeared to satisfactorily control the stripe rust.

During the growing season a total of 285 mm of rainfall was recorded. The crop was irrigated pre-sowing and also had four spring season irrigations at intervals of 60 mm (evapotranspiration (ET) minus rain). This scheduling ensured adequate soil moisture through the grain filling period.

3.10 Rice 2005-06

Rice (cv. Quest) was direct drilled into the uncultivated seed bed of five treatments on 18 October 2005. Initial flushing irrigations were applied the next day. Two flushing irrigations were applied along with two rainfall events prior to the application of permanent water on 15–17 November 2005.

The five treatments were: Flat (fallow) wheat, rice–furrow, rice–drip, soybean–furrow and soybean–drip (these drip bays were furrow irrigated in this season and a mid-season drain was applied) (see Table 1). A mid season drainage interval of approximately 80 mm ET after removal free water from the soil surface was applied.

All stubbles were burnt prior to sowing, although there was some residual stubble remaining at sowing. Fertiliser was applied at sowing 192 kg DAP /ha (35 kg N/ha).

Nitrogen was top-dressed as urea to dry soil prior to permanent flood in all treatments. Panicle initiation nitrogen was applied into the flood water for all treatments except for the mid season drain treatment. In this treatment two nitrogen fertiliser practices were followed nitrogen was either 1- applied to the dry soil prior to re-flooding of the plots (MSN mid season nitrogen) or 2- applied into floodwater at PI (as for other plots, panicle initiation nitrogen (PIN)). Nitrogen was applied 2/3 at permanent flood and 1/3 at panicle initiation or mid season drain. Four nitrogen rate topdressing treatments were applied 0, 120, 180 and 240 kg N/ha.

Weed control – pre and post sowing applications of Glyphosate were applied for control of barnyard grass and ratooning rice. A sequence of Molinate, Londax, Barnstorm and BasagranM60/MCPA was applied to ensure control of all weeds.

3.11 Wheat 2006

Wheat was sown into burnt rice stubble in four raised bed treatments on 17/18 May 2006. Two varieties (Chara and Ventura) were sown in each treatment plot which was split widthways. The wheat was sown at 100 kg N/ha with 175 kg/ha of DAP. Plots with subsurface drip irrigation were irrigated on 18 May 2006 whilst furrow irrigated plots were established on a germinating rainfall on 10 June 2006.

All plots were topdressed with 125kg N/ha as urea on 28 August and were surface irrigated on 31 August. A further four irrigations were applied, the last being on the 7 November.

3.12 Statistical analysis

Statistical analyses were conducted as split plot or randomised complete blocks as appropriate using Genstat 8/9. Least significant differences between treatments were evaluated at the 5% level.

3.13 Monitoring in Commercial crops

In addition to the major experiment at Coleambally, any commercial crops of rice grown on raised beds were monitored. Regular inspections and discussion with the growers were undertaken. The ability of the rice crop to compensate for the furrow space (the gap between the outside rows of adjacent raised beds) was investigated.

3.14 Economics

The economic analysis aimed to assess the likely benefits and costs of adoption of permanent beds in the rice based farming systems. More specifically, the economic analysis aimed to:

- to identify field layouts currently being use for irrigated RW cropping systems in Australia
- to estimate potential benefits from adoption of PRB over alternative layouts
- to determine the costs involved in the development of PRB, and
- to compare the benefits and costs of adoption of PRB by farmers.

The study considered the following four field designs for evaluation of benefits and costs of conversion to lateral permanent raised beds over an existing design; laterals raised beds are beds placed laterally across the main slope of the field within bank-less channel or drain back level basin designs rather than conventional raised beds running down the filed slope (Beecher et al., 2005).

I Non landformed natural contour
II Laser landformed natural contour
III Laser landformed square contour
IV Laser landformed square contour alternating with raised beds

3.14.1. Analytical approach

The financial analysis involves a partial budgeting approach in which the additional and foregone annual costs and benefits of the options were compared. The analysis was carried out from financial perspective.

A financial evaluation was undertaken to ascertain the attractiveness of the option from the perspective of the farmers. In undertaking a financial evaluation, it is appropriate to use financial values for all relevant inputs and outputs. ‘Financial values’ are the prices/benefits actually received by farmers for outputs or actually paid by them for inputs or losses.

The financial merit of adoption of PRB was assessed using the net present value of the investment. NPV is the difference between the present value of costs associated with the investment and the present value of benefits accruing from the investment. The proposal is deemed to have a positive impact if NPV exceeds zero.

3.14.1.1 Estimating farm level impacts of conversion to permanent beds design

The study has measured the on-farm impact of conversion to lateral permanent raised beds, a more efficient irrigation design, from different selected irrigation designs for the rice-based farming systems in Australia. The study has measured financial benefits of the research on beds which are driven by productivity gains, shifts in cropping rotations, reduction in production costs and water & labour savings at the farm level.

3.14.1.2 Measurement of the financial benefits

We used a range of techniques to measure the on-farm financial benefits and costs of adoption of permanent beds design on rice farms

Gross margin analysis

The gross margin (GM) is the gross return from a crop (yield times price) less the variable cost of production such as soil preparation, seed, fertiliser, irrigation water, plant protection costs, fuel, harvesting, insurance and levies. Overhead and operating costs that do not vary with the level of production are not considered in the GM analysis. Crops and rotations can be compared using GMs as long as there is no significant change in overhead costs between the alternative options being compared.

Costs of some inputs or operations such as irrigation water, fertiliser, machinery operations etc. are different under different field designs. Increase in yield or price also leads to increase in cost of some variable inputs and operations such as harvesting costs, insurance and research levies. Therefore, the variable costs and returns of an individual crop/enterprise have been measured for different irrigation designs and cropping rotations separately, following GM analysis.

Crop sequence gross margin analysis

Gross margin analysis deals with only one crop. Farmers grow a number of crops from the same paddock following a particular rotation. Furthermore, selection of an enterprise is done not only on the basis of its profitability as an independent enterprise but also by its contribution to other enterprises or to a cropping system. To maintain the productive capacity and economic sustainability of a farm, the farmers grow certain crops that may not be profitable in their own, but by improving soil fertility they help to increase yield of other crops grown in the rotation. They may act as a break crop to help to reduce yield losses from weed and disease. Therefore, the study has analysed the impact on crop sequence GM from conversion to permanent beds over other designs.

Improved field design offers opportunities to shift to a more profitable crop from an existing less profitable crop. Therefore, the study has first identified one typical rice-based cropping rotation from each selected field design. In a cropping rotation, different crops perform differently depending upon their placement in a particular rotation. It may lead to increase in yield or increase or reduction in use of some of the variable inputs such as fertilisers, chemicals or irrigation water used. These interrelationships and interdependences require analysis of the crop sequence budgets to enable to compare the performance of different rotations on different field designs. Therefore, the study has considered such variations while calculating gross margins for each crop in a rotation.

Permanent beds help to improve drainage after rice harvest that improves the chances of growing crops immediately after rice (an opportunity crop). The opportunity cropping not only helps to intercept water present in the upper soil profile but is also an extra source of income. Therefore, the gross margin from an opportunity crop is modified to reflect such changes.

The present value (PV) of the crop gross margin is then calculated in assessing the financial values of the selected rotations. The duration of most of the rice based rotations is up to eight years, therefore the gross margins in years two to eight are discounted back to year 1 values, using a discount rate to reflect the time preference of farmers. The PV of a rotation GM is the sum of the discounted annual gross margins from the crops in the rotation.

The PV is calculated using Equation 1:

n

$$PV = \sum_{t=1} GM_i / (1 + rate)^t \qquad \text{Equation 1}$$

where *rate* is the discount rate (4%, the real discount rate), and GM_1, GM_2, …, GM_t are the gross margins for years 1 to *n*, *n* being the rotation length

The PV of GM different rotations cannot be directly compared if they differ in duration (years). To make them comparable we will compute the PV of an infinite series (PVI) of each rotation using the **Faustman formula**, Equation 2.

$$PVI = PV / \{1-[1/(1+i)^N]\} \qquad \text{Equation 2}$$

where the denominator is the Faustman factor and is one less than the discount factor from a standard discount table (Pearse, 1990 in Elton et al., 1997).

3.14.1.3 Sensitivity analysis

To demonstrate the effect on returns of change of yield of different selected crops and discount rate used, sensitivity analysis was undertaken to give an idea about the sensitivity of these variables on returns.

3.14.2 Financial Benefits to growers

The financial benefits received by the farmers from lateral permanent raised beds vary across the different designs, but include:

- increase in returns from an individual crop / enterprise
    - due to increase in yield
    - reduction in variable input costs
    - reduction in production losses due to improved timeliness of operations
    - water savings which leads to a reduction in variable cost of the water used
    - labour savings
    - machinery costs savings
- shifts in cropping rotations with more profitable cropping options
- improved chances of growing opportunistic crops straight after rice
- income from potential sale of saved water
- savings in overhead and operating costs.

3.14.3 Key Assumptions and data used

The key data and assumptions used in the GM analysis and estimation of the financial value of the potential benefits from the adoption of the permanent raised bed technology are given below.

The impact of new technologies can be spread over many years. In this analysis, the period over which benefits and costs of the proposal are accounted is 20 years; that is, from 2006 to 2025. After 2025, it is anticipated that this technology would be replaced by new technology from future research and development.

All costs and streams of benefits were discounted to the present value. In discounting, all benefits and costs will be expressed in 2006 dollars which requires past expenditures to be converted to real 2006 dollars by the Consumer Price Index and then compounded forward at the discount rate of 4%.

Costs involved in conversion to lateral permanent beds layout from an existing layout with medium slope were considered in the benefit cost analysis.

3.14.3.1 Value of water saved

At the farm level, there are a number of choices concerning any water saved as a result of changes to irrigation design and management that use less water. Farmers may choose to use the water in increasing the area under different crops, or carry over this water to the next irrigation season or sell any water saved. In the evaluations, we assume $50.00/ML as value of the saved water that is the price it could be sold for.

3.14.3.2 Cost of hiring casual labour

A typical rice farmer employs between 6-12 weeks of casual labour to meet peak period whole farm labour requirements. To meet the peak period demand for labour for different farm operations, the farmers hire casual labour from the open market @ $15.00 per hour. The benefits of labour saved will be measured through reduction in the employment of casual labour due to adoption of the PRBs over the other selected layouts.

3.14.3.3 Income from Opportunity cropping

Rice fields are normally ponded for about five months from October to February and any remaining floodwater is drained shortly prior to harvest. Thus soil water content is high after rice, and growing winter crops immediately after rice harvest (OW or "opportunistic wheat") can use the stored soil water, while drying the soil and creating the opportunity to capture and use winter rain instead of losing it to runoff or continued percolation into the groundwater. The chances of success are best where rice crops are sown on time to allow earlier harvest, and in well-drained layouts. The study assumed that the prospects of growing an opportunity crop are 25% on non land formed natural contour, 50% on land formed natural contour and square bays and 75% on permanent raised beds

3.14.3.4 Income from fallow paddock

It is assumed that a farmer earns a gross margin of $34 per hectare (@1 DSE/ha) from sheep grazing natural grasses and weeds in a fallow paddock after the rice phase of the rotation (Geoff Duddy, Pers comm..). This amount will be included as income of the "without opportunistic wheat" rotations when they are evaluated.

3.14.4 Typical rotations considered for raised beds v/s other irrigation designs

Different rice farmers follow different field designs depending upon the level of on-farm development and the crops grown in combination with rice. There is no one rotation suited to every rice-based farm and every field design that is considered in the analysis. Therefore, the study has identified the most typical rotation from each irrigation design that allows a comparison of the financial performance of different rotations under different designs. The details of the crops, cropping rotations and length of each rotation under different irrigation designs are given in Table 3. The study has considered **2 options** in the laser land formed lateral permanent raised beds design which consider two different cropping intensities.

Table 3. Details of the crops, crop sequences and lengths of rotations for selected irrigation field designs

Irrigation design	Rotation analysed	Rotation length (Years)
I. Non land formed natural contour	RRRF(OW)WWPPP	8
II. Laser land formed natural contour	RRRF(OW)WWPPP	8
III. Laser land formed square contour	RRRF(OW)WWPPP	8
IV. Laser landformed square contour alternating with permanent raised beds	RRRFS/BSF	5
Va. Laser land formed lateral PB	RRB/SB/S	4
V b. Laser land formed lateral PB	RRRB/SB/S	5

Note: R- Rice, B- barley, S- soybean, W- wheat, OW- opportunity wheat, F- fallow

Information given in Table 6 shows that after the rice phase, on the square contour with the conventional beds (IV) and lateral permanent beds (Va &Vb) designs, the farmers can grow soybean and barley compared to the wheat and pastures they grow on the non-laser (1) and laser level contour (2 & 3) designs. The length of the rotations on the conventional and the permanent beds design is also much shorter compared to the rotations followed on the other contour based designs. Furthermore, rice with highest gross margins per hectare is grown in three out of five years on beds compared to three out of eight years on the other contour based designs. It has been observed that the non-rice phase of a rotation on beds includes double cropping of soybean and barley whereas on the other rice-pasture based rotations on contour design, in most of the years farmers grow one crop each year. In a rice-pasture based rotation, winter pasture in the last year of the rotation is cultivated in September to allow time to prepare field for sowing rice, resulting in a reduced gross margin in the third year.

To measure crop sequence gross margin from the selected rotations, the gross margins from each crop grown in different rotations under different selected designs were calculated separately for each crop grown in different selected rotations.

3.14.5 Gross margin budgets used in the analysis

The gross margins in Table 4 were calculated using the NSW Department of Primary Industries farm budget handbooks for southern NSW irrigated summer and winter crops (Singh et al., 2005; Singh et al., 2006). The information on crop yields, input use, number of irrigations, and total water used to grow different crops on different layouts is based on the findings of this research project.

Further, the aim of research on lateral permanent beds is to test whether or not the beds technology is technically and financially feasible for adoption in the rice-wheat farming systems in the rice belt in Australia. It is therefore essential to check the data used in the analysis fairly represents farmers' field level data on input use, cultural practices, and machinery costs involved in growing different crops. Therefore, some of the farming practices in these budgets were modified to more closely reflect practices in the local areas according to local agronomists and researchers including Don McCaffery, Mary-Anne Lattimore and Geoff Duddy.

In calculating the gross margins, the study used the following assumptions:

- all rice is medium grain
- Australian Standard Wheat (ASW) was used both as the opportunistic wheat and standard wheat
- sub clover was used as annual pasture
- second cross lambs were considered in this analysis
- output prices used in the GM analysis were the farm gate prices for 2005-06
- the input costs and contract rates of different field operations for growing different crops were based on the 2005-06 market prices
- the machinery costs involved in preparing seedbed for different crops were the variable costs of using own machinery only (no overhead and operating costs are considered in the analysis)
- the study has also measured the crop sequence gross margins from the selected rotations (land use sequences). While measuring gross margins from a rotation without opportunity crop, the study assumes an income of $33/ha from fallow paddock in a without opportunity crop rotation.

Table 4. Gross margins of different enterprises used in the analysis of shifts in cropping rotations possible from changes in irrigation designs in 2005-06

Crop/ enterprise	**Gross margins $/ha of different crops on different irrigation designs**				
	Design I	**Design II**	**Design III**	**Design IV**	**Design V**
1st year rice	1738	1646	1880	1720	2012
2nd year rice	1507	1531	11739	1718	2009
3rd year rice	1528	1497	1704	1669	2009
Opportunity wheat	180	343	447	-	-
1st wheat	105	245	333	-	-
2nd wheat	57	159	232	-	-
1st barley	-	-	-	198	202
2nd barley	-	-	-	197	202
1st soybean	-	-	-	915	927
2nd soybean	-	-	-	784	927
1st pasture	162	229	229	-	-
2nd pasture	133	200	200	-	-
3rd pasture	64	101	101	-	-
Probability of opportunity wheat	0.25	0.50	0.50	0.75	0.75

Source: Singh and Whitworth 2005, Singh and Whitworth, 2006 and Pers. Comm. rice growers, 2005-06. I Non landform natural contour design; II. Landform natural contour design; III. Landform square contour design; IV. Laser landform square contour alternating with permanent raised beds; V. Lateral permanent raise beds

3.14.6 Tractor and machinery used for seed bed preparation

Field preparation for growing rice on natural contour layout needs:

- 1 discing
- 1 scarifying
- 1 land reforming
- 1 rolling.

Field preparation for growing soybean includes:

- 1 deep ripping
- 1 discing
- 1 scarifying
- 1incorporation of beds
- 1 tail drain.

Whereas to prepare seedbed for sowing wheat, it requires:

- 1 discing
- 1 grading
- 2 scarifying
- 1 bank up
- 1 push end operations.

Taking into account the time required for each of these operations, the study has estimated the total tractor hours used in preparing seedbed for different crops on different layouts (Table 5).

Using this information the study has worked out the potential saving of fuel, casual labour and CO_2 released to the atmosphere due to burning of diesel to grow different crops on different layouts from year 2 to 20 years.

3.14.7 Cost of Developing Lateral Permanent Raised Beds

The cost of conversion to PRBs considered in the analysis include; initial cost of survey design, earth works, land forming, top soiling, capital costs, and annual maintenance (reshaping) costs over the life span of the system. The machinery costs for preparing PRBs considered in the analysis were the contract rates charged for different farm operations by the local machinery contractors.

Based on the level / degree of slope of a field, the study has identified three different types of fields under each layout.

1. Fields with a flat slope.
2. Field with a medium slope.
3. Fields with a steep slope.

Table 5. Total tractor use for seedbed preparation for growing crops on different selected layouts

Layout	Rice (hrs/ha)	Soybeans (hrs/ha)	Wheat (hrs/ha)	Barley (hrs/ha)
I. Non landform natural contour	1.90	-	1.27	-
II. Laser landform natural contour	1.90	-	1.27	-
III. Laser landform square contour	1.90	-	1.27	--
IV. Laser landform square contour alternating with raised beds	1.90	1.78	1.27	1.27
V. Permanent beds (from 2nd to	1.18	0.10	0.10	0.26

20th year)	

Note: Estimates of tractor time were based on 195hp tractor used for different field operation.

Working closely with the local land surveyor Mike Naylor and land forming contractor Laurie Barnhill the study has estimated the costs involved in construction of lateral permanent beds from different existing layouts with different degrees of slope (Table 6). The information given in Table 6 shows that the costs involved in construction of lateral permanent beds over an existing field layout varied depending upon the degree of slope of a field and the level of development of an existing field layout. It is more expensive to convert to lateral permanent beds from a grazing field with steep slope as compared to a laser levelled field with a steep slope.

Table 6. Cost of converting to lateral PRBs over an existing layout

		Level of slope		
	Beds in bays over an existing field	**Flat**	**Medium**	**Steep**
1	Grazing field	$1,496	$1,600	$1,690
2	Non land formed natural contour	$1,381	$1,469	$1,553
3	Landformed natural contour	$1,391	$1,417	$1,435
4	Land formed square bays	$1,325	$1,383	$1,325

Note: These estimates are based on personal communication with Mike Naylor and Laurie Barnhill.

3.14.8 Estimation of benefits

3.14.8.1 Water use and labour saved

There is no significant difference in water used for growing rice, wheat, soybean and barley on different field layouts. Therefore there was no saving of labour used for irrigation from crops grown on PRBs compared to crops grown on non landformed and landformed natural contour layouts. But soybean and barley grown on beds does help save human labour used for irrigation operations for growing these crops on layout IV.

It is estimated that permanent raised beds would help save 0.66hrs/ha or $10/ha of labour required for irrigation and $6 per ha from saving of costs involved in siphons that are used for irrigation in layout IV (personal communication P. Stott). Crops grown on PRBs would help save human labour through a reduction in the use of tractor for growing crops on lateral PRBs from year 2-20 (Table 7).

Table 7. Saving of fuel, human labour and CO_2 released in the atmosphere from reduction in the use of tractor for seedbed preparation for growing different crops on selected layouts

Layout	Rice				Wheat /Barley			
	Saving of		labour saved		Saving of		Labour saved	
	Fuel (Lt/ha)	CO^2 (Kg/ha)	(Hrs/ha)	Value ($/ha)	Fuel (Lt/ha)	CO^2 (Kg/ha)	(Hrs/ha)	Value ($/ha)
I	25	50	0.72	$11	42	84	1.17	$18
II	25	50	0.72	$11	42	84	1.17	$18
III	25	50	0.72	$11	42	84	1.17	$18
IV-R	25	50	0.72	$11	42	84	1.17	$16
IV-S	60	120	1.68	$25				

Note: Estimates are based on 36 L/hour fuel consumption of 195hp tractor used for different seedbed preparation

The information on saving of time required for seedbed preparation, diesel used, value of the labour used for growing different crops on different field layouts were derived and are given in Table 7. Growing crops on PRBs would lead to a saving of 25 litre of fuel in rice, 1.17 L/ha in wheat, 1.68 L/ha in soybeans and 1.01 L/ha in Barley (Table 7). The value of savings of these machinery costs have not been considered separately as these cost savings have been considered in developing gross margins of different crops on different field layouts over the study period.

Further, the information given in Table 7 also shows that growing crops on PRBs would also help save tractor operator's labour of $11.00 in rice, $17.00/ha in wheat and $28/ha in Soybean and barley.

4. Results and discussion

4.1 Rice 2002-03

4.1.1 Rice crop establishment

The conventional flat layout saw the establishment of 279 plants per square metre whilst raised bed treatments achieved significantly more (366 to 389) plants per square metre. The drip irrigated treatments established the lowest number of plants (269 plants per square metre) which was not significantly different to that achieved on the flat. The reduced establishment on the drip beds compared to the other bed treatments can be attributed to soil disturbances associated with drip line installation resulting in variable seed placement.

4.1.2 Dry matter production and nitrogen uptake at panicle initiation

Dry matter production at panicle initiation increased with increased N rate for all irrigation treatments (Figure 9).

Dry matter production was highest for the conventional flat treatment at all N rates, whilst there was little difference between any of the bed furrow / bed /drip treatments. NOTE: the conventional flat treatment received all fertiliser N as a pre-permanent flood application, whereas other treatments received N as a 1/3-2/3 permanent flood-panicle initiation split (as per methodology) so the difference in dry matter production at this point was expected.

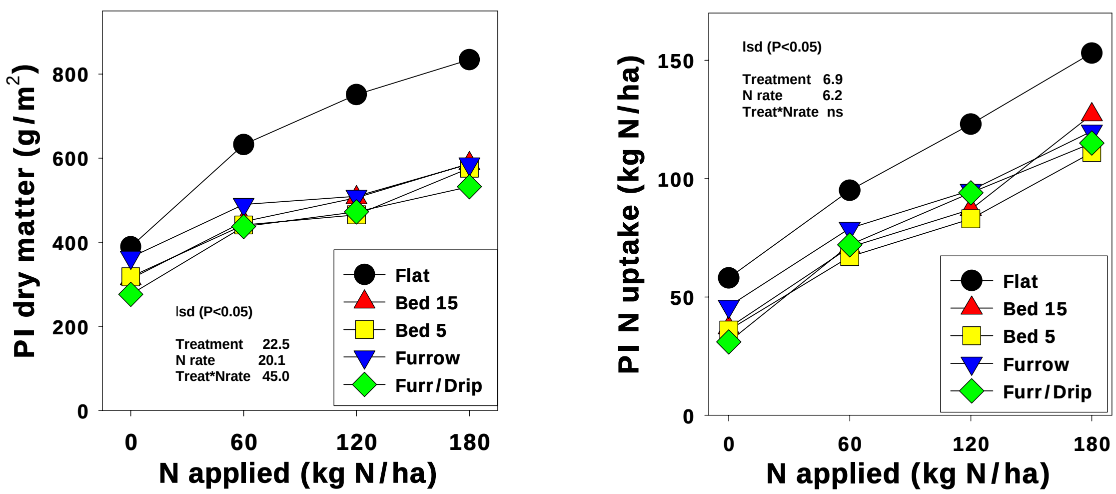


Figure 9. Dry matter production of rice at panicle initiation as influenced by nitrogen application and irrigation method

Figure 10. Nitrogen uptake at panicle initiation, as influenced by nitrogen application and irrigation method

Nitrogen uptake by the rice crop at panicle initiation increased with increasing applied N rate for all irrigation methods and was greatest in the conventional flat treatment at all N rates, (this treatment received all N in a pre-permanent flood application). Nitrogen uptake was varied amongst the bed treatments (Figure 10) with no consistent effect of irrigation treatment.

4.1.3 Dry matter production and nitrogen uptake at anthesis

Dry matter production at anthesis was highest for the conventional flat treatment at all N rates, whilst there was little difference between any of the bed furrow / bed /drip treatments (Figure 11).

Nitrogen uptake by the rice crop at anthesis increased with increasing applied N rate for all irrigation methods and was greatest in the conventional flat treatment at all N rates. Nitrogen uptake was varied amongst the bed treatments (Figure 12) with uptake aligning with depth of irrigation water at the highest nitrogen rate.

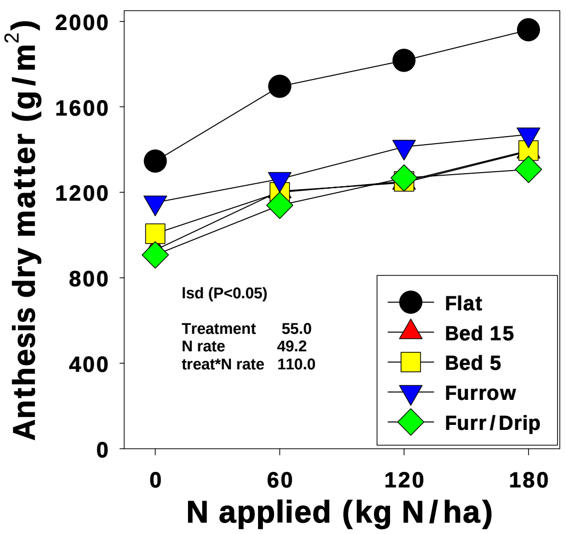


Figure 11. Dry matter production at anthesis, as influenced by nitrogen application and irrigation method

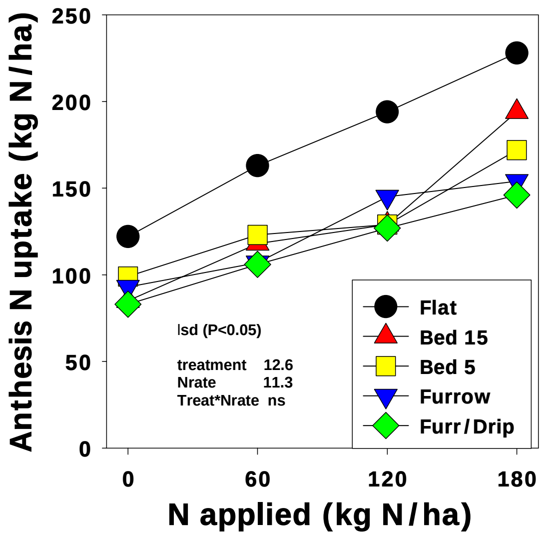


Figure 12. Nitrogen uptake at anthesis, as influenced by nitrogen application and irrigation method

4.1.4 Floret fertility

The percentage of filled florets decreased as nitrogen rate increased (presumably more florets formed with less being filled) and decreased markedly as the depth of water (particularly relevant during early pollen microspore) maintained in the rice bays decreased with different irrigation methods. This effect was accentuated at the higher nitrogen rates (Figure 13).

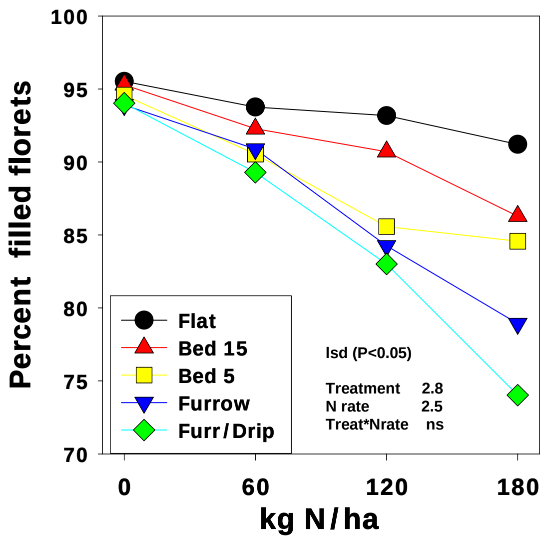


Figure 13. Floret fertility of rice as affected by irrigation method and nitrogen rate in 2002-03

4.1.5 Total dry matter production

The maximum total dry matter production for the rice crop on flat layout, flooded beds, furrow, and sub surface drip irrigated beds was 2805, 2132, 2138 and 1991 g/m^2 respectively. Harvest index of the flooded rice on flat layout, flooded beds, furrow, and sub surface drip irrigated rice was 0.44, 0.43, 0.43 and 0.41, respectively. The rice on flooded bed and furrow irrigated bed treatments, both had a lower total dry matter (24%) than the rice on flat layout. The drip irrigated rice produced both lower total dry matter (29%) than the flat layout and a lower harvest index (5%) than the other bed treatments, resulting in the lowest yield. Significant increases in total dry matter production occurred as fertiliser rates increased (Figure 14).

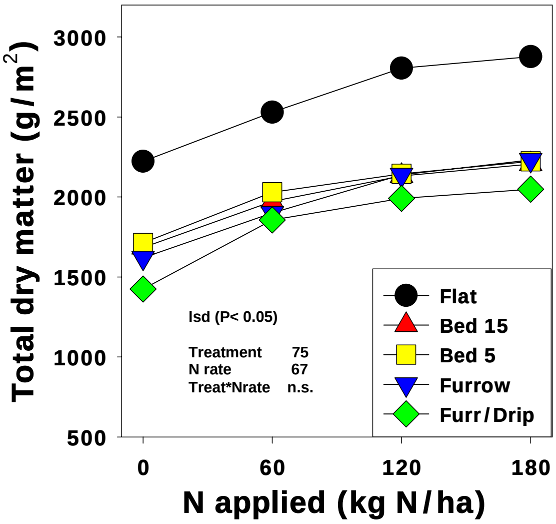


Figure 14. Total dry matter as influenced by nitrogen application and irrigation method

4.1.6 Total nitrogen uptake

Total nitrogen uptake increased with increasing N rate for all irrigation treatments (Figure 15). Nitrogen uptake decreased as the irrigation treatment applied lesser depths and duration of ponded water conditions.

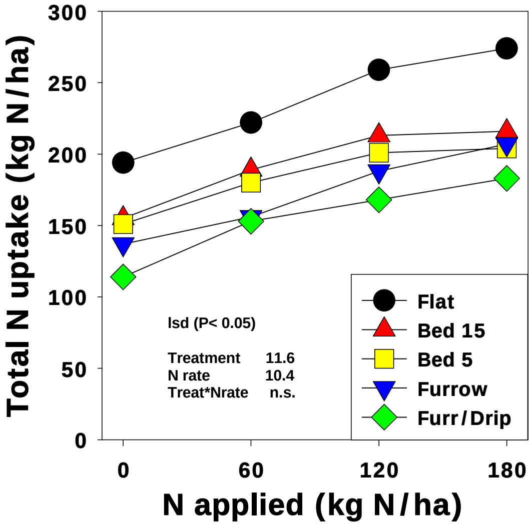


Figure 15. Total nitrogen uptake at panicle initiation, as influenced by nitrogen application and irrigation method

4.1.7 Grain yields

Average grain yields for the flat layout were 13.1 t/ha, which was considerably higher than the 10.7 t/ha achieved on the flooded beds (18 % reduction), 10 t/ha on the furrow irrigated beds (23 % reduction) and 8.7 t/ha on the sub surface drip irrigated beds (33 % reduction) (see Figure 16).

Rice grain yields on the beds were lower than the flat layout primarily because rice was not grown in the furrows in 2002-03. Samples taken from individual rows indicated that the six rows in the centre of the bed produced a similar yield to the rice grown on the flat layout. The outside two rows on each bed produced a higher yield (both more and larger panicles), but not enough to fully compensate for the effect of the furrow space.

Although not statistically significant there was a yield increase with increased nitrogen application up to the 120 kg N/ha rate after which there was a yield decrease in some treatments (furrow, fur/drip and bed 15) whilst no yield decreases were present in the other treatments.

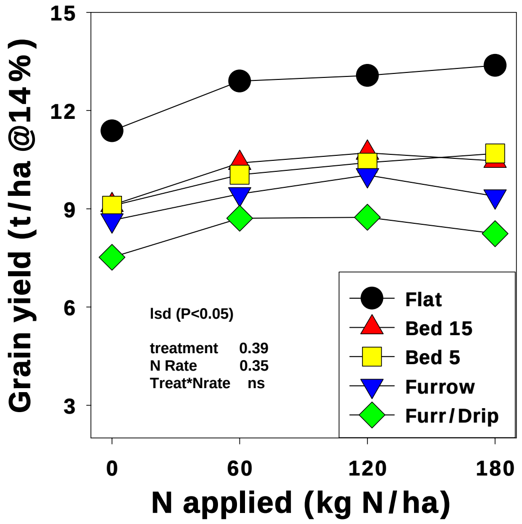


Figure 16. Rice grain yield as influenced by irrigation layout/water management and nitrogen rates in 2002-03

4.1.8 Total water use and water productivity

Total water use for the flooded rice on the flat layout was 18.7 ML/ha, compared with 18.1 ML/ha for flooded beds, 17.2 ML/ha for furrow irrigated and 15.1 ML/ha for sub surface drip irrigated (Figure 17). This equated to water savings of 4% in the flooded beds, 8% in the furrow irrigated beds and 19% in the sub surface drip irrigated beds. These water use figures only include water on (irrigations and rainfall) and off (surface drainage) the rice, and do not take into account soil moisture remaining in the profile at harvest. The soil profile was extremely dry and cracked to depth prior to irrigating the rice crop and approximately an additional 1.8 ML/ha was retained in the profile after harvest compared to pre irrigation situation.

Water productivity was higher in the flooded rice on flat layout than the rice on beds (Figure 18) in this season. Even though the beds required less water, the superior yields in the conventionally grown rice resulted in higher water productivity. Water productivity of the rice on the flat layout was 0.70 t/ML, compared with 0.59 t/ML in the flooded beds, 0.58 t/ML on the furrow irrigated rice and 0.58 t/ML on the drip irrigated rice.

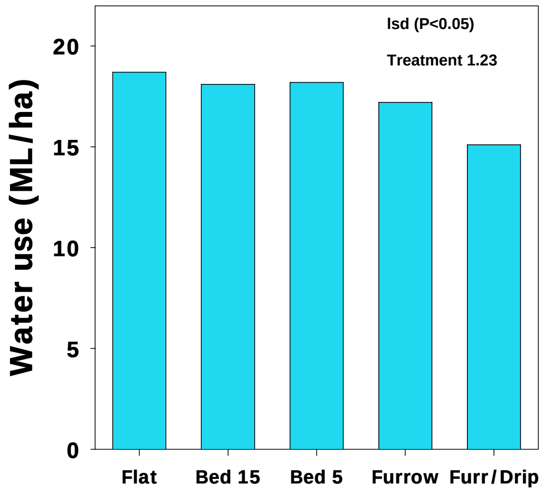


Figure 17. Water use of rice grown using a range of irrigation methods/ strategies

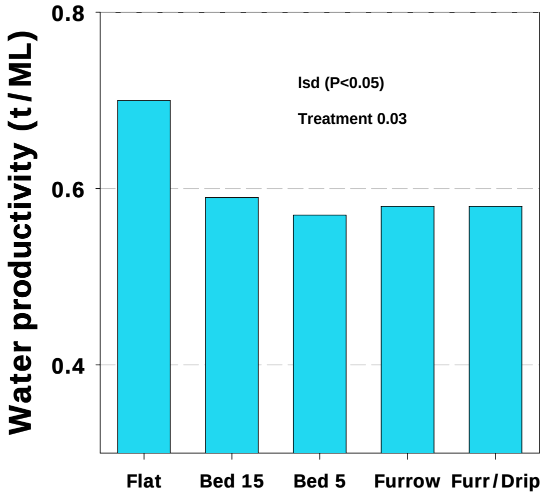


Figure 18. Water productivity of rice grown using a range of irrigation methods/strategies in 2002-03

4.2 Wheat/Barley 2003

4.2.1 Establishment

The twin disc seeder (Figure 7) used did not achieve adequate seed depth in untilled conditions and could not sow seed into the bed shoulders and furrows. Establishment on the shoulder of the beds and in the furrow was poor and variable. Lack of rain after sowing compounded the difficult conditions encountered during establishment. The delayed germination and establishment reduced the yield potential of both wheat and barley. Apart from a total of about 5mm of rainfall around 1 June, there was no rainfall until late June / early July. The plant establishment numbers (Figure 19) were well below that desired; Lacy (2006) suggests 150-200 plants per square metre.

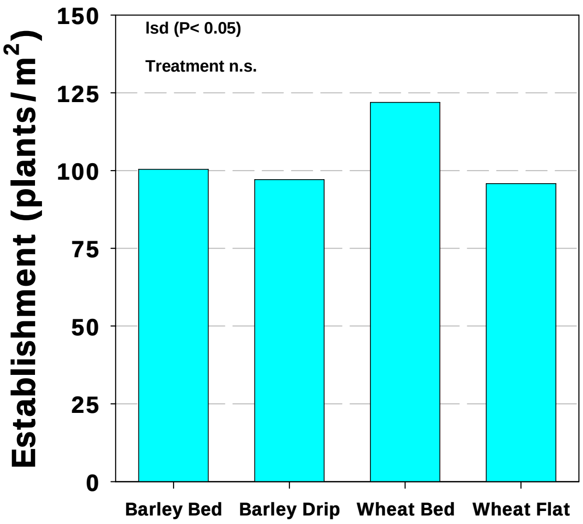


Figure 19. Establishment of barley and wheat on raised bed and flat treatments

4.2.2 Dry matter production at anthesis and at physiological maturity

There was a significant dry matter increase due to nitrogen applications in all crop/ irrigation treatments (Figure 20). There was no interaction between irrigation methods and nitrogen rates. There was no difference in dry matter production between either beds and flat for wheat or between bed (furrow) and drip for barley. This is not surprising given that no irrigations were possible until 18 September whilst anthesis occurred between the 5 September (wheat) and 10 September (barley). Crop growth was occurring in response to minor rainfall and stored soil moisture following the prior rice crop.

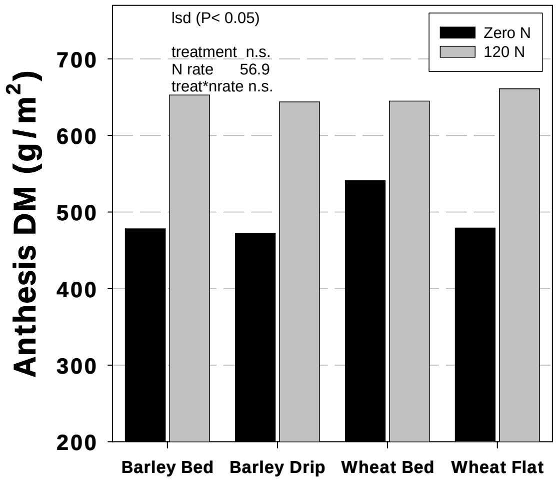


Figure 20. Anthesis dry matter production of barley and wheat grown using different fertiliser and irrigation methods

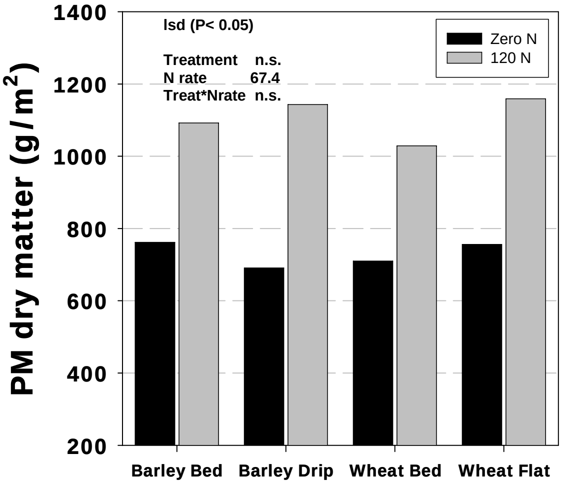


Figure 21. Total dry matter production of wheat and barley as influenced by fertiliser application and irrigation treatment

At physiological maturity (Figure 21) fertilised treatments produced greater than 1000 g per square metre with no significant difference between irrigation methods/layouts or between wheat and barley. Barley on beds had the lowest production. Unfertilised treatments produced 60–70% of the dry matter production of fertilised treatments.

4.2.3 Grain yield

Grain yields for both barley and wheat ranged from 4.8 to 5.4 t/ha (Figure 22). Yields of wheat on beds and flat were similar (4.8–5.0 t/ha), but the yield on beds was disadvantaged by lack of suitable machinery for sowing the bed shoulders/furrows. Yields of barley with furrow and subsurface drip irrigation on beds were also similar (5.3–5.4 t/ha), and were slightly higher than yield of wheat. Wheat and barley yields were reduced compared to expectations due to poor plant establishment in all treatments (Figure 18). Wheat yield were impacted by the occurrence of stripe rust and although aerially sprayed twice using Tilt which gave good control, yields were still below expected levels.

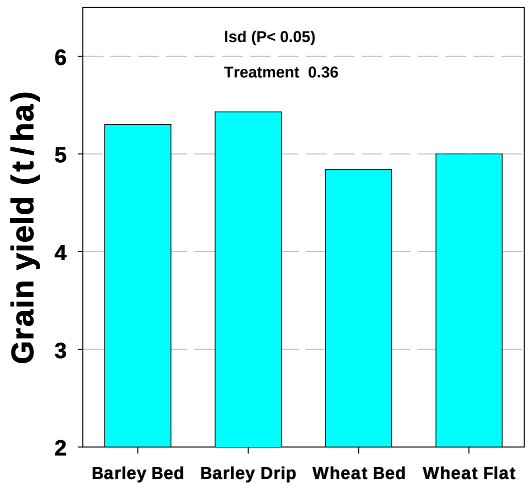
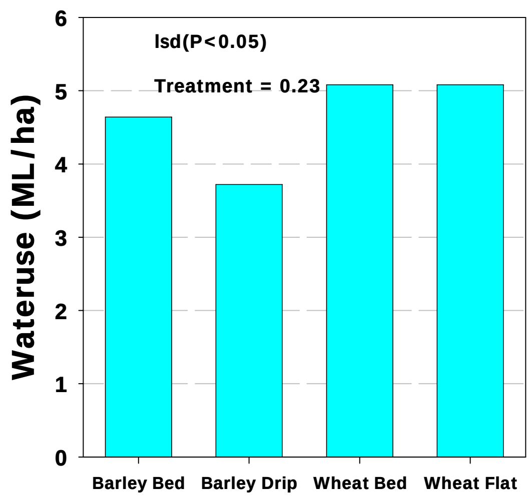


Figure 22. Grain yield of barley and wheat as influenced by irrigation method where 120 kg N/ha was applied

4.2.4 Water use and water productivity

The barley drip treatment had a significantly lower water use than the other irrigation treatments (Figure 23) and consequently higher water productivity (Figure 24).



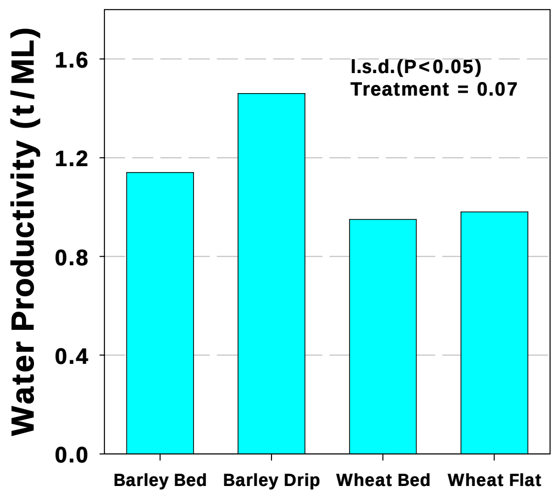


Figure 23. Water use of barley and wheat grown using different irrigation methods

Figure 24. Water productivity of barley and wheat grown using different irrigation methods

4.3 Rice 2003-04

4.3.1 Plant establishment

Plant establishment was less than desired, with only 95-96 plants per square metre being present in drip and furrow irrigated bed treatments. Establishment on the shoulder of the beds and in the furrow was poor due to deep seed placement in our attempt to direct drill both beds and bed shoulders with the Barton disc openers. The machine was very heavy and depth control of seed placement was an issue.

4.3.2 Dry matter production at panicle initiation

Dry matter production at PI (Figure 25) was significant less than would be necessary to produce an acceptable crop yield. Even on the fertilised plots, dry matter production was only 300 g/m^2. This was substantially less dry matter production than at the same time last rice season. Nitrogen uptake at panicle initiation (Figure 26) was only 40-50 kg N/ha on the fertilised treatments, substantially less than the desired 100+ kg N/ha uptake at this growth stage.

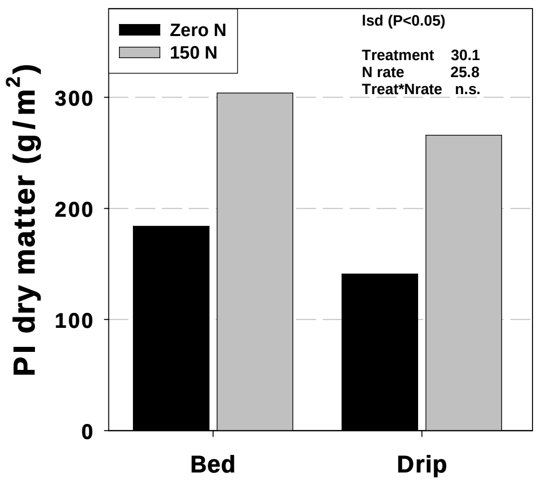


Figure 25. Effect of irrigation method and fertiliser management on dry matter production at panicle initiation 2003-04

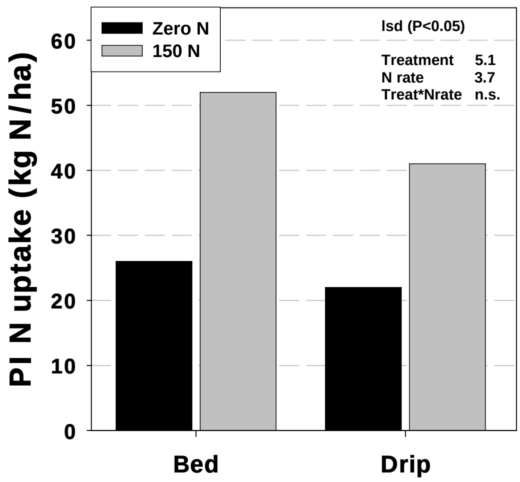


Figure 26. Nitrogen uptake at panicle initiation as affected by irrigation method and fertiliser management

4.3.3 Anthesis dry matter and anthesis N uptake

The application of an additional 100 kg N/ha topdressed as urea at PI led to significant increases above the non topdressed treatments in dry matter production (Figure 27) and N uptake (Figure 28) at anthesis.

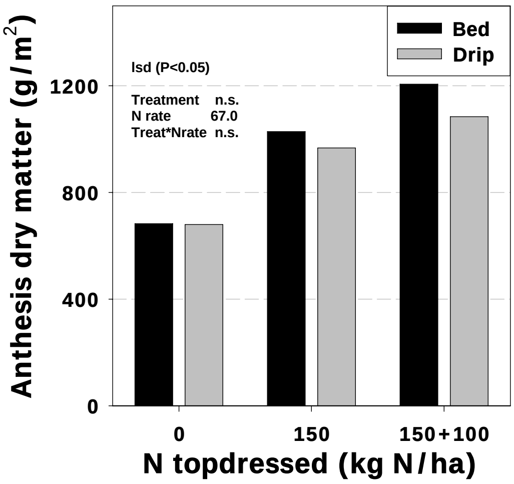


Figure 27. Anthesis dry matter production as affected by irrigation method and fertiliser management

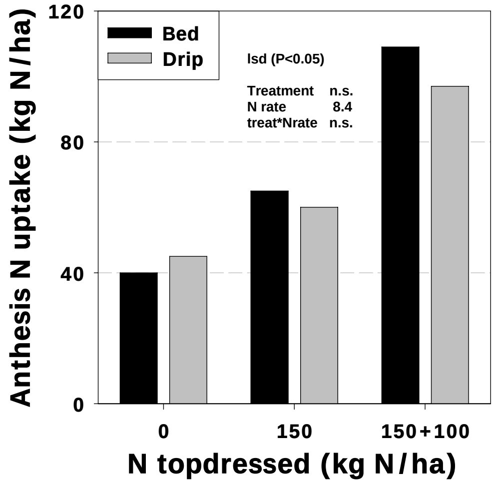


Figure 28. Anthesis nitrogen uptake as affected by irrigation method and fertiliser management

4.3.4 Total dry matter production and total nitrogen uptake

Total dry matter production for the rice on the furrow, and sub surface drip irrigated beds was 1860 and 1872 g/m^2, respectively with 250 kg/ha of applied N (Figure 29). There was no significant difference in total dry matter production between drip and furrow irrigated treatments. Even at this level of fertiliser application, dry matter production was reduced some 35% compared to the previous season.

Harvest index of the rice was 0.41 on both bed (furrow) and sub surface drip irrigated rice.

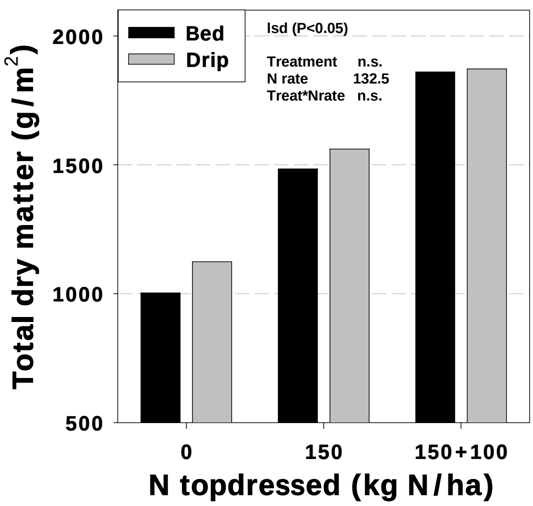


Figure 29. Total dry matter production as affected by irrigation method and fertiliser management

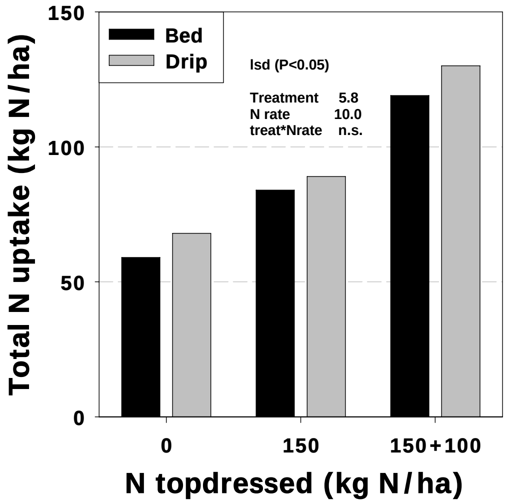


Figure 30. Total nitrogen uptake affected by irrigation method and fertiliser management

Total nitrogen uptake was significantly depressed compared to the previous season where 120 and 140 kg N/ha accumulated on drip and furrow irrigated treatments at zero topdressed N and where 160 and 180 kg N/ha accumulated on drip and furrow irrigated treatments at 120 topdressed N, as roughly comparable fertiliser applications. Total N uptake at the highest rate, this season did not exceed 140 kg N/ha (Figure 30). The combination of poor establishment and nitrogen losses from the permanent flood applied urea due to the intermittent flooding, contributed to the reduced plant growth and nitrogen uptake.

4.3.5 Floret fertility

Floret fertility tended to decrease with increasing nitrogen rate. The level of floret fertility, approximately 70 % for the fertilised treatments, was lower than that recorded in the previous rice growing season (compare Figure 31 to Figure 13). Given that both irrigation treatments in this season did not have ponded water for cold temperature protection during the early pollen microspore period and that cold temperatures **did** occur during this period, the level of fertility achieved is as expected.

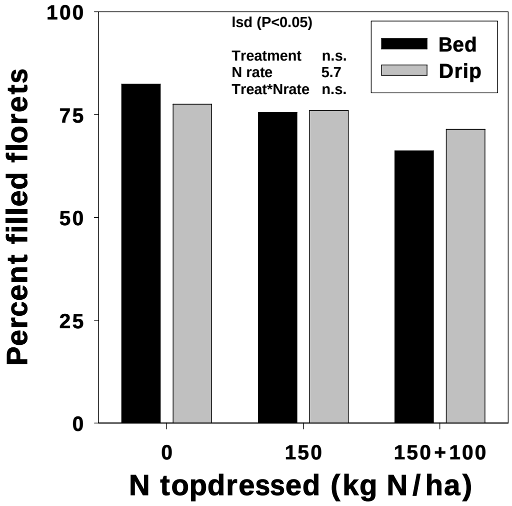


Figure 31. Floret fertility as affected by irrigation method and fertiliser management in 2003-04

4.3.6 Grain yield

Yields achieved were up to 8.1 t/ha on the PI fertilised subplots (Figure 32), below, but approaching the 2003-04 CIA average district yield (8.3 t/ha) for the variety Quest. The CIA commercial crops were grown under conventional aerial sown conditions, having continuously ponded conditions and deep water after panicle initiation protecting the florets from cold temperatures during the early pollen microspore period.

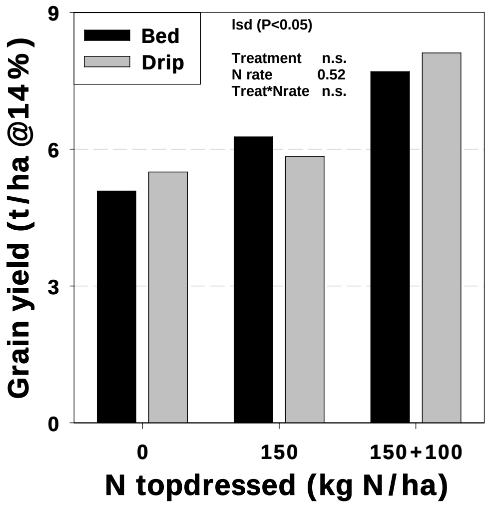


Figure 32. Grain yield as influenced by irrigation method and fertiliser applications in 2003-04

Rice yields were in line with expectations, given the decision **not** to apply deep permanent water during the rice growing season which proved unfavourable to the growth/yield of rice under the applied treatments. Cold temperature damage at EPM reduced grain yield due to the increased occurrence of unfilled florets (Figure 31) compared to the 2000-03 season. The rice yields were also reduced by the poor initial plant stand due to deep seed placement in our attempt to direct drill both beds and bed shoulders with the Barton disc openers. The intermittent flooding possibly caused a loss of applied nitrogen by ammonia volatilization from urea surface applied at permanent flood (150 kg N/ha) along with problems with Dirty Dora in the crop (control issues due to the adjacent soybean crops).

Further nitrogen (100 kg N/ha) was applied to sub plots in both furrow and drip irrigated treatments at panicle initiation following NIR N tissue testing. This application resulted in a significant increase in grain yield of both irrigation treatments.

4.3.7 Total water use and water productivity

Furrow irrigated rice used 13.6 ML/ha, and subsurface drip irrigated rice, which was irrigated at about 1.1 x ETo (1299 mm) used 14.3 ML/ha. Water productivity was similar to the previous season for furrow and drip irrigated treatments, although as indicated, yields were lower but so was water use (Table 8).

Table 8. Total water use and water productivity for the 2003-04 rice crop

Treatment	N rate	Water use ML/ha	Water Productivity t/ML
Furrow	150+100	13.7	0.57
Drip	150+100	14.3	0.57
l.s.d.		n.s.	n.s.

4.4 Soybeans 2003-04

The soybeans grew well although a little variable in places, due possibly to variation in nodulation as the field had never previously grown soybeans. Plant establishment was quite acceptable (Table 9) There was no significant difference between the irrigation treatments in dry matter production at R5 or physiological maturity (Table 9).

Soybean yields were satisfactory with furrow and subsurface drip treatments yielding 3.68 and 3.05 t/ha, respectively (Table 9). There was, however a significant yield advantage in favour of the furrow irrigated treatment compared to the drip treatment. Similarly furrow irrigated soybeans had a significantly greater 100 seed weight compared to drip irrigated treatment.

Table 9. Establishment, growth, grain yield, 100 seed weight, total water use, and water productivity (WP) of soybeans using different irrigation treatments 2003-04

Treatment	**Estab.** Plant/m^2	**R5 DM** g/m^2	**PM DM** g/m^2	**Yield** t/ha	**100 seed** wt. (g)	**Wateruse** ML/ha	**WP** t/ML
Drip	33.2	360	637	3.05	15.3	5.6	0.54
Furrow	33.4	443	693	3.68	18.7	9.5	0.39
l.s.d.	n.s.	n.s.	n.s.	0.23	2.0	1.3	0.10

These values do not take into account soil moisture remaining in the profile at harvest. This may vary water use and WP proportionately.

The irrigation treatments showed large differences in water use between furrow irrigated (9.5 ML/ha) and subsurface drip irrigation (5.6 ML/ha). Water productivity thus varied across irrigation treatments with 0.39 t/ML and 0.54 t/ML for furrow and sub surface drip, respectively. Although yields for drip irrigated plots were acceptable we consider that irrigation was prematurely finished (as result of pumping failure) when looking at the soil moisture profiles.

4.5 Wheat and barley 2004

Sowing on the 13 May was followed by a germinating rainfall (around 24 May 2004) which allowed excellent wheat and barley plant establishment being 166–196 and 125–130 plants/m^2 respectively (Figure 33). This set the opportunity for a high potential yield of both the wheat and barley. The Chara wheat was infected by stripe rust and was aerially sprayed once using Tilt® which gave good control.

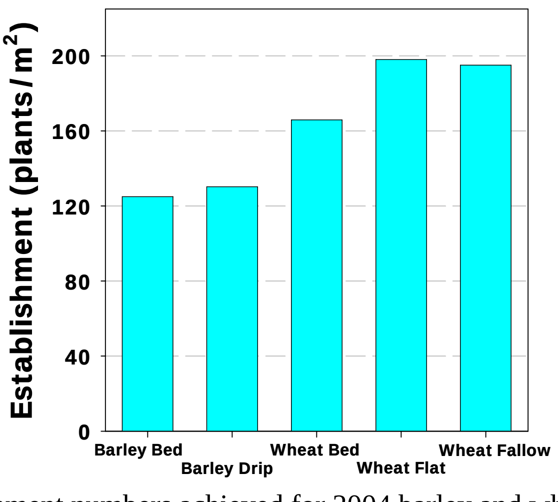


Figure 33. Plant establishment numbers achieved for 2004 barley and wheat crops

4.5.1 Dry matter production at anthesis and physiological maturity

Barley and wheat dry matter increased significantly at anthesis and physiological maturity in response to nitrogen fertiliser.

At anthesis wheat grown following rice then wheat on beds or on the flat produced more dry matter than wheat following a rice fallow sequence. Barley grown following furrow irrigated soybeans had greater dry matter production than barley following drip irrigated soybeans (Figure 34). The increased production by these treatments probably reflects higher residual soil moisture levels of those treatments where in season rainfall contributed only 115mm prior to anthesis.

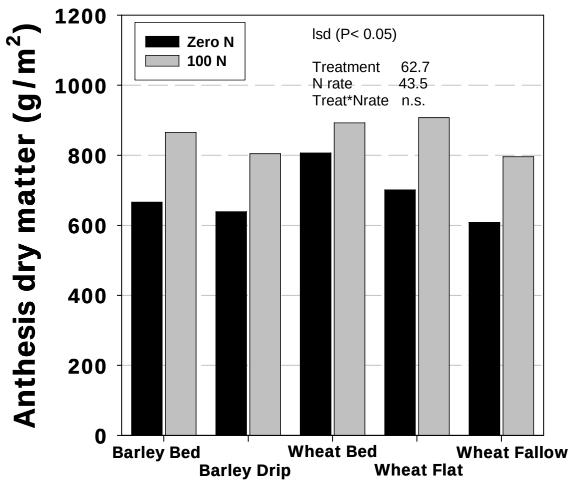


Figure 34. Dry matter production at anthesis of barley and wheat crops as affected by fertiliser management and irrigation method during 2004

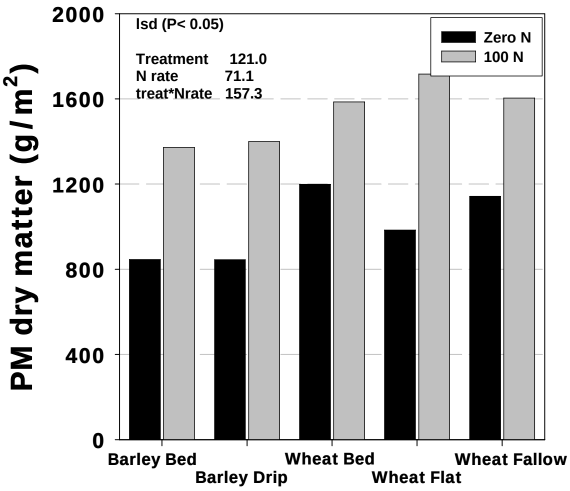


Figure 35. Dry matter production at physiological maturity of barley and wheat crops during 2004

Dry matter production at physiological maturity showed a significant response to nitrogen application for barley and wheat (Figure 35). There was no significant difference in dry matter production between furrow and drip irrigated barley treatments following four spring irrigations. There was also no significant difference in dry matter production between the three wheat treatments.

4.5.2 Grain yield

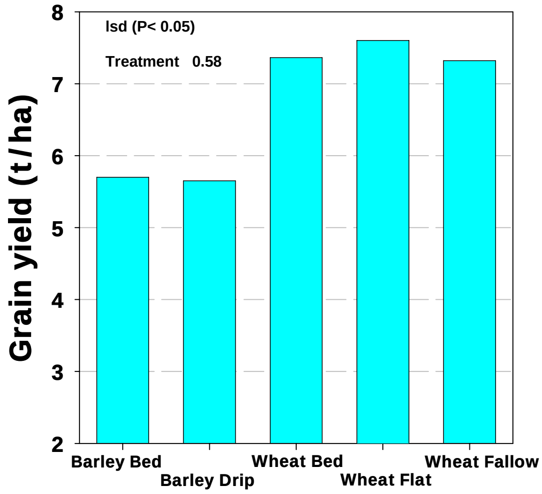


Figure 36. Wheat and barley harvest grain yield for 2004 at 100 kg/ha applied nitrogen

Yields of wheat (Figure 36) on beds and flat were similar (7.32–7.60 t/ha), reflecting in part the drought conditions reducing the incidence of waterlogged conditions on the flat treatments. There was no significant difference in wheat yield between the irrigation layout treatments. Yields of the barley treatments with furrow and subsurface drip irrigation on beds were also not significantly different.

4.5.3 Water use and water productivity

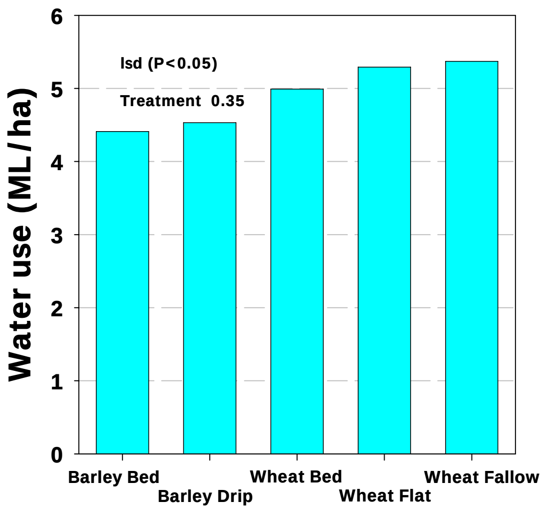


Figure 37. Water use for 2004 barley and wheat crops (irrigation and rainfall)[1]

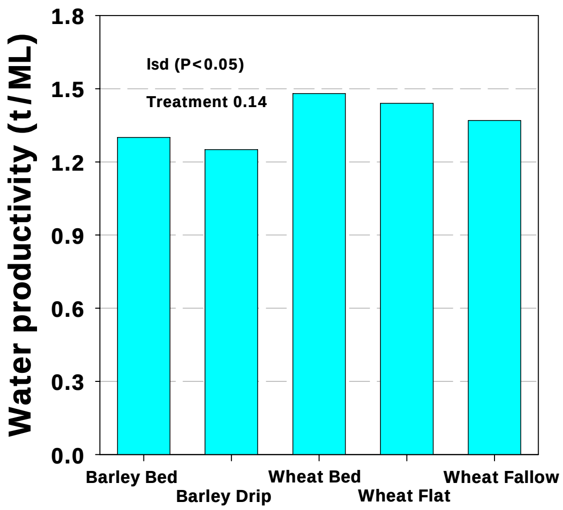


Figure 38. Water productivity for 2004 barley and wheat crops (irrigation and rainfall)[1]

[1] Water Productivity (WP). These values do not take into account soil moisture remaining in the profile at harvest. This may decrease water use and increase WP proportionately

The wheat treatments have a significantly higher water use than the barley treatments due to an extra irrigation (Figure 37). The wheat treatments have a significantly higher water productivity result (Figure 38) than the barley because of higher grain yields regardless of irrigation / layout treatments.

4.6 Rice 2004-05

4.6.1 Establishment

The rice establishment achieved using the Stubble King seeder direct drilling into both beds and bed shoulders was excellent in all treatments, being on average 236 and 224 plants per square metre on the furrow irrigated beds and drip irrigated beds, respectively.

4.6.2 Dry matter production and nitrogen uptake at panicle initiation

At panicle initiation there was a significant response in both dry matter production (Figure 39) and nitrogen uptake (Figure 40) to fertiliser application. There was no significant difference in dry matter production or nitrogen uptake between the irrigation methods. Nitrogen uptake at panicle initiation was less than recommended to achieve high grain yields (less than 100 kg N/ha for furrow irrigated treatments and less than 85 kg N/ha for the drip irrigated treatment).

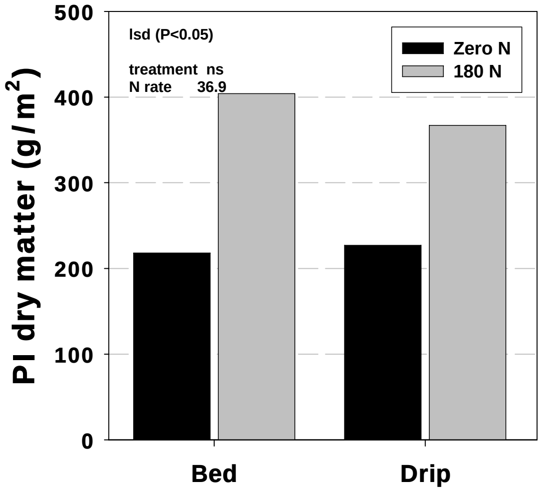


Figure 39. Dry matter production at panicle initiation as affected by irrigation method and fertiliser management

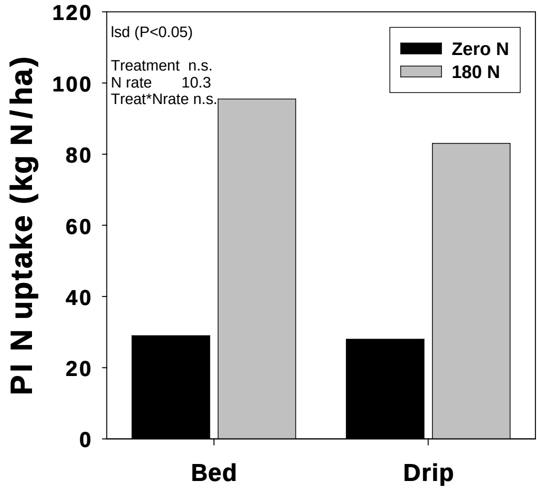


Figure 40. Nitrogen uptake at panicle initiation as affected by irrigation method and fertiliser management

4.6.3 Dry matter production and nitrogen uptake at anthesis

At anthesis there was no difference in dry matter production due to irrigation method whilst there was a significant response to fertiliser (Figure 41). Nitrogen uptake was significantly higher on the bed/furrow irrigated treatment than on the drip irrigated treatment (Figure 42).

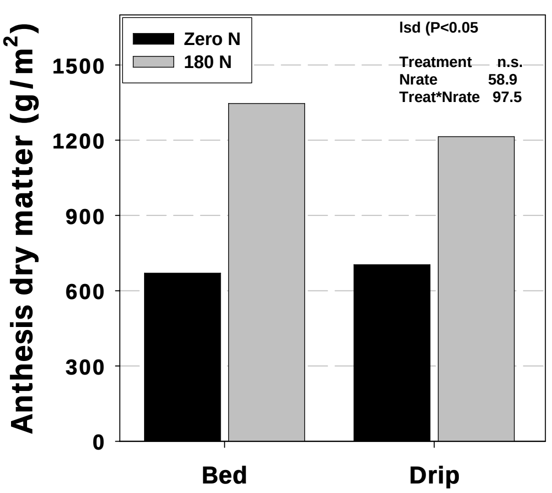


Figure 41. Dry matter production at anthesis as affected by irrigation method and fertiliser management

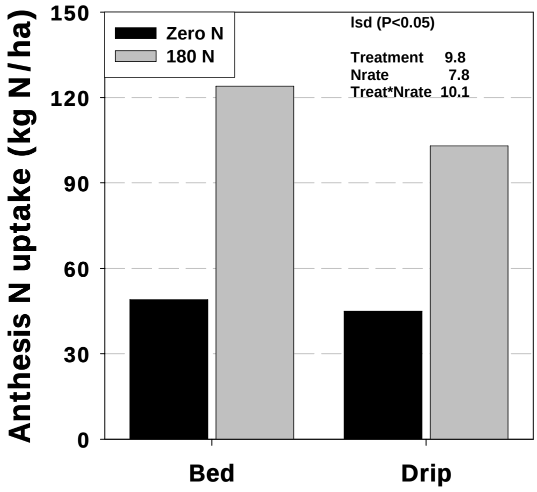


Figure 42. Nitrogen uptake at anthesis as affected by irrigation method and fertiliser management

4.6.4 Dry matter production and nitrogen uptake at physiological maturity

At physiological maturity there was a significant difference in dry matter production due to irrigation method and a significant response to fertiliser (Figure 43). The dry matter production of both irrigation treatments was in the range 15-17 t/ha much less than would allow a high grain yield. Nitrogen uptake (Figure 44) was significantly higher on the bed/furrow irrigated treatment than on the drip irrigated treatment although the level of uptake was relatively poor.

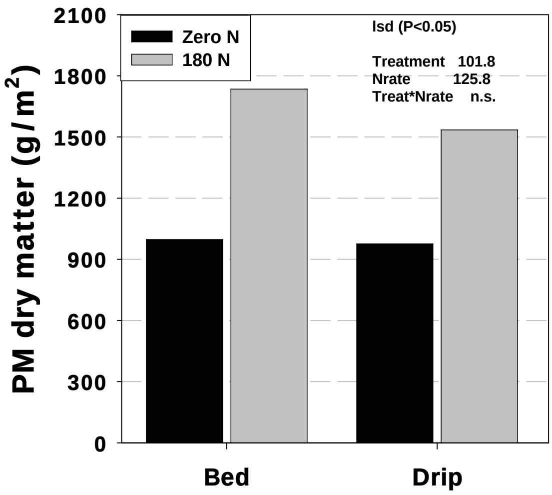


Figure 43. Total dry matter production as affected by irrigation method and fertiliser management

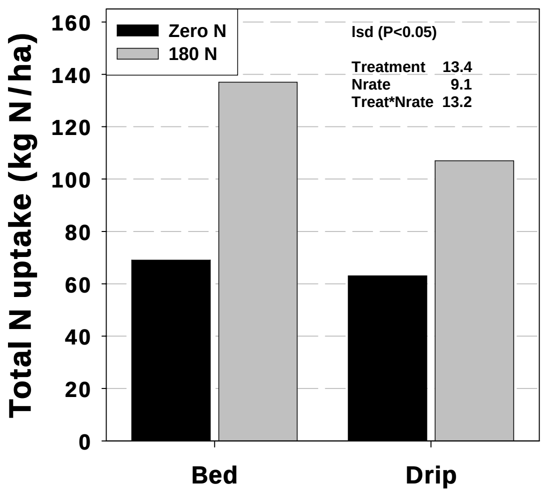


Figure 44. Total nitrogen uptake as affected by irrigation method and fertiliser management

4.6.5 Floret fertility

Floret fertility of both furrow and drip irrigation treatments was substantially reduced from the levels observed in the two previous seasons. In the 2002-03 season, floret fertility for the furrow and drip treatments was in the order of 80 and 75 %, respectively, whilst in 2003-04, the floret fertility was approximately 75 % for both furrow and drip treatments. The floret fertility level of the fertilised drip treatment in 2004-05 where no deep water through EPM was applied was less than 40 %, whilst the furrow treatment was about 60 % for the fertilised treatment (Figure 45).

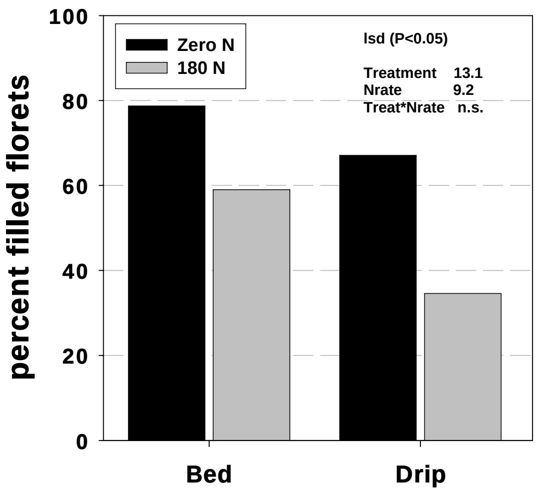


Figure 45. The effect of irrigation method and nitrogen application levels on floret fertility in 2004-05

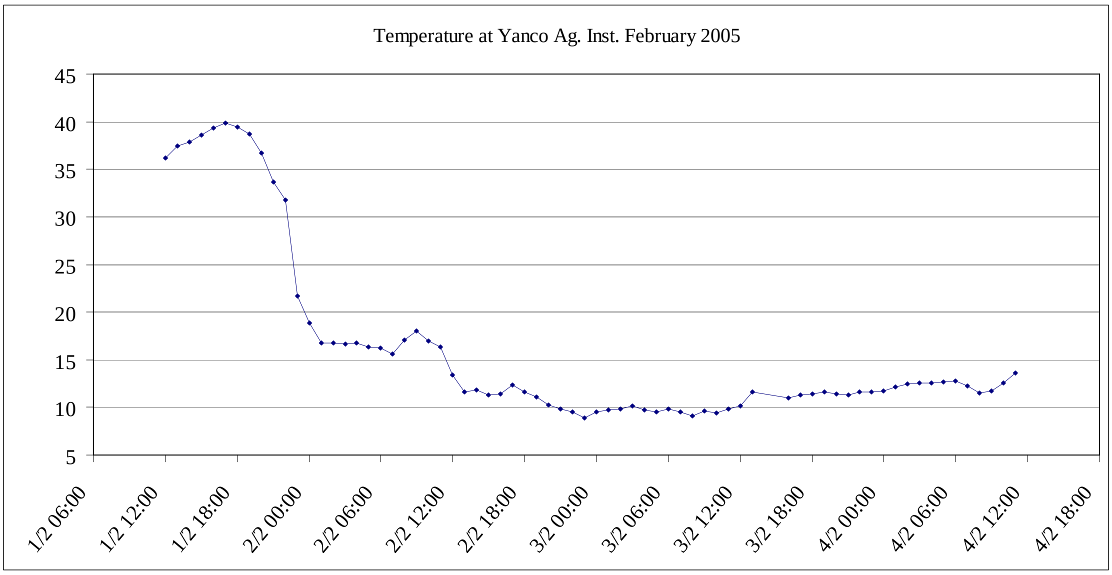


Figure 46. Air temperature at Yanco Agricultural Institute 1–4 February 2005

Ambient air temperatures during the early pollen microspore period for the 2004-05 rice season fell from 40^{o} C to 17^{o} C over about nine hours and then remained below 15^{o}C for more than 48 hours (Figure 46). Temperatures below 19^{o} C can reduce floret fertility and ultimate grain yields (Beecher et al., 2004). Thus low air temperatures during the early pollen microspore period had a devastating impact of grain yields.

4.6.6 Grain yield

Yields achieved were up to 6.1 t/ha on the subplots fertilised at PI, higher than the 2004–05 CIA average district yield (5.7 t/ha) for cv. Quest grown under conventional aerial sown rice conditions (continuous ponding and deep water after PI). For the drip irrigated plots without deep water at EPM the grain yield outcome was disastrous less than 4 t/ha (Figure 47).

Rice yields were severely reduced by the cold temperatures experienced during the first week of February 2005 (see Figure 46). Cold temperature damage at EPM was indicated by the presence of unfilled florets (more than 60% for the drip treatment) (Figure 45).

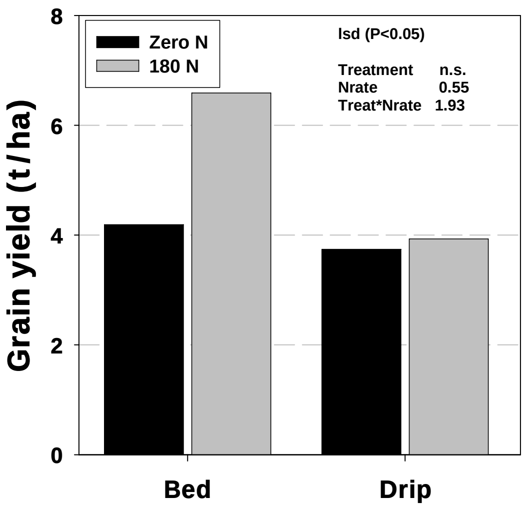


Figure 47. Grain yield as affected by irrigation method and fertiliser management 2004-05

4.6.7 Water use

Irrigation water delivery measurements were confounded by leaking banks which made maintaining deep water through EPM a major issue. Leaking banks were caused by presence of yabbies, mice and mole crickets. Consequently no water use or water productivity data is presented for rice during this season.

4.7 Soybeans 2004-05

The soybeans established well although a little variable in places and plant establishment was quite acceptable (Table 10). There was a significant difference between the irrigation treatments in dry matter production at physiological maturity with the drip treatment being greater than the furrow treatment (Table 10).

Soybean yields were satisfactory with both furrow and subsurface drip treatments yielding 3.08 and 3.32 t/ha, respectively (Table 10). There was a significant yield advantage in favour of the drip irrigated treatment, compared to the furrow irrigated treatment.

Table 10. Establishment, growth, grain yield, harvest index, total water use, and water productivity (WP) of soybeans using different irrigation treatments 2004-05

Treatment	**Estab.** Plant/m^2	**R5 DM** g/m^2	**PM DM** g/m^2	**Yield** t/ha	**HI**	**Wateruse** ML/ha	**WP** t/ML
Drip	31	554	666	3.32	0.53	5.6	0.59
Furrow	25	527	561	3.08	0.56	5.7	0.54
l.s.d.	n.s.	n.s.	45	0.23	n.s.	n.s	n.s.

These values do not take into account soil moisture remaining in the profile at harvest. This would vary water use and WP proportionately.

Water use was similar for furrow irrigated (5.7 ML/ha) and sub surface drip irrigated (5.6 ML/ha) treatments. Water productivity across irrigation treatments was 0.54 t/ML and 0.59 t/ML for furrow and sub surface drip irrigated soybeans, respectively. This reflected improved scheduling of the furrow irrigation treatment from the previous season and a similar result in both years for the sub surface drip irrigated treatment.

4.8 Wheat 2005

4.8.1 Establishment

Plant establishment was excellent with no difference between irrigation layouts (Figure 48).

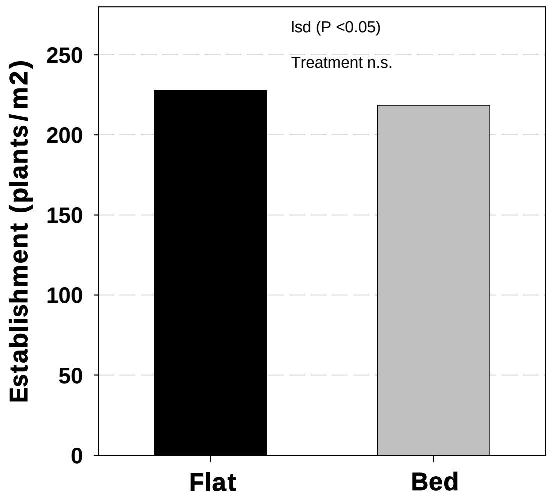


Figure 48. Effect of irrigation layout on wheat crop establishment 2005

4.8.2 Dry matter production at anthesis and physiological maturity

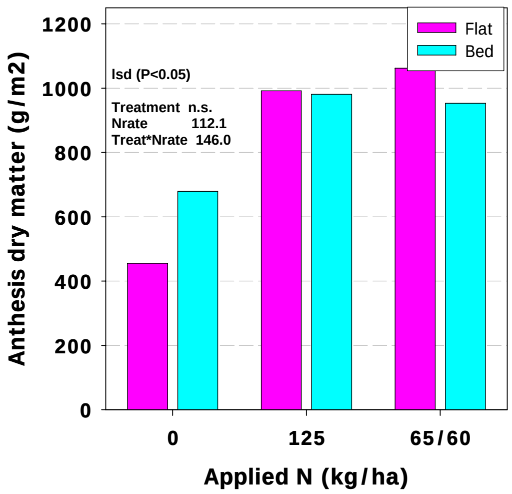


Figure 49. Effect of irrigation layout and fertiliser management on dry matter production at anthesis

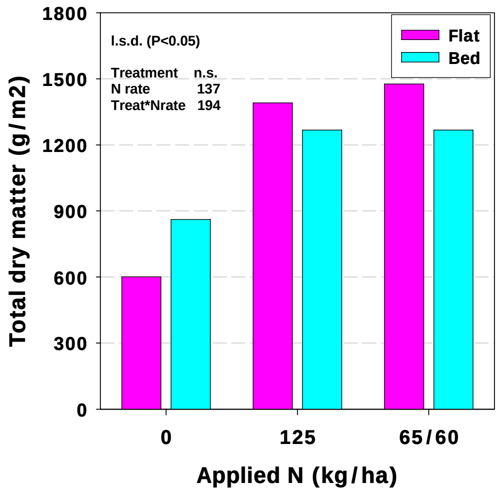


Figure 50. Effect of irrigation layout and fertiliser management on total dry matter production at PM

Dry matter production (Figure 49) at anthesis was significantly higher in the bed than the flat irrigation layout treatment when no nitrogen was applied, when nitrogen was applied there was no difference between irrigation layout treatments. At physiological maturity the dry matter production for the beds was again higher than the flat irrigation layout treatment when no nitrogen was applied, but for the split nitrogen treatment the flat layout produced significantly more dry matter than the bed irrigation layout (Figure 50). There was a significant response to fertiliser application at anthesis and physiological maturity.

4.8.3 Grain yields from quadrat and header harvest

Harvester grain yields were higher than the grain yields measured by quadrat harvests due to grain loss from the stationary thrasher used to process the hand cut samples (Figure 51 and 52). Although the Flat treatments yielded the highest, there was no significant difference in grain yield between the treatments. Harvest grain yield was 6.8 and 6.5 t/ha for the split and single N topdressing treatments respectively on the flat layout and 6.04 and 6.15 t/ha respectively on the beds (Figure 52).

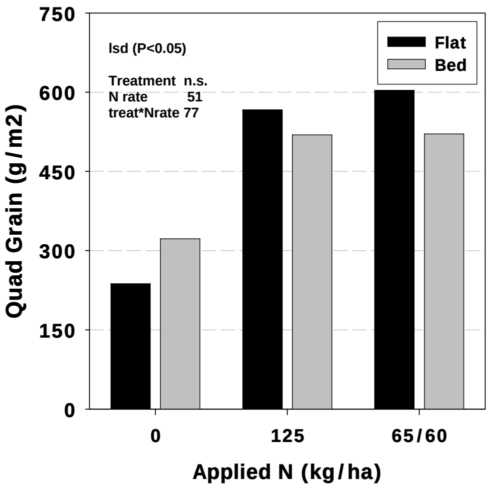


Figure 51. Effect of irrigation layout and fertiliser management on quadrat grain yield

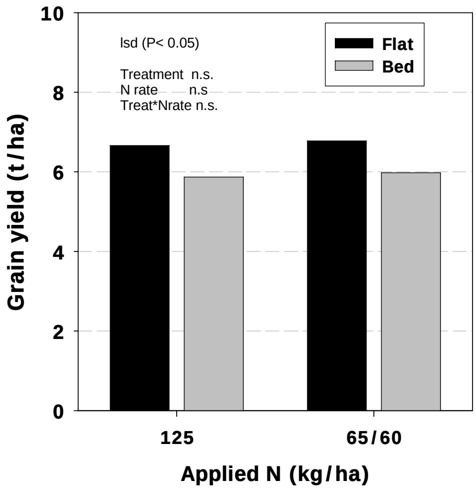


Figure 52. Effect of irrigation layout and fertiliser management on harvested grain yield

Although during irrigations, water was ponded on the flat treatments for approximately 24 hours to simulate commercial field conditions, the yields were higher (though not significantly) on the flat than on the raised beds. The split application of nitrogen did not produce a significant increase in yield above the single application (Figure 52).

Given that the crop was well watered out the final yields on both the flat and on the raised beds were disappointing compared to yields achieved in the previous season. Yield may have been constrained by: sowing date being delayed later than the recommended sowing date for high yielding (8 t/ha) crops, and possibly the impact of high temperatures during grain fill. Flowering did not occur till 19 October which led to higher temperatures during grain filling. Summation of solar radiation from head emergence to the end of grain fill indicated that compared to the 2004 season, the duration of grain fill was nine days less, suggesting the shortened grain filling period contributed to the less than expected yield. Stripe rust was present but timely applications of fungicide limited its spread and it should not have contributed to a reduction in yield.

4.8.4 Water use and water productivity

The flat irrigation treatment used significantly more water than the bed treatment (Figure 53), however, the higher water use was due in some part to the extended ponding period (24 hours) applied to this treatment (this may have also contributed to the higher yield on this treatment). The higher yield of the flat treatment negated its higher water use resulting in the water productivity being similar for the flat and bed treatments (Figure 54).

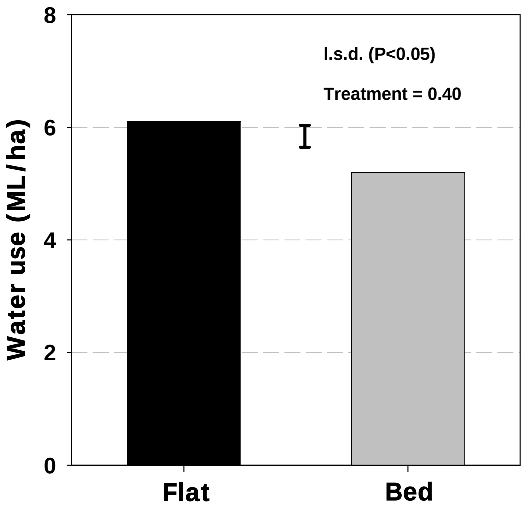


Figure 53. Effect of irrigation layout on water use

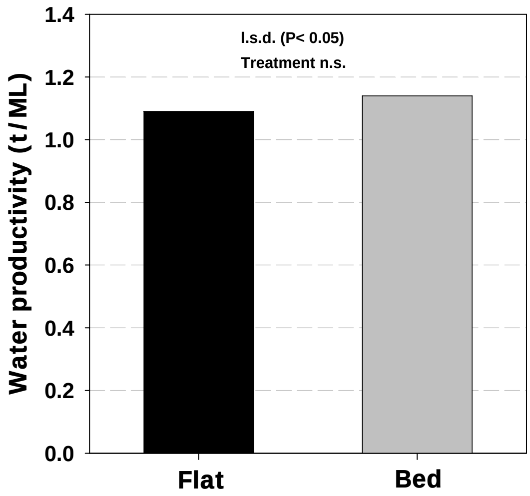


Figure 54. Effect of irrigation layout on water productivity

4.9 Rice 2005-06

4.9.1 Establishment

Plant establishment counts indicated mean plant numbers of 240 to 300 plants per square meter across the various treatments. These plant numbers are considered more than adequate for a high yield potential crop.

4.9.2 Dry matter production at panicle initiation

At panicle initiation dry matter production could be separated into three general groups – rice on flat following wheat and long fallow, rice on beds following soybeans and rice on beds following rice. All crop sequence/irrigation method treatments responded significantly to nitrogen treatments. The flat treatment following wheat produced the highest dry matter at all nitrogen rates whilst the drip irrigated treatment produced the least (Figure 55). The dry matter production on the MSD treatment was significantly affected by the timing of the nitrogen application (MSN compared to PIN) except at the highest nitrogen application rate.

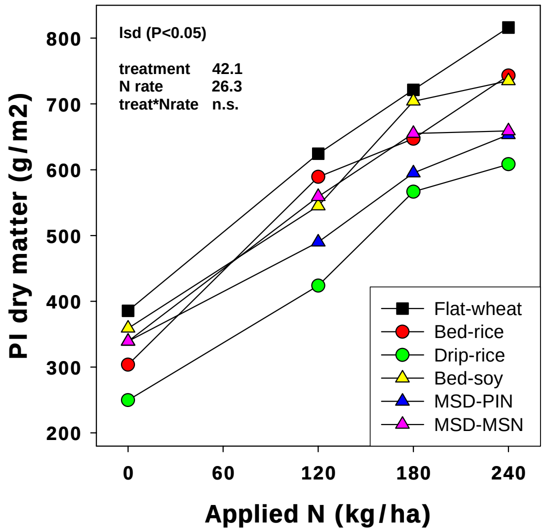


Figure 55. Effect of irrigation method, crop sequence and nitrogen management on dry matter production at panicle initiation of rice 2005-06

4.9.3 Nitrogen uptake at panicle initiation

The nitrogen uptake at panicle initiation (Figure 56) was significantly influence by crop sequence / irrigation method and by nitrogen application rate. Again the nitrogen application timing in the MSD treatment significantly affected the nitrogen uptake. The MSD-MSN treatment had nitrogen applied to dry soil and then flooded one week prior to the panicle initiation samples being taken and all other treatments had no nitrogen applied before the panicle initiation sampling. This was plenty of time for the rice plants in the MSD-MSN treatment to take up the applied nitrogen, increasing its concentration in the plant leading to a high nitrogen uptake level. This increased nitrogen uptake was achieved at much higher efficiency (ie. lower losses) than where the plots were ponded at the time of nitrogen topdressing.

Excluding the MSD-MSN treatment, the flat treatment following wheat had the highest nitrogen uptake at panicle initiation being significantly higher than the other comparable fertiliser treatments. The bed treatments following soybeans were the next highest along with rice on bed treatment whilst the drip irrigated treatment had the lowest nitrogen uptake at all nitrogen rates.

This ranking of treatments reflects the previous cropping history with single season cropping treatment (ie. the flat-wheat treatment) having the highest nitrogen uptake, the double cropping treatments involving soybeans (bed-soybean and MSD-PIN treatments) having the next highest nitrogen uptake whilst the treatments involving continuous rice on beds (bed-rice or drip-rice) having lower levels of nitrogen uptake. The drip-rice had the lowest nitrogen uptake overall.

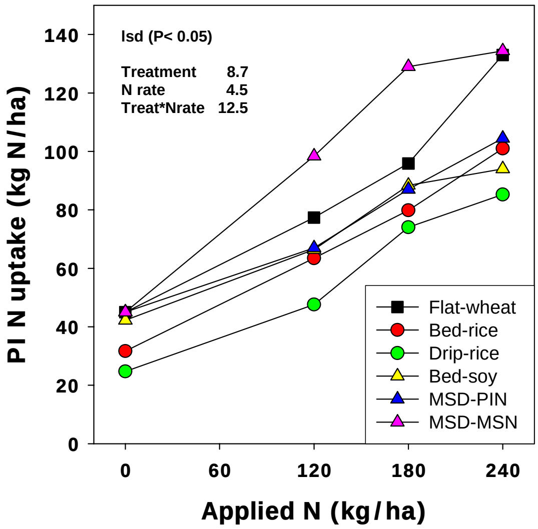


Figure 56. Effect of irrigation method, crop sequence and nitrogen management on nitrogen uptake at panicle initiation of rice 2005-06

4.9.4 Dry matter production at anthesis

The flat-wheat treatment produced the highest dry matter at anthesis (Figure 57). At zero nitrogen there was no difference between the flat-wheat treatment and the treatments that had previously grown soybean. Dry matter on the bed-rice treatment was significantly less than the flat-wheat and soybean based treatments but was significantly greater than the drip irrigated rice treatment. The drip irrigated rice treatment had the lowest dry matter production across all nitrogen fertiliser rates.

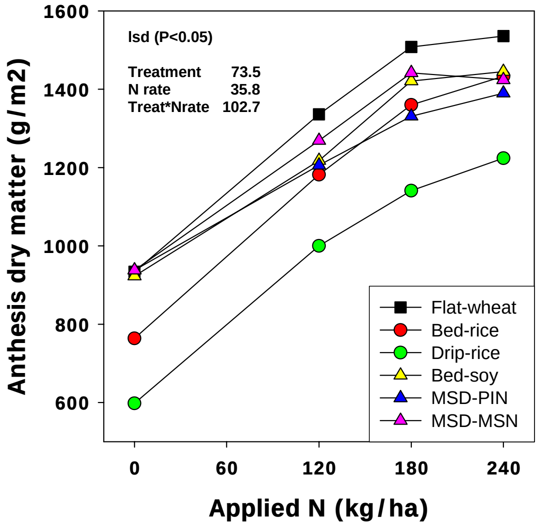


Figure 57. Effect of irr … gement on dry matter production of rice at anthesis 2005-06

At the highest nitrogen fertiliser rate (240 kg N/ha) the flat wheat treatment had the highest nitrogen uptake which was significant higher all other treatments. The bed rice and soybean based treatments were not significantly different from each other (Figure 57) but were significantly higher in anthesis dry matter production than the drip-rice treatment.

4.9.5 Nitrogen uptake at anthesis

Nitrogen uptake at anthesis increased across all nitrogen application rates. There was no difference in anthesis nitrogen uptake between the flat wheat treatment and the MSD-MSN treatment below the 240 kg N/ha level (Figure 58). At the 240 kg N/ha level the flat wheat treatment had a significantly higher nitrogen uptake than all other treatments, whilst there was no significant difference between the drip-rice, bed-rice and MSD –PIN treatments. The nitrogen uptake of the MSD-MSN treatment followed that of the flat-wheat treatment across the 120 and 180 kg N/ha but did not show the same rate of uptake at 240 kg N/ha.

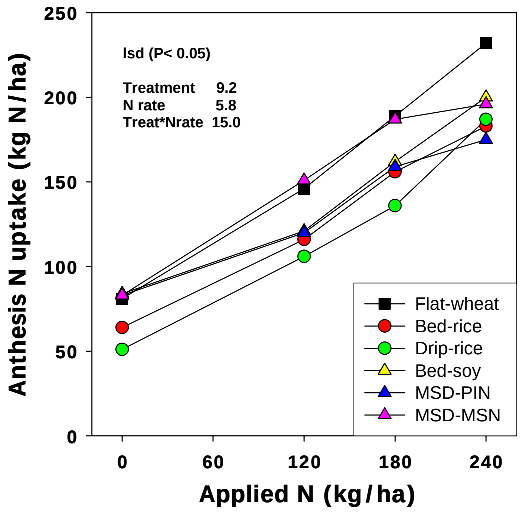


Figure 58. Effect of irrigation method, crop sequence and nitrogen on N uptake at anthesis

4.9.6 Total dry matter production

Total dry matter increased with increasing nitrogen application (Figure 59). Rice on beds after soybeans, either flooded or MSD treatments, produced as much rice as the flat treatment at the 180 and 240 topdressed nitrogen rates(lowered MSD-MSN and MSD-PIN at the 240 N rate caused by grain being shed on these plots due to lodging).

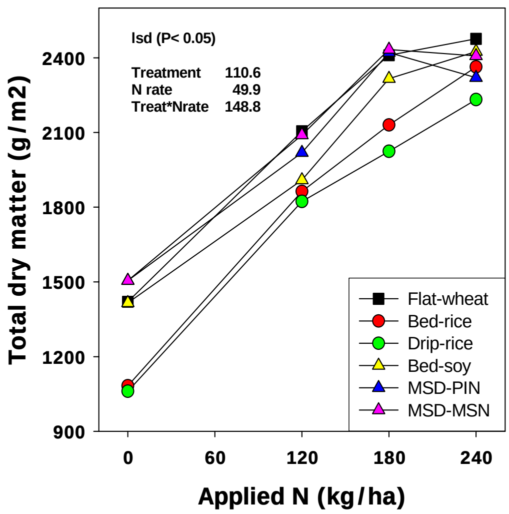


Figure 59. Effect of irrigation method, crop sequence and nitrogen on total dry matter production

4.9.7 Total nitrogen uptake

At physiological maturity there was no different in total nitrogen uptake between the bed-rice and drip-rice treatments (Figure 60). These two treatments had significantly less nitrogen uptake than all other treatments. The remaining four treatments were not significantly different from each other at zero nitrogen. This difference would appear to indicate the difference in crop sequences of the cropping / irrigation treatments. These differences remain at 120 and 180 kg N/ha. Whilst at 240 kg N/ha the flat treatment has significantly more nitrogen uptake than all other treatments. The other treatments are not significantly different in nitrogen uptake at 240 kg N/ha although the MSD treatments were subject to lodging and grain shedding**.**

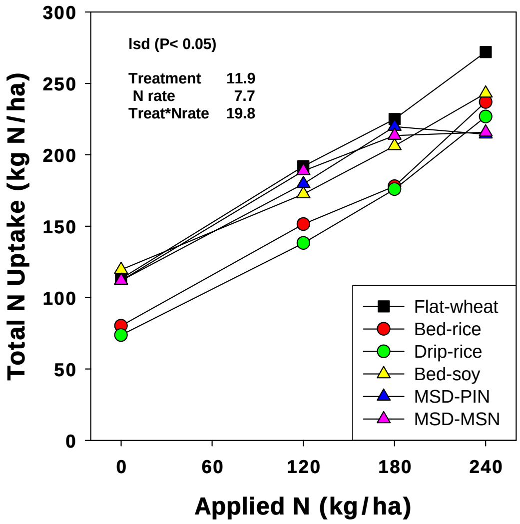


Figure 60. Effect of irrigation method, crop sequence and nitrogen management on total nitrogen uptake

4.9.8 Floret fertility

Floret fertility tended to decrease with increasing nitrogen application for all treatments (Figure 61) although there was variability in the data (exaggerated in graph due to the small range). The general level of floret fertility achieved was lower but similar to that found in 2002-03 (Figure 13). This level was substantially better than that occurring in 2003-04 (Figure 31) and 2004-05 (Figure 45) season results.

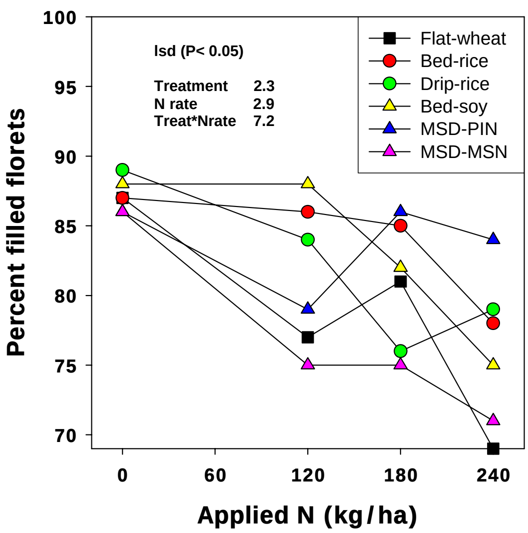


Figure 61. Effect of irrigation method, crop sequence and nitrogen management on floret fertility

4.9.9 Grain yield

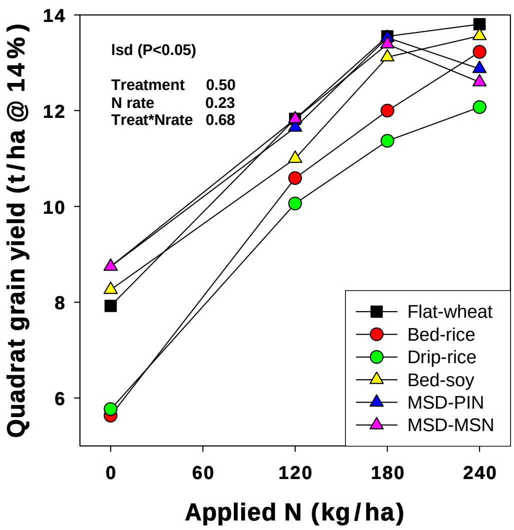


Figure 62. Effect of irrigation method, crop sequence and nitrogen management on grain yield

Rice grain yields increased with increased topdressed N for all treatments except MSD treatments at 240 kg N/ha. This was due to increases in dry matter with increased nitrogen application (Figure 59) and the level of filled florets was relatively high in all treatments (Figure 61), a reflection of the favourable EPM temperatures.

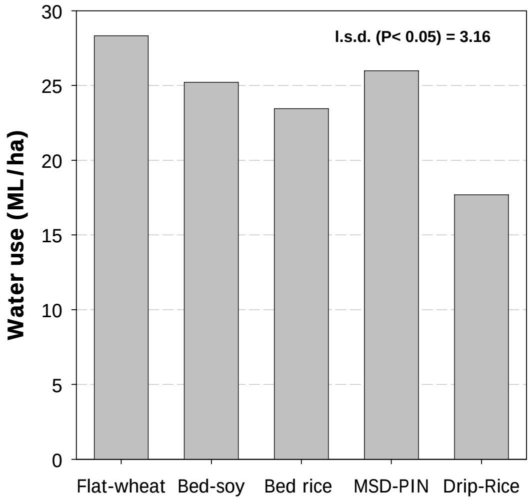
At zero nitrogen, the flat wheat treatment and the soybean based treatments (bed-soy and MSD) were not significantly different from each other. The yield of the bed-rice and drip-rice treatments were not significantly different from each other but were significantly lower than all other treatments

The grain yield of the MSD-MSN and MSN-PIN treatments was lower at the highest N rate (240 kg N/ha) due to increased lodging and grain shedding. The grain yield of the rice grown after continuous rice (bed rice or bed-drip treatments) was lower than all other treatments, especially at zero and low topdressed N rates (Figure 62). Four years of continuous rice growing had reduced soil nitrogen levels causing a significant reduction in grain yield when limited nitrogen is applied. The application of large amounts of nitrogen increased grain yield to acceptable levels. The bed-rice treatment equalled the yields of the rice following wheat and soybean treatments at the highest nitrogen topdressing rate.

4.9.10 Water use and water productivity

Water use for surface irrigated treatments was high even for the high temperature, low rainfall weather conditions (Figure 63). The water use of flat, bed-rice, MSD and bed-soy did vary but were not significantly from each other. The rice drip water use was significantly less than all other treatments (Figure 63). Water use at the experiment was considerably higher than previously measured. Considerably higher rice water use during than previously measured was observed at several commercial sites during 2005-06. Water use at the site varied between replicates with the highest water use being recorded in the southern part of the trial where soil conditions were not as suitable for low water use rice growing (see Figure 4 and 6).

The drip-rice treatment had the highest water productivity, which was significantly higher than all other treatments (Figure 64). The water productivity was not significantly different between all other treatments.



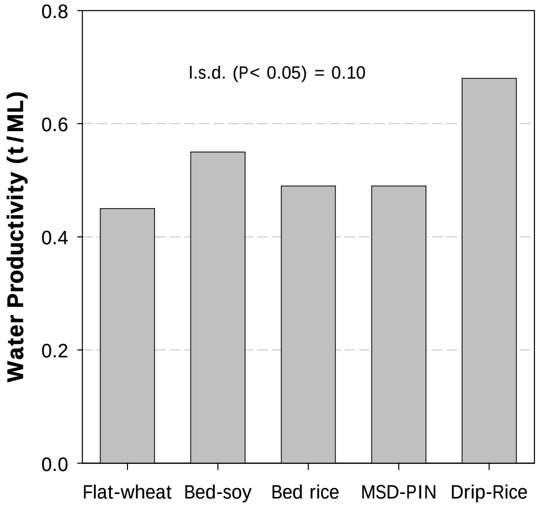


Figure 63. Water use for 2005-06 rice crop (irrigation and rainfall)[1]

Figure 64. Water productivity for 2005-06 rice crop (irrigation and rainfall)[1]

[1] Water Productivity (WP). These values do not take into account soil moisture remaining in the profile at harvest. This may decrease water use and increase WP proportionately

4.10 Wheat 2006

4.10.1 Establishment

Plant establishment was excellent with no difference between irrigation layouts or varieties (Figure 65).

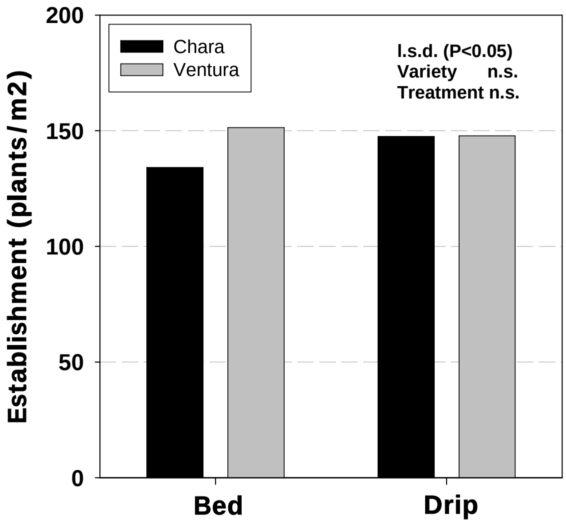


Figure 65. Effect of irrigation layout and wheat variety on crop establishment.

4.10.2 Anthesis and total dry matter production

There was no significant difference in dry matter production at anthesis between irrigation layouts or cropping history (Figure 66). There was a significant difference between varieties with Chara producing significantly more than Ventura.

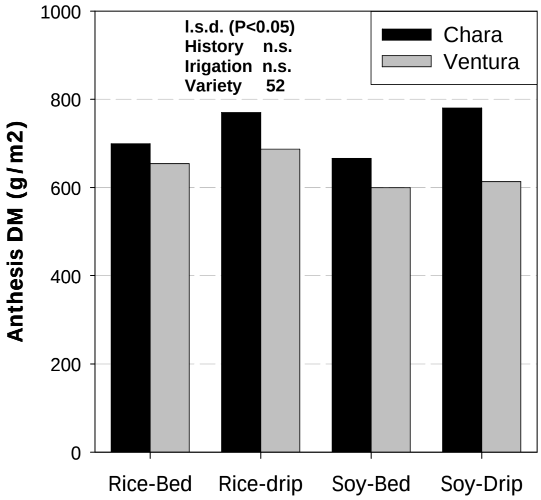


Figure 66. Effect of irrigation layout, crop history and variety on anthesis dry matter

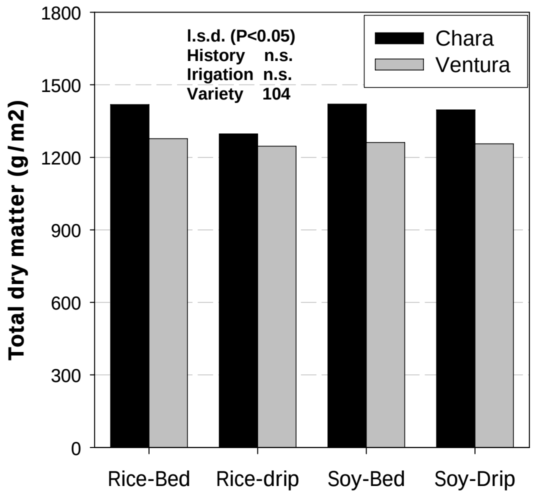


Figure 67. Effect of irrigation layout, crop history and variety on total dry matter

At physiological maturity there was no difference in total dry matter production between cropping history or irrigation layout (Figure 67). There was a significant difference between varieties with Chara producing significantly more dry matter.

4.10.3 Harvest grain yield

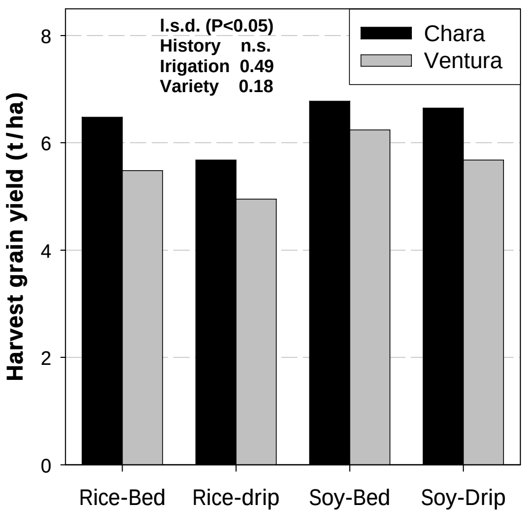


Figure 68. Effect of irrigation layout, crop history and variety on harvested grain yield

Yields of treatments with a soybean cropping history were not significantly different to those with a rice cropping history (Figure 68). The furrow irrigated treatments yielded significantly more than the drip irrigated treatments and Chara yielded significantly more than Ventura. There were no significant treatment interactions.

4.10.4 Water use and water productivity

The irrigation and rainfall water use of the bed treatment (4.3 ML) was 0.5 ML higher than the drip irrigated treatments (3.8) (Figure 69). The water productivity of different irrigation layouts was not significantly different. Chara had a significantly higher water productivity than Ventura (Figure 70).

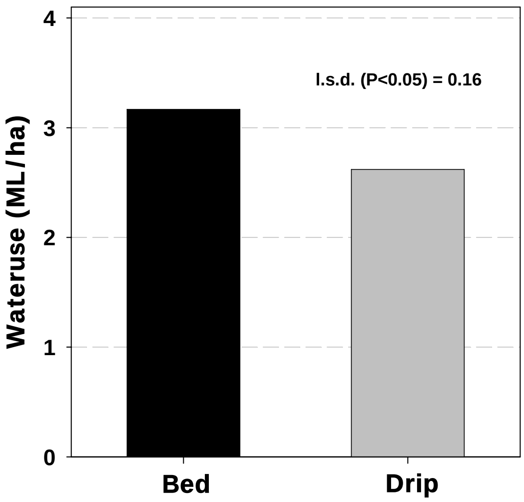


Figure 69. Effect of irrigation layout on wheat crop water use

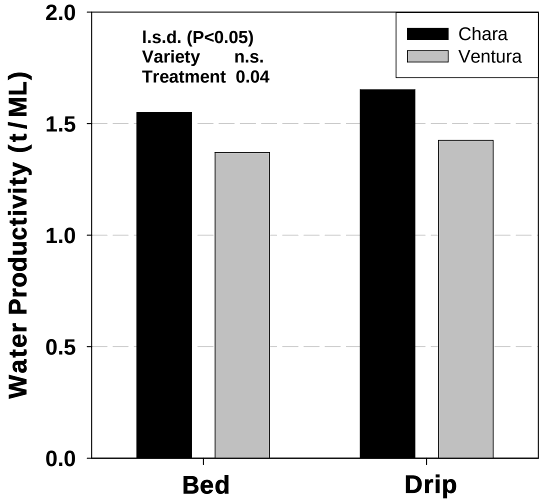


Figure 70. Effect of irrigation layout and cultivar on water productivity

4.11 Monitoring in commercial crops

This was done in collaboration with participating growers. Information on management and observations of problems, solutions and bonuses was sought from the growers.

Drought conditions and low availability of irrigation water during the period of the project has meant that growers generally have not been in a financial or physical (water availability) position to grow rice in many cases. Irrigation allocations have been low over all rice growing areas and in the Murray Valley were such that in 2004-05 there was inadequate water to grow much rice.

One rice grower at Jerilderie has grown rice on beds (when sufficient irrigation water has been available) during the period of this project. He has successfully grown commercial rice on beds on several occasions in 2001/02 (10 t/ha), 2003-04 (9.5 t/ha) and in 2005-06 (11 t/ha). The grower grew approximately 40 ha of rice on raised beds in 2005-06. There were two fields–one a 'new' layout with zero-zero grade and terraced between 'bays', with each bay containing 81 x 1.8 m wide beds. The step between rice terraces was about 150 mm. The variety Amaroo was drill sown on 2nd October and, as with his previous crops, establishment was very uniform (Figure 71). Grain yield was 10 t/ha, slightly above the district average, confirming that commercially acceptable rice yields are achievable on raised bed layouts.

Another grower in the Murrumbidgee Valley, has trialled small areas of rice on raised beds using groundwater as an irrigation supply, so there are salinity issues involved as well.

Other growers have totally landformed recently acquired farms to the 'beds within bays' bankless channel design, however as yet they are not intending to grow rice on beds but will grow other crops on beds in the layout. This approach is followed by riparian growers in the Hay district where a maize/wheat on beds rotation is followed by rice on the flat in a zero-zero graded layout.

Figure 71. Rice crop establishment in October 2005 at Jerilderie in a commercial field of drill sown rice on raised beds in a terraced bankless channel irrigation layout. There were NO seeds planted in the furrow with seven rows sown across the top of beds at 22 cm spacing.

4.12 Economics

4.12.1 Benefit cost analysis

We have undertaken benefit cost analysis to measure the benefits of lateral permanent raised beds over the other existing field designs being used for growing rice and rice based cropping rotations. Here, we have looked into gross margins, savings from water, labour, income from opportunity crops, shifts in crop rotations and crop options considering one rotation selected from each irrigation design.

Since the rotations selected for analysis vary in duration (years), therefore, we have computed the PVI of an infinite series of each rotation using Eq.2 (section 3.1.2). The information on the present value of benefits, present value of costs and the net present value of benefits from adoption of lateral permanent raised beds is presented in Table 11.

Table 11. Present value of costs, Gross margin and NPV of benefits from Permanent beds over different existing layouts

Field layout	PV of cost ($/ha)	PV of GMs ($/ha)	NPV of benefits ($/ha)	
			From layout 5 (a)	From layout 5 (b)
I. Natural contour	$2,976	$15,350	$15,704 (46%)	$17,626 (49%)
II. laser landformed natural contour	$2,922	$16,628	$14,425 (42%)	$16,347 (46%)
III. Laser landformed square contour	$2,887	$19,307	$11,746 (35%)	$13,669 (38%)
IV. Laser landformed square contour alternating with raised beds	$2,887	$31,010	$44 (0.12%)	$1,976 (5.5%)
V. Permanent raised beds				
Rotation Va		$34,029		$1,966 (5.3%)
Rotation Vb		$35,951		-

Note: Figures in parenthesis are the percentage increase in NPV of benefits from V over other selected layouts

The results presented in Table 11 revealed that over 20 years period, the PV of the total benefits from rotation Va and Vb were $34,029/ha and 35,951 respectively. The present value of costs involved in converting to lateral permanent beds were $2976, $2922/ha and $2,897/ha when converted from layout I, II and, III and IV respectively.

Further, the critical appraisal of the results presented in Table 11 shows that the conversion of a non landformed natural contour design to a lateral permanent raised bed design (Vb) leads to a net benefit of $17,626 (49%) per hectare over the extended period. Whereas conversion to the lateral permanent raised beds from a laser landformed natural contour, laser landformed square contour, laser landformed square contour with rice-soy rotation and landformed permanent raised beds (Va) results in a net benefit of $116,347 (46%), $13,669 (38%), $1,966 (5.6%) $1,922 (5.3%) per hectare respectively.

4.12.2 Sensitivity analysis

A sensitivity analysis was undertaken to show the effects on the NPV of financial benefits of changes in the yield of summer and winter crops grown on PRBs (Table 12). The following yield levels of rice, soybean and wheat were considered in the sensitivity analysis**:**

- 10% decline in rice yield on lateral permanent raised beds
- 10% increase and decrease in yield of Soybean on beds
- 10% increase or decrease in yield of barley on beds
- 7% and 10% real discount rate**.**

Table 12. Sensitivity of results to changing values of selected parameters

Parameter	NPV of benefits of PRB (Vb) over all other layouts Layouts				
	I	II	III	IV	V(a)
Default results with rice yield@11t/ha, Soy @3.3t/ha, Barley@5.5t/ha and discount rate@ 4%	$17,626	$16,347	$13,669	$1,976	$1,966
Rice					
10% decrease in yield	$14,221	$12,943	$10,264	$-1,438	1,355
Soybean					
10% increase in yield	$18,882	$17,604	$14,925	$3,223	$1,576
10% decrease in yield	$16,369	$15,091	$12,412	$710	$2,268
Barley					
10% increase in yield	18,210	$16,931	$14,257	$2,550	$1,761
10% decrease in yield	$17090	$15,812	$13,113	$1,431	$2,071
Discount rate used					
7% real discount rate	$10,506	$9,676	$7,779	$338	$1202
10% real discount rate	$7,482	$6899	$5,442	$33	$994

The results of the sensitivity analysis presented in Table 12 shows that the NPV of benefits are more sensitive to change in discount rate and a decline in yield of rice than a change in the yield of soybean or barley. Still any increase in yield of different crops grown on beds would further increase the benefits from lateral permanent beds that would also help its widespread adoption of this technology.

5. General discussion

5.1 Crop performance

5.1.1 Rice

Rice crop performance on raised beds was as successful as that achieved by rice on conventional flat systems. Rice yields and crop growth on raised beds were equivalent to those achieved on the flat. Adequate weed control was achieved in the raised bed layouts.

The possibility of cold temperature conditions during the early pollen microspore stage of crop development inducing floret sterility when using current rice varieties remains a significant hazard (viz 2003/4 and 2004/5 rice crop performance where no deep water was applied). So it is necessary to ensure the impact of these conditions is minimised/managed by the use of deep water conditions (Williams and Angus 1994) for all rice growing layouts including raised beds.

Other crops (wheat, barley and soybeans) were successfully grown in rotation with rice on raised beds in zero graded layouts.

For rice crops there is the capability of being able to achieve uniform water depth control across each bay compared to a 5-10 cm water depth variation across the bay in a conventional graded field layout. This has implications for improved and uniform crop establishment and for the more efficient and effective use of herbicides and to reduce the volume of water required to be held in the bay at any point in time.

5.1.2 Wheat and barley

Raised beds did not provide yield advantages for wheat or barley compared to flat irrigation layouts that have been clearly demonstrated in other work (Thompson and North 1994) and were anticipated in this experiment. This could have been due to how water was supplied to plots in experiment or more likely might just reflect the absence of winter rainfall conditions conducive to development of waterlogged conditions during the experimental period.

Winter cereal crop performance in the experiment was limited due to delayed sowing in mid to late May, significantly later than the late April – early May optimum recommendation of (Lacy 2006) to achieve 8 t/ha yields. Sowing time was constrained by growing wheat after rice (ie. late harvest even with low rainfall during autumn of each season of the experiment and by low rainfall conditions generally). This was exacerbated by an inability to access irrigation water during early September when soil moisture levels were depleted by lack of sufficient winter rainfall.

Outbreaks of wheat stripe rust occurred during the experiment and although fungicides were applied rust may have also impacted on wheat yield outcomes.

5.1.3 Soybean

Soybean growth and yield performance under both furrow and drip irrigation were regarded as highly satisfactory given the later than optimum sowing dates of soybean imposed by the double cropping regime. Double cropping barley and soybeans with current varieties, especially as barley stubbles need to be burnt prior to soybean sowing, leaves little time between harvest and sowing of the following crop.

5.2 Grower attitudes

Growers are interested in the concept, perceiving lots of advantages **BUT** they want to see performance of the system under a range of conditions, especially in wet winters with consequent waterlogged conditions.

These zero-graded basin layouts can be adapted to tramlining (cultural operation traffic being confined to /restricted to defined patterns trafficking (axiomatically where beds are included
This can provide advantages in terms of limiting soil compaction to particular furrows/ tramlines), improving machinery access along these trafficked tramlines following irrigation. Matching irrigation layouts to machinery (or vice versa) improvements in machinery efficiency will be achieved

Growers identify that labour savings are perceived as a major advantage of these style of irrigation layouts. These systems have a significant advantage over conventional graded furrow systems in that there are no syphons to start, stop or shift. The style of layouts being discussed lend themselves to automation in terms of opening irrigation channel structure and the systems are capable of being automated.

5.3 Limitations to the experiment

The experiment was conducted during period without significant winter/spring rainfall events so issues of compaction, waterlogging, access were not encountered in the experiment. Commercial situations need to be monitored during wet winter /spring periods as the situation arises and issues and solutions explored at that time.

Limitations imposed by the need to accurately measure water on/off and often poor access to large irrigation water flows meant that the irrigation intake opportunity times were extended compared to what could happen in the commercial situation.

5.4 Limitations to adoption

Adoption of beds in zero graded may be limited by two significant constraints:

- existing land slope – land with flat to very flat grades may not allow the economic development of terraces with appropriate steps between irrigation bays (from one bay to the next down stream bay)
- lack of access to high irrigation flow rates, in balance with size of irrigation bays.

Although substantial irrigation flow rates (greater than say 25 ML/day) can be achieved by riparian irrigators or irrigators with on farm storages, district irrigation infrastructure may limit the ability to adopt these irrigation layouts due to the inability to deliver irrigation flow rates of sufficient volume.

Adoption of increased cropping intensity (wheat after rice) is constrained by the need to remove or otherwise handle rice stubble residues in all rice growing locations. Stubble is currently mulched and burnt in most situations, limitations on stubble burning either for concerns about greenhouse gas generation or from growers desire to improve soil organic carbon levels may restrict adoption of double cropping systems.

Double cropping in soybean **-** barley rotations is currently restricted in the Murray Valley due to strict bans on stubble burning for wildfire control in summer. This means that alternative approaches of handling barley crop residues to burning are needed. Opportunities for this may be the use of the Happy Seeder approach currently being further investigated by John Blackwell, Charles Sturt University. Manipulation of seed row spacing and inter row sowing of succeeding crops which could be achieved on raised bed layouts or with precision guidance steering systems may offer another alternative.

The adoption of raised beds is problematic on properties where livestock and cropping enterprises are jointly undertaken. Beds/furrows and livestock are considered incompatible due to the increased possibility of livestock becoming cast (unable to stand if caught in an unsuitable position in the furrow).

Water savings during ricegrowing through the use of raised beds compared to conventional flat layouts are unlikely to occur. Where reduced water applications are made it is likely that yields will also be reduced (Thompson et al., 2003).

5.5 Economics

For evaluation of benefits and costs of conversion to lateral permanent raised beds over an existing design, the study considered four field designs; non landformed natural contour; laser landformed natural contour; laser landformed square contour and laser landformed square contour alternating with raised beds, currently being followed by rice growers to grow different summer and winter crops.

Using a partial budgeting approach the study estimated and compared the additional and foregone annual costs and benefits of the options. The analysis was carried out from financial perspective.
The study used a gross margin and crop sequence gross margin analysis to estimate the present value of gross margins over the 20 years accounting period. One rotation from each filed layout was selected to measure potential benefits of the technology.

The results of the benefit cost analysis have revealed that the adoption of permanent raised beds leads to a significant increase in the benefits over the other existing designs being used for rice-based farming systems. The results of the sensitivity analysis show that the NPV of benefits are highly sensitive to change in discount rate used in the analysis and a decline in rice yield compared to any change in the yield of soybean and barley. Still any increase in yield of different crops grown on beds would further increase the benefits from lateral permanent beds that would also help its widespread adoption of this technology. The technology is viable from financial perspective.

6. Implications

Beds within terraced, bankless channel systems are being adopted in the MIA, CIA, Murray Valley and by riparian and groundwater irrigators. A range of crops are being grown under variations this style of layout including rice, wheat, maize, cotton, faba beans, chickpeas, barley, sunflowers.
The area of adoption is not great at this stage but considerable attention is being applied to the performance of these commercial fields by other irrigators.

Surveyors and designers are generating and installing irrigation designs based on these concepts in the rice growing areas of southern New South Wales. Some growers are using relatively expensive designs in terms of structures and piping to achieve terraces/steps between bays in commercial situations but consider the labour saving benefits worthwhile.

Further work be undertaken on this style of irrigation layout to explore the distribution uniformity of irrigations and to explore the water saving possibilities of these designs at commercial scale (North 2007) and studies currently being undertaken by Michael Grabham, NSW DPI, Griffith. Preliminary data (Hoogers, pers comm..) indicates that shorter irrigations (decreased opportunity time) are being used by irrigators with resulting reduced potential for deep drainage for crops other than rice such as faba bean.

The ongoing adoption of terraced zero graded bankless channel rice layouts, including raised beds, appears likely given the increased cropping choice and flexibility and the significantly reduced labour requirement made possible by this type of layout. The adoption of these layouts will be constrained to locations where existing land grades allow creation of zero graded layouts with appropriate terrace widths (landforming costs not being excessive) and steps to allow adequate drainage and to where access to large irrigation flows are available in order to achieve satisfactory short duration water on/water off times for crops other than rice. There may be significant improvements to be made where pastures are grown in rotation with rice in flat layouts by increasing irrigation flow rates and reducing water on/ water off times.

The potential of these irrigation layouts fits with grower and grains industry desires to increase crop range/yield e.g. crops after and in rotation with rice, faba beans, soybeans, canola, wheat, barley. The layouts would link to precision agriculture concepts – compaction control, tramlining, machinery efficiencies and uniform or varied input application.

Adoption of permanent raised beds would not only help increase farmers' income through more intensive cropping and increase in productivity; it will help improve water productivity which will lead to a sustainable use of land and water. Further, reduction in the use of tractor and other machinery for preparing seedbed for different crops would help in reduction in green house gas emissions (CO_2) to the atmosphere.

7. Recommendations

Adoption of zero graded bankless terraced rice field irrigation designs, (basin layout) potentially incorporating raised beds (lateral beds) should be promoted to rice growers in appropriate locations with regard to existing slopes and access to high irrigation flows.

Irrigators and surveyor/designers need to consider the field size in relation to potential water flows and implications for access to adequate flows if this style of layout is adopted by increased number of growers within irrigation areas and districts. Consideration needs to be given for installation of on farm storages providing the opportunity to achieve the high irrigation delivery rates required.

The current experiment was undertaken during very dry climatic conditions (drought). Monitoring of the performance of the irrigation layouts in farmers' fields during higher rainfall and potentially waterlogging conditions needs to be undertaken when the opportunity arises.

8. Appendices

8.1 Publications

8.1.1 Journal Articles

Humphreys E., Meisner C., Gupta R., Timsina J., Beecher H.G., Tang Yong Lu, Yadvinder-Singh, Gill M.A., Masih I., Zheng Jia Guo and Thompson J.A. (2005). Water savings in rice-wheat systems. *Plant Production Science* 8(3), 242-258.

Humphreys E., Lewin L.G., Khan S., Beecher H.G., Lacy J., Thompson J., Batten G.D., Brown A., Russell C., Christen E.W. and Dunn B. (2006). Integrated approaches to increasing water productivity in rice-based systems in south east Australia. *Field Crops Research* 97, 19-33.

Beecher H.G., Dunn B.W., Thompson J.A., Humphreys E., Mathews S.K. and Timsina J. (2006). Effect of raised beds, irrigation and nitrogen management on growth, yield and water use of rice in south-eastern Australia. *Australian Journal of Experimental Agriculture* 46(10), 1363–1372.

8.1.2 Conferences and workshops

Beecher G., Lewin L. and Humphreys L. (2003). 'Strategies for Improving Rice Water Use in the Australian Rice Industry' International rice conference "Modern Rice Farming", 13-16 October, Alor Setar, Kedah, Malaysia.

Beecher G., Thompson J., Dunn B., Humphreys L., Mathews S., Johnston D., Christen E., Timsina J., Smith D., Singh R.P., Xevi E. (2003). Alternative Irrigation Methods For Rice-based Cropping Systems: Permanent Beds and Sub-Surface Drip. 3rd Temperate Rice Conference, Punta Del Este, Uruguay, 10-13 March 2003. Compact disc.

Dunn B.W., Mathews S.K., Beecher H.G., Thompson J.A. and Humphreys E. (2004). Growing rice on raised beds in south-eastern Australia. 4th International Crop Science Congress, 26 Sep-1 Oct 2004, Brisbane, Australia (poster paper) Accessed at: http://www.cropscience.org.au/icsc2004/poster/1/2/705_dunna.htm (verified 1 August 2006).

Dunn B.W., Mathews S.K., Beecher H.G., Thompson J.A. and Humphreys E. (2004). Growing rice on raised beds in south-eastern Australia. 4th International Crop Science Congress, 26 Sep-1 Oct 2004, Brisbane, Australia (poster paper) Accessed at: http://www.cropscience.org.au/icsc2004/poster/1/2/705_dunna.htm (verified 1 August 2006).

Humphreys E., Meisner C., Gupta R., Timsina J., Beecher H.G., Tang Yong Lu, Yadvinder-Singh, Gill M.A., Masih I., Zheng Jia Guo and Thomposon J.A. (2004). Water savings in rice-wheat systems. 4th International Crop Science Congress, 26 Sep-1 Oct 2004, Brisbane, Australia. Accessed at: http://www.cropscience.org.au/icsc2004/symposia/1/2/237_humphreyse.htm (verified 1 August 2006).

Beecher H.G., Thompson J.A., Dunn B.W., and Mathews S.K. (2005). Successful Permanent Raised Beds in the irrigated farming systems of the Murrumbidgee / Murray Valleys of NSW, Australia. In Roth, CH, Fischer, RA and Meisner, CA Eds (2005) Evaluation and performance of permanent raised bed cropping systems in Asia, Australia and Mexico. pp 129-143. Proceedings of a workshop held at Griffith, Australia, 1-3 March 2005. ACIAR Proceedings 121.

Mathews S.K., Dunn B.W., Beecher H.G., Thompson J.A., Timsina J. and Johnston D.W. (2005). Soybean performance on raised beds in a rice irrigation layout 13th Australian Soybean Conference, Barooga, NSW, 1-3 March 2005.

Singh R.P. and Beecher G. (2005). Economic Assessment of Permanent Raised Beds for Rice-based Farming Systems in Australia: An Analytical Framework. In Roth, CH, Fischer, RA and Meisner, CA Eds (2005) Evaluation and performance of permanent raised bed cropping systems in Asia, Australia and Mexico. pp 191-199. Proceedings of a workshop held at Griffith, Australia, 1-3 March 2005. ACIAR Proceedings 121.

Timsina J., Boote K., Beecher H.G., Thompson J.A., Mathews S.K. and Dunn B.W. (2005). Evaluation of CSM-CROPGRO- soybean model for irrigated cropping systems in southern New South Wales. 13th Australian Soybean Conference Soybeans : Maximising Potential. Barooga March 2005.

Beecher H.G., Dunn B.W., Thompson J.A., Humphreys E., Mathews S.K. and Timsina J. (2007). Performance of rice on raised bed system compared to conventional field layouts in South-eastern Australia. 4th International Temperate Rice Conference, Novara, Italy. June 2007 accepted.

8.1.3 Farmer magazines

McCaffery D., Thompson J., Humphreys E., Beecher G., Ellwood N, Taylor M and Polkinghorne B. (2002). Best bet guidelines for rice on beds. Farmers' Newsletter Large Area No. 161, 16-18. Accessed at: http://www.irec.org.au/farmer_f/pdf_172/Direct%20drilling%20into%20stubble.pdf (verified 1 August 2006).

Beecher G., Thompson J., Humphreys E., Dunn B., Mathews S., Singh R. and Johnston D. (2004). Permanent beds for sustainable cropping systems on rice farms. Irrigation – more from less. GRDC Grains Research Update, 17 August 2004, Moama, pp. 92-96.

Beecher H.G., Dunn B.W., Mathews S.K., Thompson J.A., Humphreys E. and Johnston D. (2005). Permanent beds for sustainable cropping systems on rice farms. Farmers' Newsletter Rice R&D Issue No. 168 pp. 25-27.

Beecher, H.G., Dunn, B.W., Mathews, S.K., Thompson, J.A., Singh, R.P, Humphreys, E., Timsina, J., O'Keeffe, K. and Johnston, D. (2006). Permanent lateral beds for sustainable cropping systems on rice farms. Farmers' Newsletter Large Area No.171, pp. 24-27. Accessed at: http://www.irec.org.au/farmer_f/pdf_171/Permant%20beds%20for%20sustainable%20cropping.pdf (verified 1 August 2006).

Beecher G., Dunn B., Mathews S., Thompson J., Singh R.P., Humphreys L., Jagadish Timsina, Keiran O'Keeffe & Daniel Johnston. (2007) Permanent lateral beds for sustainable cropping systems on rice farms. IREC Farmers Newsletter, Rice R&D edition, No 174 pp. 4-8.

Matthew S., Beecher G., Dunn B., Thompson J., Humphreys E. and Johnston D. (2004). Permanent beds for sustainable cropping systems. Farmers' Newsletter Large Area No. 165 pp. 4-7.

8.1.4 Other

Humphreys E., Muirhead W.A., Lewin L.G., Thompson J.A., Stapper M., O'Keeffe K.R. and Beecher H.G. (2003). Increasing water use efficiency: Rice-based farming systems of southern NSW. Natural Resource Management Special Issue June 2003.

Mathews S.K., Humphreys E., Beecher H.G., Dunn B.W. and Johnston D.W. (2005). Nitrogen management for rice on permanent raised beds in south east Australia. IAEA Coordinated Research Project on Integrated Soil, Water and Nutrient Management for Sustainable Rice-Wheat Cropping Systems. Progress Report.

Mathews S,K., Humphreys E., Beecher H.G. (2006). Nitrogen management for rice on permanent raised beds in south east Australia. IAEA Coordinated Research Project on Integrated Soil, Water and Nutrient Management for Sustainable Rice-Wheat Cropping Systems. Progress Report.

8.2 Visitors to experimental site

2002

- Yang-Ho Park Plant Nutrition Management Lab Korea
- 12 Dec 2002 Malaysian Visitors - Felcra Plantation Services
- Dec 2002 Soybean group Coleambally growers and agribusiness
- Dec 2002 Murrumbidgee College Students
- Dec 2002 Rural Industries Research and Development Committee Rice Research Committee

2003

- Jan 2003 Moulamein farmers – 5 members of Farming Systems group from Western Murray valley
- 26 February 2003 ~50 members of the CRC for Sustainable Rice Production during the CRC Annual Symposium/ Annual Rice Field Days
- 11 March 2003 ~ 40-50 farmers at Demonstration Farm field day
- 20 March 2003 ~10 members of Rice Breeding/Physiology team YAI
- 20 March 2003 ~10 University of Sydney Agriculture Students
- 21 March 2003 NSW Agriculture Southern Farming System Irrigation Extension Team
- 24 March 2003 Dr Tony Fischer ACIAR – site inspection
- 26 March 2003 Chilean Rice industry delegation
- 21 October 2003 Mr Manikum, Acting India High Commissioner to Australia, Mr Jain Secretary of Agriculture for India, Mr Verma Secretary of Agriculture, Rajasthan, Dr Sarswat, Indian Maize program
- 22 October 2003 Dr Kim Chung Kon, Dr Kim Yeon-Gyu, Dr Son Jong Rok, Korean Rice Industry

2004

- 10 Feb 2004 Israeli Cotton Board Growers
- 2 Mar 2004 Thai visitors (Heng/Orasa) and field visit
- 4 Mar 2004 Coleambally Growers Field Day
- 5 Mar 2004 Annual Rice Field Day - Yanco
  - ACIAR Program Managers
- 4 Sept 2004 Sydney University
- 4 Nov 2004 Coleambally demonstration farm Field day
- 16 Nov 2004 Coleambally Growers Field Day

2005

- 5 Feb 2005 ACIAR Workshop
- 5 Mar 2005 Coleambally Rice Field Day ~ xx growers and agribusiness staff
- 29 Sep 2005 50 plus University of Sydney Agriculture, Ag Economics, Environmental Science
- 28 Feb 2005 Annual RIRDC Rice Field Day Coleambally
- 3 Mar 2005 ACIAR PRB Workshop Field visit
- 24 Feb 2005 Pioneer Seed staff
- 15 Mar 2005 Agribusiness personnel from the Lachlan Valley
- May 2005 GRDC project review team visit – Phil Price and Dr Mark Peoples
- 25 Oct 2005 Dr Bob Ziegler, Director General IRRI
- 8 Nov 2005 Coleambally Rice Field Day
- 22 Nov 2005 Professor Vo Tang Xuan. Angian University, Vietnam

2006

- 9 Mar 2006 Dr Gene Hoffman, ex Director USDA Salinity Lab

8.3 Presentations

2002

Beecher G., Thompson J., Dunn B., Humphreys E., Christen E., Timsina J., Smith D. and Singh R.P. (2002). Permanent beds for sustainable cropping systems on irrigated farms. Poster presented at RIRDC Rice Research and Development Committee "Research Seminar". August 2002, Leeton, Australia.

2003

- ACIAR project review, Yanco Agricultural Institute 25 July 2003
- NSW Agriculture NSW Agriculture Research / Extension Meeting YAI 29 July 2003
- IREC Cropping Seminar, Darlington Point 30 July 2003
- A presentation of the Permanent beds for sustainable cropping systems on rice farms experiment was made at the RIRDC Rice R&D meeting. 4/5 August 2003
- Rice Pre-season meetings to rice growers – Griffith(40), Whitton (35), Coleambally (75), Finley (110), Deniliquin (50), Wakool (78), Hay(9) **Total farmers 397**

2004

- Presentations were made to Coleambally rice growers on experimental progress at an on-site field day 2 March 2004
- Presentation at a Coleambally grower meeting March 2004.
- NSW Agriculture NSW Agriculture Research / Extension Meeting Yanco Agricultural Institute 29 July 2004
- RIRDC Rice Rand D Review August 2004
- GRDC Grains Research Update Moama August 2004
- ACIAR Review Ludihana, Punjab, India September 2004
- Presentations on the experiments were made at Rice Pre-season meetings for rice growers at Griffith, Whitton, Coleambally, Finley, Deniliquin, Wakool and Hay September 2004

2005

- ACIAR Workshop/ conference CSIRO Griffith March 2005
- GRDC project Review May 2005
- NSW DPI Research / Extension Meeting YAI July 2005
- RIRDC Rice Rand D Review August 2005

2006

- IREC Irrigated Farm competition, Wilbriggie 9 May 2006
- NSW DPI Rice Research / Extension Meeting YAI July 2006
- RIRDC Rice R and D Review August 2006
- ACIAR review Ludhiana, Punjab September 2006

8.4 Publicity / Newspaper articles:

Newspaper articles

- Local Newspaper inserts: re ACIAR review day / Field Experiment
- Rice CRC Newsletter: re ACIAR review day / Field Experiment
- NSW Agriculture, Centre of Excellence, Yanco Agricultural Institute Website
- An article on the experiment was published in The Ricegrower segment of Australian Grain Magazine (January-February 2004)
- An article has been prepared for the GRDC Crop Doctor series
- Electronic newsletter materials as per Grainzone News and Rice CRC Updates
- Handouts at Rice Field day presentations and on-site grower field days
- The Land: Rice Field day Presentation re Field Experiment
- Local Newspaper inserts: re ACIAR review day / Field Experiment The Rural Insert 1 August 2003
- Rice CRC Newsletter: re ACIAR review day / Field Experiment
- Weekly Times : easier crop switches 4 January 2006

9. References

Beecher H.G., Thompson J.A., McCaffery D.W. and Muir J.S. (1998). Cropping on raised beds in southern NSW. Agfact P1.2.1, NSW Agriculture, NSW, Australia. pp. 23.

Beecher G., Fleming M., Evans L. and Vial L. (2004). Water and irrigation management. In "Production of Quality Rice in South eastern Australia." (Ed. LM Kealey and WS Clampett) Rural Industries Research and Development Corporation, Canberra.

Beecher, H.G., Thompson, J.A., Dunn, B.W. and Mathews, S.K. (2005). Successful Permanent Raised Beds in the irrigated farming systems of the Murrumbidgee / Murray Valleys of NSW, Australia. In Roth, C.H., Fischer, R.A. and Meisner, C.A. ed. (2005). Evaluation and performance of permanent raised bed cropping systems in Asia, Australia and Mexico. Proceedings of a workshop held in Griffith Australia. 1-3 March 2005. ACIAR proceedings No 121.

(DLWC) Department of Land and Water Conservation (1998). Securing Our Water Future: progress on many fronts April, 1998.

Dwyer L. (1992). Rice 2000: Environmental Policy Paper. Dwyer Leslie Pty Ltd, Canberra, ACT.

Elton K.J., Hutton R., and Mullen J.D. (1997). The Returns from Some Replanting Strategies in the Orange Industry, NSW Agriculture.

GHD (1985). Waterlogging and Land Salinisation in Irrigated Areas of NSW. Summary Report - Problems and Strategies. Gutteridge, Haskins and Davey for the Water Resources Commission, Sydney, NSW.

Hoey D. (1992). Groundwater levels in the Deniboota, Berriquin and Wakool-Tullakool Districts. Farmers' Newsletter Large Area No. 140

Lacy J. (2006). Checking is essential for 8 t/ha of wheat. IREC Farmers Newsletter No 172 pp. 24-26. http://www.irec.org.au/farmer_f/pdf_172/Wheat%20-%20the%20eight%20tonne%20club.pdf

van der Lely A. (1992). Groundwater conditions in the MIA&D and CIA. Farmers' Newsletter Large Area No. 140.

Muirhead W.A. and Humphreys E. (eds) (1984). Rootzone Limitations to Crop Production on Clay Soils. Symposium of the Australian Society of Soil Science Inc. Riverina Branch, Griffith, NSW, 25-27 Sept 1984. CSIRO: Melbourne, Australia.

North S. (2007). Improving the performance of Basin (Contour) irrigation systems in the Southern Murray Darling Basin – A scoping study. A review of past research and current practices to identify research, development and extension needs. NSW Department of Primary Industries, Deniliquin NSW 2710.

Thompson J. and North S. (1994). Raised beds reduce winter waterlogging. IREC Farmers Newsletter No 143 pp. 38.

Thompson J., Griffin D. and North S. (2003). Improving the water use efficiency of rice. Final report. Project 1204 Cooperative Research Centre for Sustainable Rice Production, Yanco, New South Wales.

Singh R. and Whitworth R. (2005). *Farm Budget Handbook 2005: Southern NSW Irrigated Summer Crops*, NSW Department of Primary Industries, Yanco.

Singh R. and Whitworth R. (2006). *'Farm Budget Handbook 2006: Southern NSW Irrigated Winter Crops'*, NSW Department of Primary Industries, Yanco.

Williams R.L. and Angus J.F. (1994). Deep floodwater protects high-nitrogen rice crops from low-temperature damage. *Australian Journal of Experimental Agriculture* 34(7) 927 – 932.