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TABLE OF CONTENTS

PROJECT SUMMARY:

Quantifying and maximising the benefits of crops after rice

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At the time this project was conceived, rising watertables and subsequent salinisation were considered to be the major threats to the sustainability of irrigated agriculture in the rice growing areas of southern NSW. The biggest threat to sustainability at present is the reduced availability and higher cost of water as a result of the water reforms, and more recently prolonged drought. The hypothesis of this project was that growing crops immediately after rice would increase water use efficiency and profitability of rice-based cropping systems while reducing net recharge.

Field experiments were conducted from 1998 to 2000 on two soil types to evaluate the effect of non-irrigated wheat after rice on watertables and net recharge. Rainfall during the wheat season was reasonably similar in all 3 years (270-318 mm) and higher than average (220 mm). Yield and biomass production of early sown (24 April) wheat were higher than yield of late wheat (29 June) (grain yield 4.7 vs 3.8 t/ha at 12% moisture). In the absence of irrigation, the soil profile remained wet in fallow areas, whereas there was considerable drying in areas planted to wheat. The drying created capacity in the soil profile to capture and use winter rainfall. There was a general increase in depth to the watertable during the first half of the season where non-irrigated wheat was grown after rice, but not in the fallow areas. However, in all situations, the watertable rose around the time of rice sowing each year due to a rise in the regional groundwater level. The lumped water balance studies suggested net discharge of about 1 ML/ha between the time of sowing and harvesting wheat after rice in each of the three years, mostly due to higher upflow due to crop water use. In the fallow, net discharge/recharge was close to zero.

The CERES Wheat and SWAGMAN® Destiny models performed very well in simulating a wide range of crop and soil water parameters, although the validation data sets were limited in that the yield range was smaller than desirable. Consistent with the field studies, yield of non-irrigated early sown wheat (median 3.8 t/ha) was usually much higher than yield of late sown wheat (median 1.8 t/ha). With one or two irrigations yields of both early and late sown wheat almost always increased, by around 1 t/ha with one irrigation at heading, and an additional 0.5 t/ha with a second irrigation during grain filling. It was only with frequent irrigation (whenever cumulative ETo-rain since the previous irrigation reached 60 mm) that yields of late sown wheat matched (or surpassed) yields of early sown wheat. However, the irrigation requirement for late wheat irrigated at ETo-rain 60 mm was almost always much higher than for early wheat with the same irrigation management (by >100 mm in most years). While irrigation increased yield, it also increased net recharge, with final watertables generally higher by 0.5 to 0.8 m for wheat after rice (wet initial soil) with irrigation at ETo-rain 60 mm compared with no irrigation.

The model simulations showed that with wheat after rice, there was net discharge in almost all years, regardless of initial watertable depth (0.5-1.5 m). In comparison, net recharge occurred in 18 to 48% of years with fallow after rice, the amount of recharge increase as initial depth to the watertable increased. For non-irrigated wheat after rice, salinity of the watertable was

important where the watertable was shallow (0.5 m), with yield reductions in excess of 1 t/ha in most years. However for deeper watertables, there was no effect of watertable salinity for non-irrigated wheat. With irrigation, watertable salinity had no impact on yields.

Growing wheat immediately after rice was financially beneficial, with an increase in Net Present Value (NPV) ranging from 31 to 126 $/ha/yr depending on the rotation. Assuming that the rate of adoption is doubled over 20 years as a result of the project, the NPV of benefits was estimated to be $5.6 million compared with costs of $1.1 million, resulting in a benefit cost ratio of 5.3.

1. Background to the Project

At the time this project was conceived, rising watertables and subsequent salinisation were considered to be the major threats to the sustainability of irrigated agriculture in the rice growing areas of southern NSW. Past studies suggested that ponded rice culture contributes about 50% of the accessions to the groundwater, and other significant sources are channel leakage, other irrigated crops/pastures and winter rainfall (GHD 1985; Dwyer Leslie 1992).

Much has change since project inception, in particular the introduction of water reforms (Humphreys and Robinson 2003), and most recently a 3-year (to date) drought. Australian irrigation farmers, and rice growers in particular, are now under considerable pressure to increase economic returns to water by increasing irrigation water productivity (g product per kg water) and/or producing higher value commodities (Humphreys et al. 2003). Substantial progress has been made since the early 1980s, largely through increasing yields through improved varieties and management, and partly through measures to reduce irrigation water use. These measures were driven in the past by the need to reduce deep drainage losses to control watertables and prevent secondary salinisation (Humphreys et al. 2005).

At the time of project inception, there was considerable opinion and some evidence that growing winter crops or pasture after rice decreases the potential for additions to the watertable (Muirhead 1978), and runoff, from winter rainfall in rice stubble paddocks. About 150,000 ha of rice were normally grown, with wheat the major winter crop grown in rotation with rice. However, only a few farmers regularly sowed wheat (or other crops) into rice stubbles shortly after rice harvest, to take advantage of the large amount of water stored in the soil after rice harvest. Often, rice stubbles lay idle for many months after the end of rice harvest, and establishment of wheat was delayed until the autumn in the following year. The stubble suppressed evaporation and weed growth (and therefore evapotranspiration), resulting in little opportunity for the soil profile to dry and increasing the potential for additions to the watertable. The water balance study for the Benerembah Irrigation District indicated that 45% of the additions to the watertable occurred from stubble and fallow ground in a wet year (Woodard and Rahman 1994). The reluctance of most rice growers to sow crops or pasture shortly after rice suggested that there may be physical and cultural constraints that needed to be overcome to make this an attractive option.

This project sought to identify constraints and keys to growing crops after rice, and to quantify and demonstrate the impacts on watertables and rootzone salinisation, and tradeoffs between irrigation management, yield and watertable impacts.

2. Objectives

a) determine knowledge of farmers' perceptions of:
   - (i) constraints to growing crops/pastures immediately after rice
   - (ii) factors leading to successful production of crops after rice
   - (iii) impacts on sustainability (environmental, economic)

b) undertake field determinations and demonstrations of the impacts of growing wheat directly after rice on water use efficiency of rice-wheat systems and net recharge

c) compile existing data from rice-wheat cropping in southern Australia, and use these data to do
d) validate and calibrate the CERES Wheat and SWAGMAN Destiny models for wheat in the rice growing areas of southern NSW

e) use the calibrated models to predict impacts of wheat after rice on watertables and rootzone salinity for a range of seasonal conditions, watertable depths, soil types, sowing dates and irrigation management, and tradeoffs between yield and net recharge management

3. Introductory technical information concerning the problem or research need

None

4. Methodology

a) *Mail survey to determine farmer perceptions of constraints and opportunities for the production of crops after rice*

A mail survey of rice growers was conducted in May 1998. The survey was included in a Ricegrowers' of Australia Association mailout to approximately 2,200 rice growers.

b) *On-farm replicated field experiments to determine impacts on watertables of growing crops after rice, and their productivity*

Four replicated field experiments were conducted on 2 soil types over 3 seasons from 1998 to 2000 (Table 1). In each experiment components of the water balance for wheat planted after rice were compared with stubble retained fallow. Volumetric soil water content and soil matric potential were measured twice weekly using neutron counts, tensiometers and gypsum blocks near the centre of each plot, and capacitance probes in 2000. Groundwater was monitored using 1 and 3 m testwells, and 3 m piezometers near the centre of each plot, and one 6 m piezometer at each site. Micro lysimeters were used at both sites in 1999 to determine soil evaporation from the fallow plots. Crop development and biomass were determined at key stages, and grain yield and yield components were determined.

c) *Review and compilation of crop and soil water data for wheat in rice-based systems*
d) *Use of data to validate and calibrate the CERES Wheat and SWAGMAN Destiny models*

Data from 3 experiments in the rice growing area in southern NSW were used to determine genetic coefficients for three wheat varieties for use in the CERES-Wheat and SWAGMAN® Destiny models (Table 2). Three independent data sets from the same region were then used to validate the models. The data sets were from 3 replicated field experiments in the Murrumbidgee and Coleambally Irrigation Areas, including the 1998 field experiments in this report, and from 3 experiments in weighing lysimeters at CSIRO Griffith.

Table 1. Summary of experiments 1998-2000

	Site 1		Site 2	
	1998	1999	1999	2000
Soil type	Beelbangera clay loam	Beelbangera clay loam	Wilbriggie clay loam	Wilbriggie clay loam
Treatments	• Stubble fallow • Early wheat • Late wheat	• Stubble fallow • Early wheat	• Stubble fallow • Wheat	• Stubble fallow • Early wheat
Plot size (m^2)	25 x 25	25 x 25	30 x 30	30 x 30
Wheat variety	Janz	Whistler	Triller	Whistler
Sowing rate (kg/ha)	150	150	150	125
Sowing date	24 April (29 June)	20 April	20 & 28 May	27 April
Row spacing (m)	0.15	0.15	0.15 (broadcast)	0.15
Plant density (no./m2)	344 (320)	222	282	114
Sowing method	Sod seeded in burnt rice stubble	Sod seeded in burnt wheat stubble	Sod seeded in burnt rice stubble	Sod seeded in burnt wheat stubble
Pre-sowing fertilizer	-	-	-	Urea (31 Mar) 50 kg N/ha
Fertilizer with seed	DAP @192 kg/ha 34 kg N/ha 38 kg P/ha 3 kg S/ha	DAP @ 180 kg/ha 32 kg N/hs 36 kg P/ha 3 kg S/ha	DAP @180/kg/ha 32 kg N/ha 36 kg P/ha 3 kg S/ha	DAP @ 125 kg/ha 23 kg N/ha 25 kg P/ha 2 kg S/ha
Top-dressed fertilizer	Urea E 60 kg N/ha 21Jun E 60 kg N/ha 3 Sep L 60 kg N/ha 21 Jul L 60 kg N/ha	Urea 60 kg N/ha 3 Jun 60 kg N/ha 13 July	Urea 60 kg N/ha 13 Jul 60 kg N/ha 9 Sept	Urea 60 kg N/ha 7 Aug 60 kg N/ha 12 Sep
Herbicides presowing	- Round-up @1 L/ha on 17 Apr - Hoegrass @ 1.5 L/ha on 4 Sep	Round-up @1 L/ha on 13 April,	none	- Round-up @ 1.5 L/ha on 30 Mar - Camba (MCPA + Dicamba) @ 0.5 L/ha on 1 Aug and @ 1 L/ha on 17 Aug
Fungicides	None	none	Folicur (Tebuconazole) @ 290 mL/ha on 14 Oct	none
Water management	Rainfed	1 pre-sowing irrigation (1 April) 1 estab. (19 May) then rainfed	Rainfed	1 pre-sowing irrigation (29 Feb) then rainfed
Key growth stages Jointing Flowering Maturity Harvest	 30 July (20 Sept) 1 7 Sep (18 Oct) 3 Nov (25 Nov) 24 Nov (16 Dec)	 29 July 26 Sept 11 Nov 2 Dec	 6 Sept (2-9 Sept) 7 Oct (2-11 Oct) 20 Nov 10 Dec	 7 Aug 29 Nov
Grain moisture contet at harvest (%)	8.4 (9.8)	8.0	12.4	9.2
Grain yield (t/ha) at 12%	Header 5.0 (3.3) Hand 4.7 (3.8)	Header 5.2 Hand 5.8	Header 2.4 Hand 2.9	
Total rainfall (mm)	270 (224)	314	306	318
Experimental design	RCBD	RCBD	RCBD	RCBD
No. Of replicates	3	3	4	4

Table 2. Data sets used for determination of genetic coefficients and crop model validation

Identifier	Coly 93	Early 98	Late 98	L186	L287	Whit 85
Location	northern CIA	near Hanwood	near Hanwood	CSIRO Griffith	CSIRO Griffith	near Whitton
Type of experiment	Field	Field	Field	Lysimeter	Lysimeter	Field
Previous crop	Rice 92/93	Rice 97/98	Rice 97/98	Soybean 85/86	Wheat 86	Rice 83/84
Variety	Janz	Janz	Janz	Yecora	Yecora	Bindawarra
Sowing date	1 May 93	24 Apr 98	29 Jun 98	30 May 86	25 May 87	14 Jun 85
N rate (kg N/ha)	115	154	154	138	139	123
No. irrigations	4 flood	0	0	11 sprinkler	10 sprinkler	7 (3 sprinkler and 4 flood)
Irrigation amt (mm)	226	0	0	229	188	245
Harvest date	9 Dec 83	24 Nov 98	16 Dec 98	28 Nov 86	12 Nov 87	12 Dec 85
Reference	Humphreys *et al.*. (1996)	Humphreys *et al.*. 2001	Humphreys *et al.*. 2001	Meyer 1988	Meyer 1988	Melhuish *et al.* 1985
Data used for determination of Genetic Coefficients	**YES**	-	-	-	**YES**	**YES**

e) *use the calibrated models to predict impacts of wheat after rice on watertables and rootzone salinity for a range of seasonal conditions, watertable depths, soil types, sowing dates and irrigation management*

Simulations were run for wheat using SWAGMAN® Destiny in strategic mode, which enables up to five variations in a single parameter (e.g. initial watertable depth) to be run automatically. The site conditions that were varied were initial watertable depth and salinity, initial soil water content and soil type. The management actions investigated were sowing date and irrigation management. The model was run for 39 years of daily Griffith weather data and cumulative probability distributions were developed for yield, final depth to the watertable, and final soil salinity in the upper rootzone (0-40 cm) and below 40 cm (40 cm to the watertable depth). The fixed conditions and variables used in the model simulations are summarised in Table 3, and described in more detail in Smith et al.(2005).

Initial SWC was varied from "dry" to "wet", where a wet profile has a water content at the drained upper limit (DUL or field capacity) and a dry profile has a water content at the lower limit (wilting point) over 0-1.5 m, with a water content at DUL below this depth. The SWC of the intermediate ("inter") profile was half way between the wet and dry profiles. SWC for wheat sown after rice would be expected to be similar to the wet profile, or perhaps somewhere between the wet and inter profiles, bearing in mind that the initial conditions were set on 1 January, whereas rice is ponded until around the end of February after which there is some surface soil drying. The initial dry soil profile was included as an extreme comparison, and is relevant when considering the impact of pre-irrigation of wheat when the soil profile is dry to depth, as is common after a winter crop and summer fallow.

Table 3: The fixed conditions and variables used in the model simulations

The *fixed conditions* for all runs were:	
wheat variety	cv. Janz
irrigation water salinity	0.2 dS/m (3.6 dS/m for selected simulations)
irrigation efficiency	100%
deep drainage (below 5m)	0.1mm/day
soil salinity	0.5 dS/m (soil solution)
fertility	no fertility constraint
sowing rate	n/a **–** maximum yield potential set at 7.0 t/ha
initial conditions	1 January
start of scenario	1 January
The *parameters that were varied* were:	
sowing date	**24 April** ("early wheat") **29 June** ("late wheat")
weather	**39 years** of CSIRO Griffith data from 1962 to 2000
irrigation	**no irrigation** **one** irrigation (100 mm) at flowering **two** irrigations at flowering and grain filling (100 mm each) **ETo=60, 90 or 120 mm** irrigated at cumulative ETo-rain of 60, 90 or 120 mm – irrigation amount 60, 90 and 120 mm, respectively
soil type	**Mundiwa clay loam** (shallow clay loam A <10cm and heavy clay B) **Yooroobla clay** (self-mulching clay soil – heavy clay to depth) **Beelbangera clay loam** (deeper clay loam A and clay B but better structured and with a higher hydraulic conductivity than Mundiwa) **Hanwood loam** (clay loam to depth)
initial soil water content	**wet -** drained upper limit (DUL **-** similar to field capacity) throughout profile **dry** - lower limit (LL-wilting point) 0-1.5 m, then DUL below 1.5 m **inter** - mid-way beteween DUL and LL to 1.5 m,then DUL below 1.5 m
initial depth to watertable	**0.5 m** **1.0 m** **1.5 m**
starting watertable salinity	**1 dS/m** **20 dS/m**

5. Detailed results and discussion

a) knowledge of farmers' perceptions of:

(i) *constraints to growing crops/pastures immediately after rice*
(ii) *factors leading to successful production of crops after rice*
(iii) *impacts on sustainability (environmental, economic)*

A mail survey of rice growers was conducted in May 1998 with 310 useable responses (14% response rate). Forty-three per cent of the respondents regularly grew winter crops shortly after rice harvest, mostly wheat or oats. Extrapolation of the survey results suggested that about 39% of the rice area in the MIA&Benerembah was regularly sown to crops after rice, compared with only 5-7% of the area in other regions. The survey responses may be biased – people who practised cropping after rice may have been more inclined to reply to the survey. The main reasons for sowing crops after rice were economic and to use stored soil water. The 3 main keys to success were considered to be good layouts/drainage, earliness (early rice harvest, early stubble burning, early winter crop sowing) and a good stubble burn. Further details are available in Humphreys and Bhuiyan (1999).

b) On-farm replicated field experiments to determine impacts on watertables of growing crops after rice, and their productivity

<u>1998 field experiment</u>

1998 Site 1 – Beelbangera clay loam

Rainfall from 15 April to 24 November totalled 298 mm, and was fairly evenly spread across the growing season (Fig. 1). Total dry matter production in the early sown wheat was higher than in the late sown wheat throughout the season (Fig. 5). Grain yield was also higher in the early sown wheat (4.7 t/ha *vs.* 3.8 t/ha at 12% moisture).

In mid April the depth to watertable in all treatments was around 1.45 m. By the end of June the watertable in the early sown wheat was significantly lower than in the other treatments (Fig. 1). The watertable in the stubble retained and late sown wheat treatments was much more responsive to significant rainfall events, while the watertable continued to decline in the early sown wheat until September. The decline was associated with higher water use by the early sown crop as evidenced by soil drying (Fig. 2). A similar effect was observed in the late sown crop as the season progressed. The sudden rise in the watertable in September in the early sown wheat was probably due to a rise in regional groundwater pressures coincident with the start of the irrigation season. This was investigated further during 1999 (see below). The soil profile with stubble retained remained at near saturation throughout the season, whereas soil water depletion of 60-100 mm occurred in the wheat treatments (Fig. 3).

Fig. 1. Effect of sowing wheat after rice on depth to watertable - Site 1, 1998

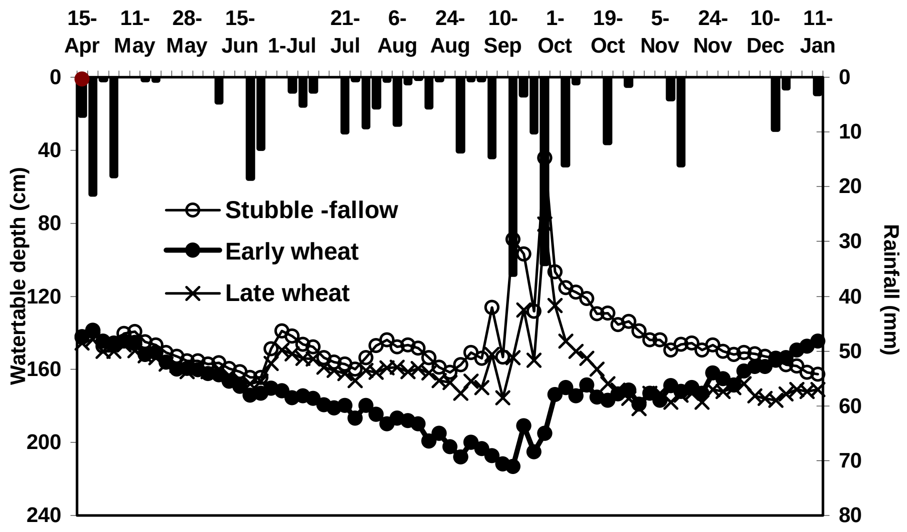


Fig. 2 Soil water content (SWC) at 0.4 m depth - Site 1, 1998

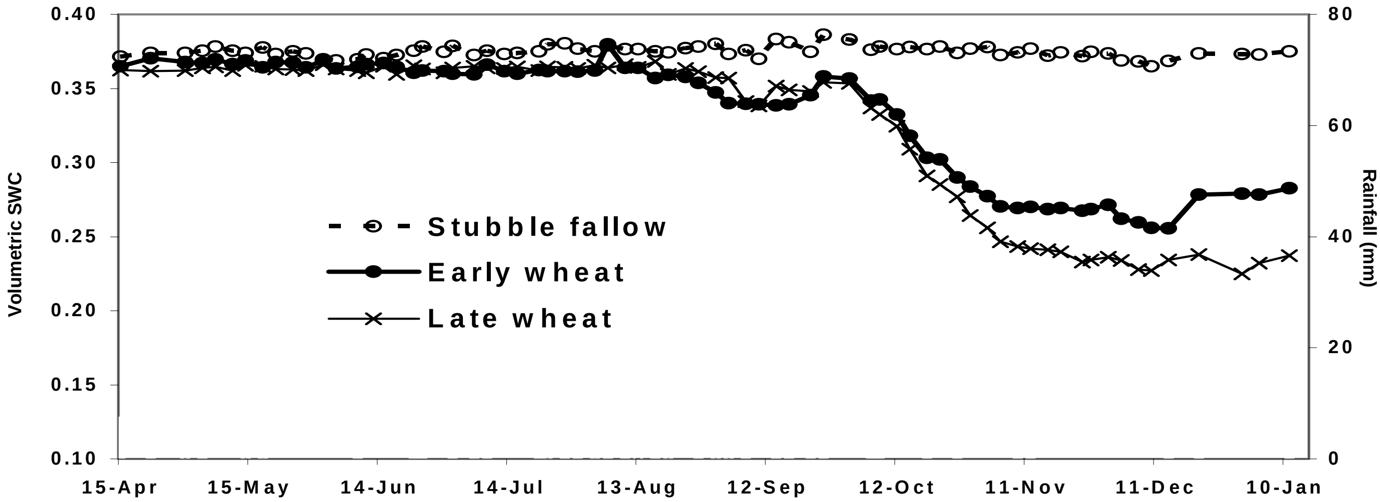
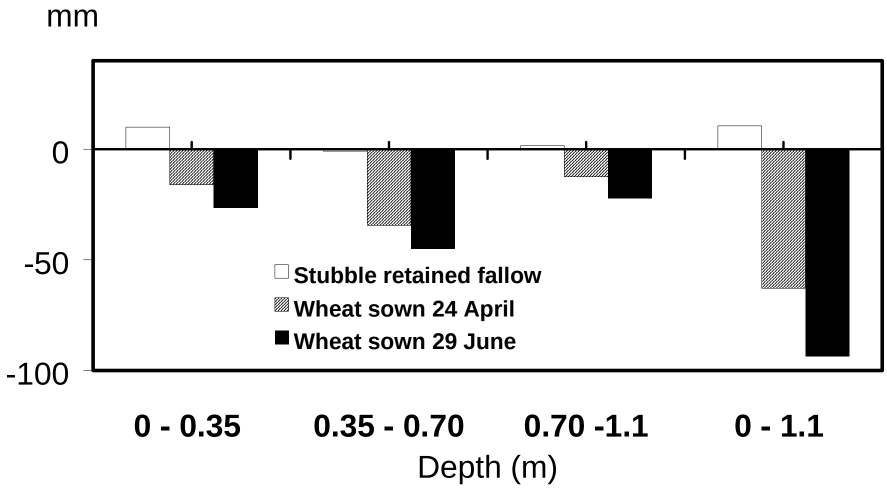


Fig. 3 Soil water depletion - Site 1, 1998



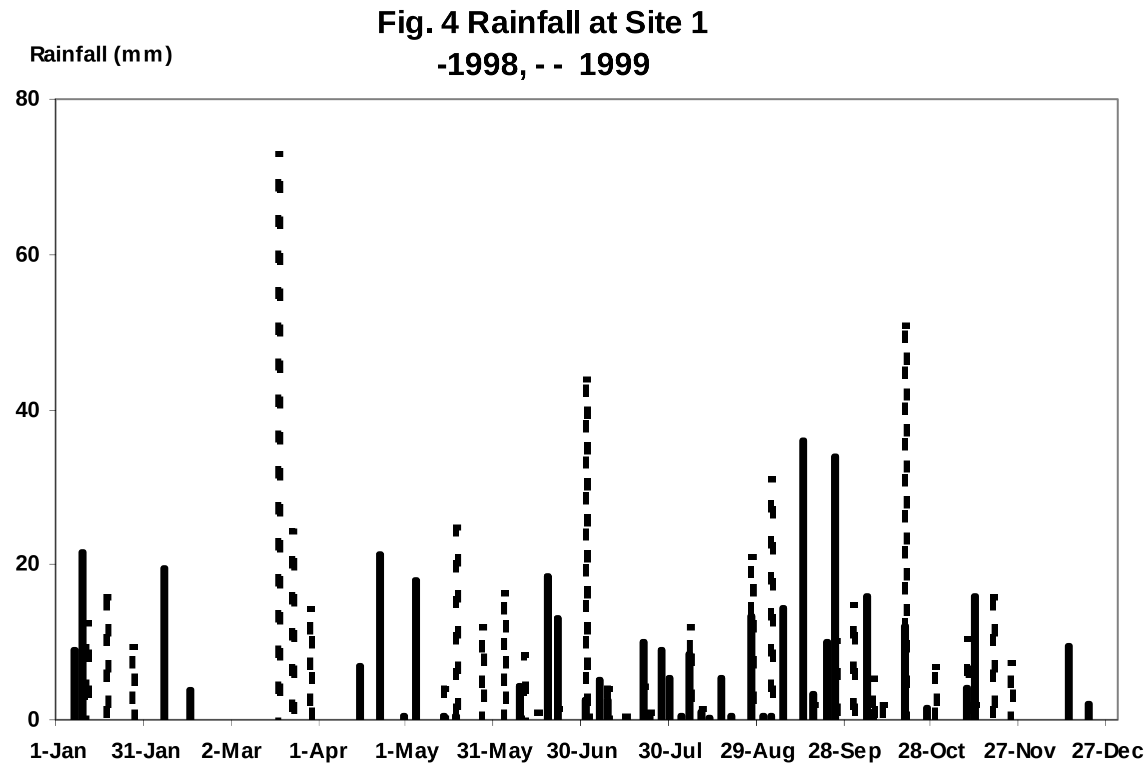


Fig. 4 Rainfall at Site 1
-1998, - - 1999
Rainfall (mm)
80
60
40
20
0
1-Jan
31-Jan
2-Mar
1-Apr
1-May
31-May
30-Jun
30-Jul
29-Aug
28-Sep
28-Oct
27-Nov
27-Dec

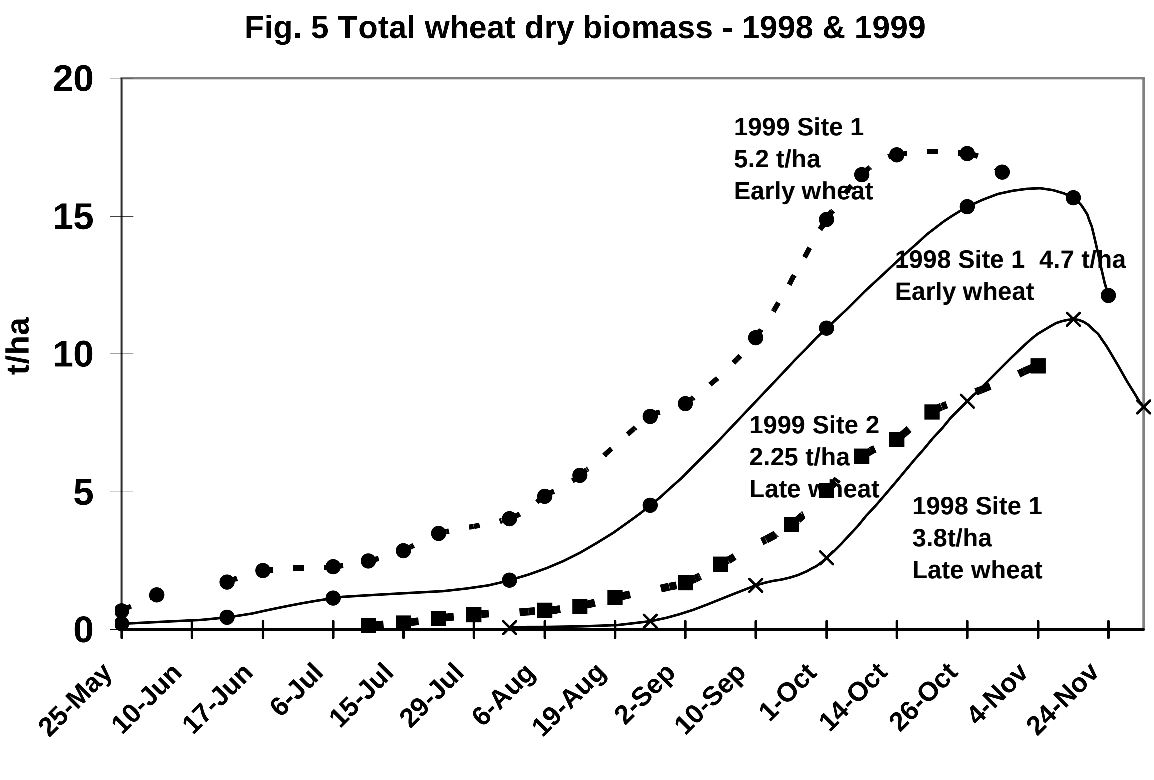


Fig. 5 Total wheat dry biomass - 1998 & 1999
t/ha
20
15
10
5
0
1999 Site 1
5.2 t/ha
Early wheat
1998 Site 1 4.7 t/ha
Early wheat
1999 Site 2
2.25 t/ha
Late wheat
1998 Site 1
3.8t/ha
Late wheat
25-May
10-Jun
17-Jun
6-Jul
15-Jul
29-Jul
6-Aug
19-Aug
2-Sep
10-Sep
1-Oct
14-Oct
26-Oct
4-Nov
24-Nov

__1999 field experiments__

1999 Site 1- Beelbangera clay loam

Total rainfall at Site 1 was similar in 1998 and 1999 (314 mm between 15 April and 24 November 1999 compared with 298 mm in 1998). Again it was relatively evenly distributed across the growing season (Fig. 4). Biomass production and grain yield of early wheat were slightly higher than in 1998 (5.2 cf. 4.7 t/ha) (Fig. 5). The effects of growing wheat on depth to the water table and soil water depletion were similar to those observed in 1998 (Fig. 6). Figure 7 compares soil water content at 0.4 m depth from shortly after harvest of the first crop through to harvest of the second crop. At the end of the first crop the soil was much drier in the wheat plots than in the fallow. Heavy rainfall in late March did not fully refill the profile, hence the decision to irrigate the site (including fallow plots) on 1 April. As the season progressed, the crop again dried down the profile whereas the soil water content in the fallow remained at near saturation as in 1998.

As in 1998, the watertable under the wheat slowly declined until early October, and then rose around the time the adjacent paddock was flooded for rice sowing. The piezometric data shows that under the wheat there was a downwards gradient from 3 to 6 m until early August. There was no gradient from mid August to mid October, and an upwards gradient thereafter (Fig. 6). These data suggest that the effect of the wheat on the watertable was confounded by the regional groundwater pressures.

Evaporation from the microlysimeters in the stubble plots was compared with reference evapotranspiration (ETo) at CSIRO Griffith, 10 km from the field Site. The “crop” factor Kc was calculated as Kc=measured evaporation/ETo. The crop factor averaged 0.13 (standard deviation 0.07) between mid August and early November (Fig. 8).

Fig. 6. Piezometer pressure levels in wheat plots (2 m, 3 m) and adjacent to experiment (6 m) at Site 1 in 1999

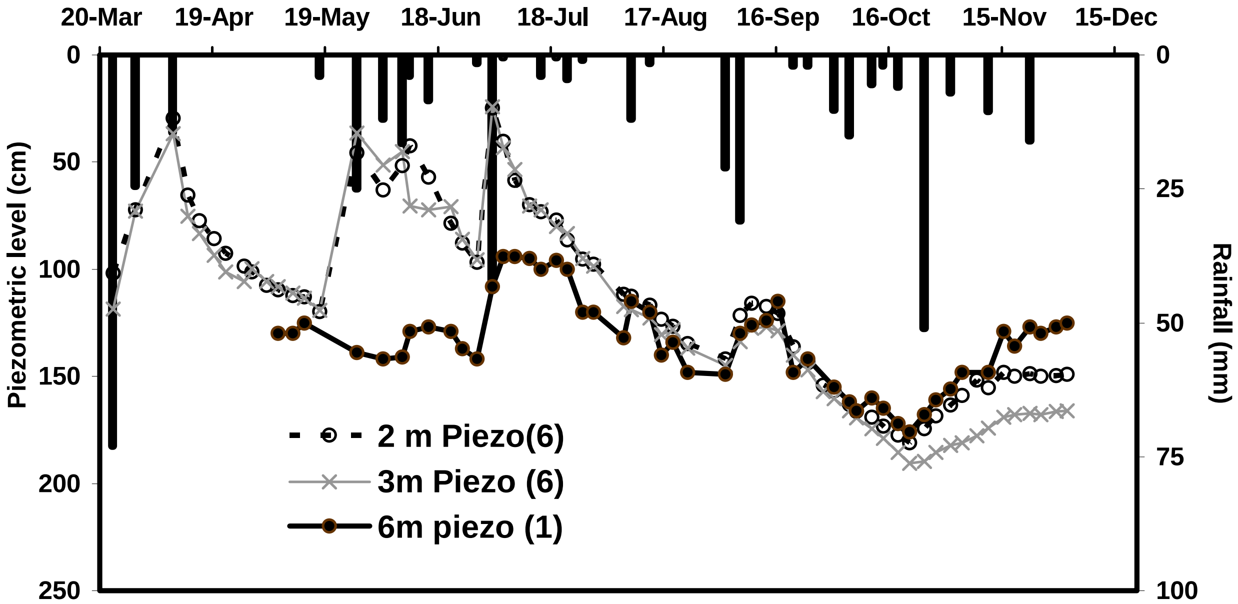


Fig. 7. Soil water content at 0.4 m, Beelbangera clay loam, 1999

Arrows show dates of flood irrigations - to simulate post rice conditions (full profile) in 2nd year, & to establish crop

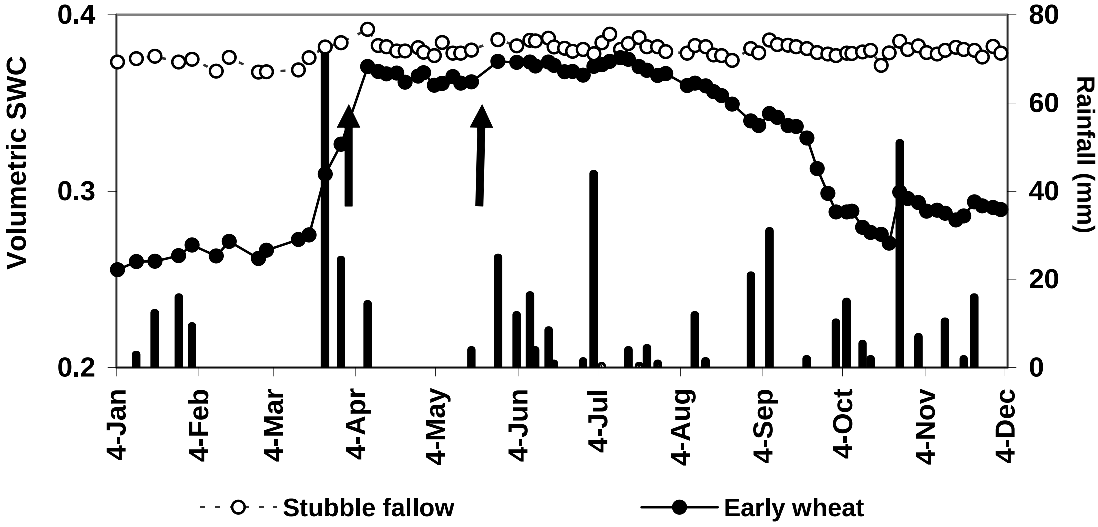
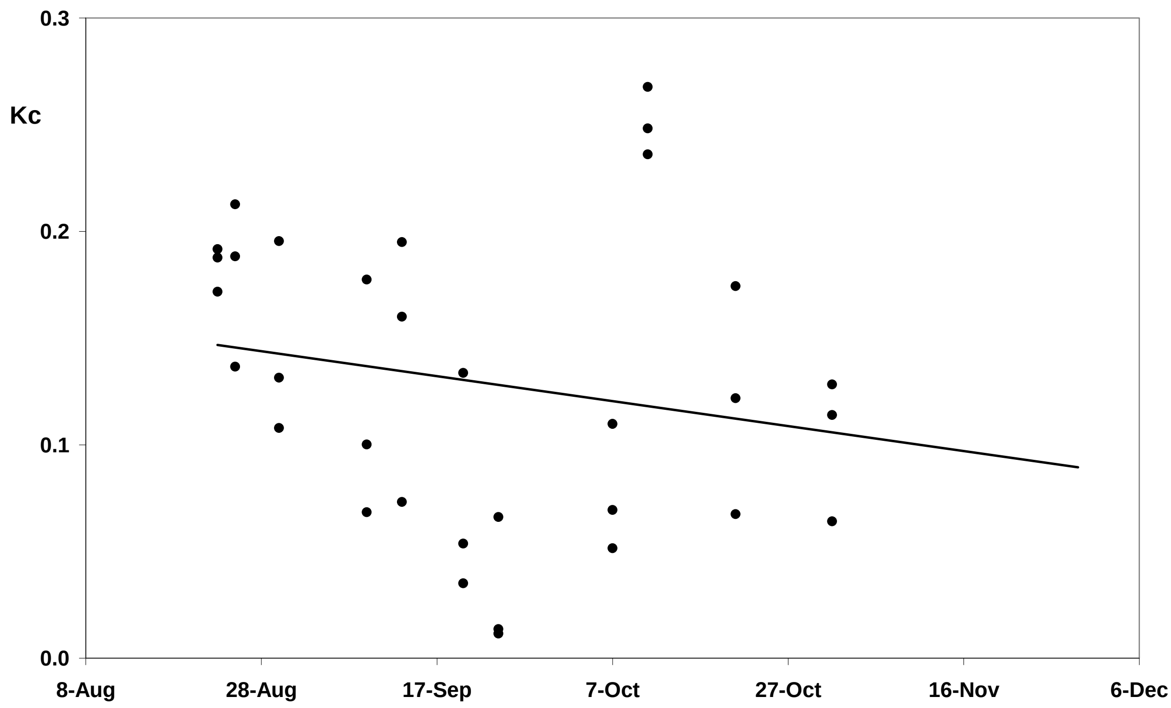


Fig. 8. Fallow "crop" factor (Kc = soil evaporation/ETo) determined in microlysimeters at Site 1 in 1999



1999 Site 2 - Wilbriggie clay loam

A second site comparing stubble retained fallow and planted treatments was established on a heavier soil type, as the subsoil at Site 1 appeared to be a relatively permeable subplastic clay. Wet weather in autumn delayed rice harvest and establishment of the wheat. The wheat was sown on 20 May 1999 and was resown on 28 May 1999 due to waterlogging damage caused by heavy rain shortly after the first sowing.

Crop growth was suppressed due to early waterlogging and later due to a severe rust infestation (Fig. 5). Biomass production peaked at around 10 t/ha (yield 2.3 t/ha). The crop dried the soil profile compared to the fallow treatment (e.g. Fig. 9), but not to the same extent as at Site 1. There was no difference in depth to the watertable between the treatments (Fig. 10) throughout the season.

The lumped water balance indicated that deep drainage below 1 m was similar under wheat and fallow areas, and that deep drainage was associated with significant rain events (Fig. 11). However upflow was much higher with wheat, and at the time of harvest net upflow in the wheat was 0.9 ML/ha, compared with net deep drainage of 0.1 ML/ha in the fallow area. Therefore there was a difference of 1 ML/ha in net recharge between the wheat and fallow areas.

The crop factor determined from the microlysimeters averaged 0.10 (standard deviation 0.04) for the period from late August to early November in the stubble retained treatment (Fig. 12).

Fig. 9. Soil water content (SWC) at 0.4 m depth - Site 2, 1999

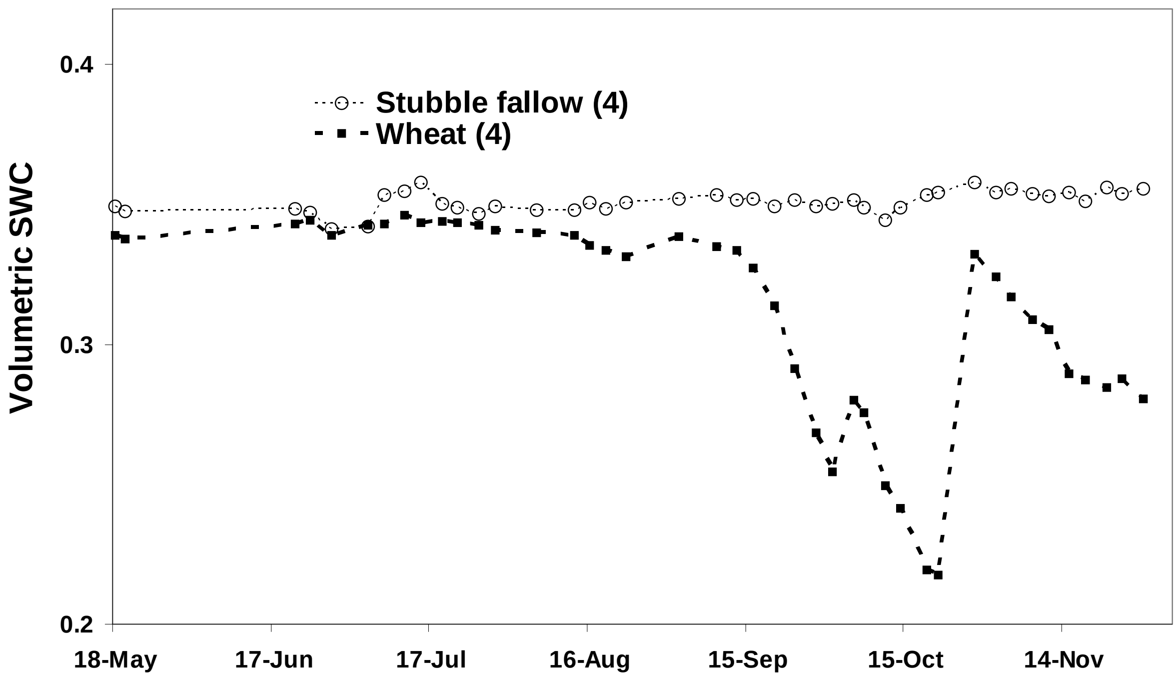


Fig. 10. Effect of sowing wheat on depth to watertable (3 m piezometer) Site 2, 1999 (vertical bars are STDs)

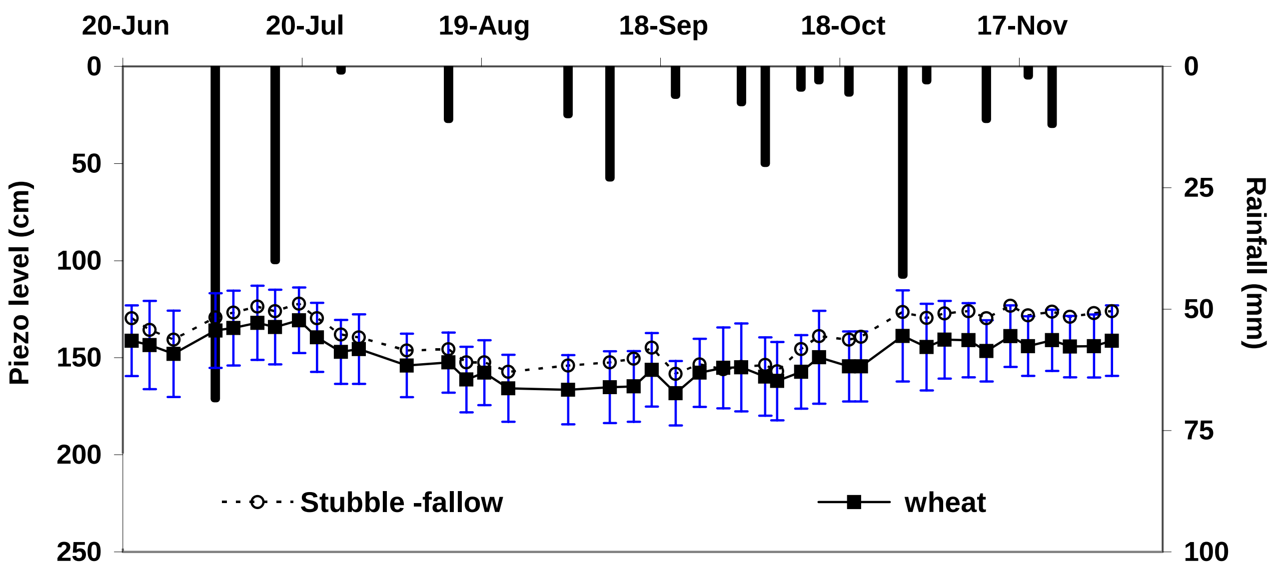


Fig. 11 Deep drainage in fallow at Site 2 (2000) calculated from lumped water balance (positive values are deep drainage, negative values are upflow)

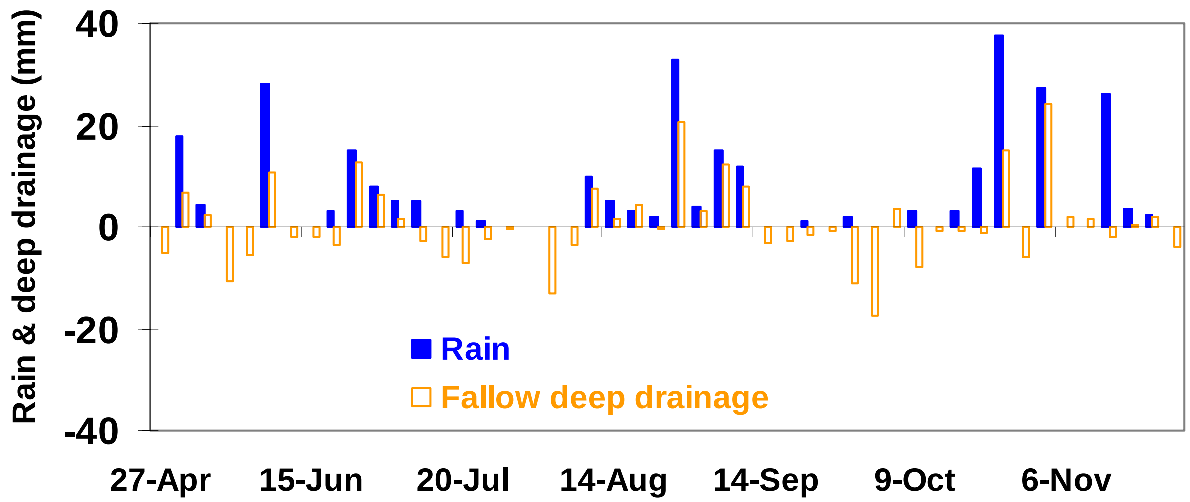
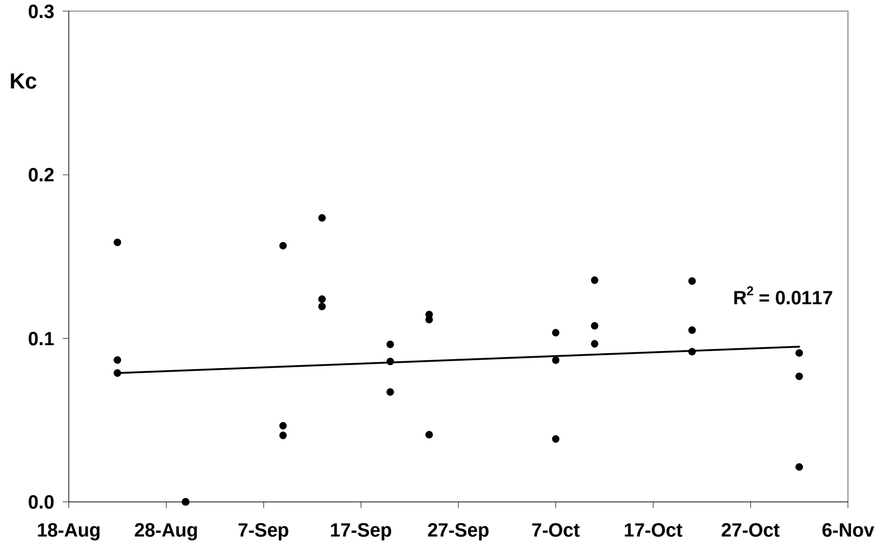


Fig. 12. Fallow "crop" factor (Kc = soil evaporation/ETo) determined in microlysimeters at Site 1 in 1999



2000 Site 2 – Wilbriggie clay loam

The fourth and final field experiment comparing wheat and fallow treatments was implemented in 2000 on the site used in 1999. The site was pre-irrigated on 29 February to fill the profile to simulate soil water status at the end of a rice crop. Soil water monitoring was enhanced by the installation of Enviroscan loggers in 6 plots, with soil water content at 5 depths logged hourly. This provided much better information on the soil water dynamics, as demonstrated in Figure 13a, which shows that most of the rain (falling on 2 Nov.) in a wheat plot was captured in the upper rootzone, and some drainage to 40-70 cm. As the increase in soil water content at these depths was very small, and the soil remained relatively dry at 40cm, the amount of drainage past 70 cm is likely to have been small. There was no effect at 100 cm, although the soil at this depth was already very wet. As in previous years, soil water content in the fallow treatment remained high throughout the season, whereas there was significant drying of the rootzone in the wheat treatments (Figs 13b,c).

As in 1999, the lumped water balance suggested much higher upflow in the wheat plots (1.6 ML/ha) compared with the fallow (0.6 ML/ha), while deep drainage below 1 m was similar (0.5 ML/ha in the wheat, 0.7 ML/ha in the fallow). As a result, there was net upflow of 1.1 ML/ha in the wheat compared with net recharge of 0.1 ML/ha in the fallow.

Fig. 13a. VWC increase after a rain event of 37mm in a wheat plot - site 2, 2000

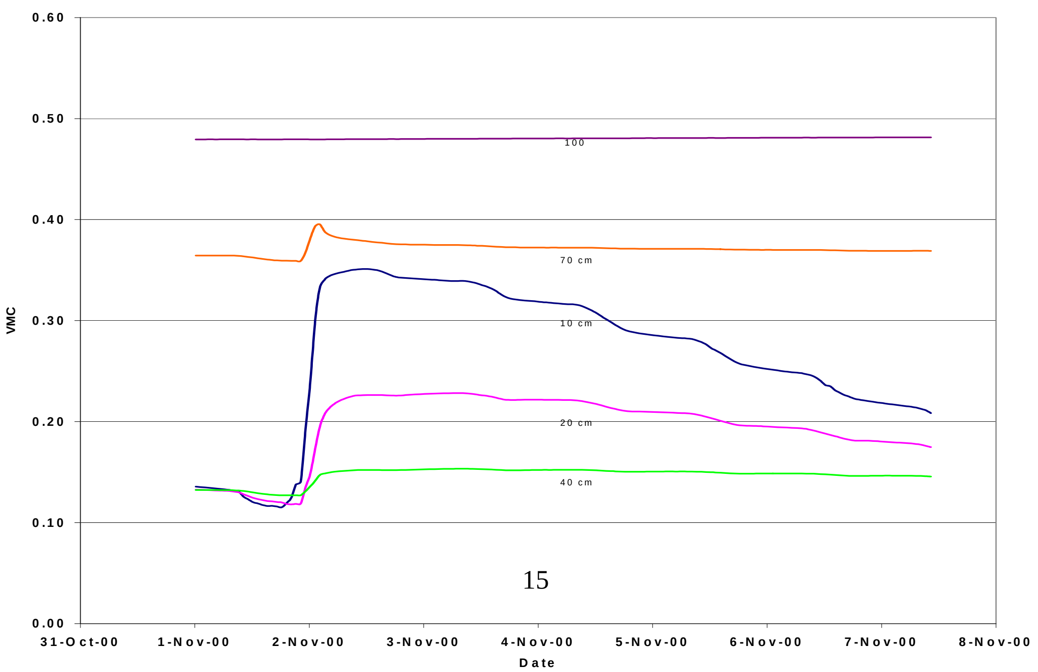


Fig. 13b. VWC @ 10cm for wheat and stubble

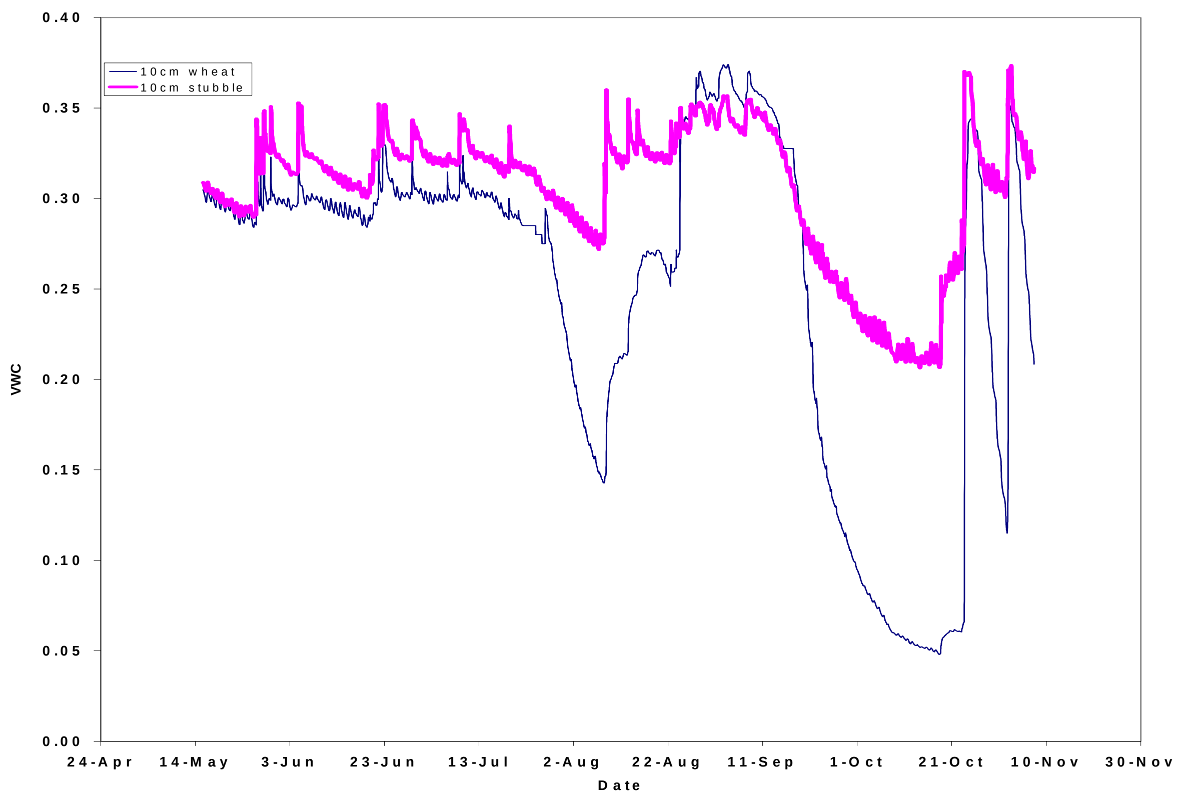
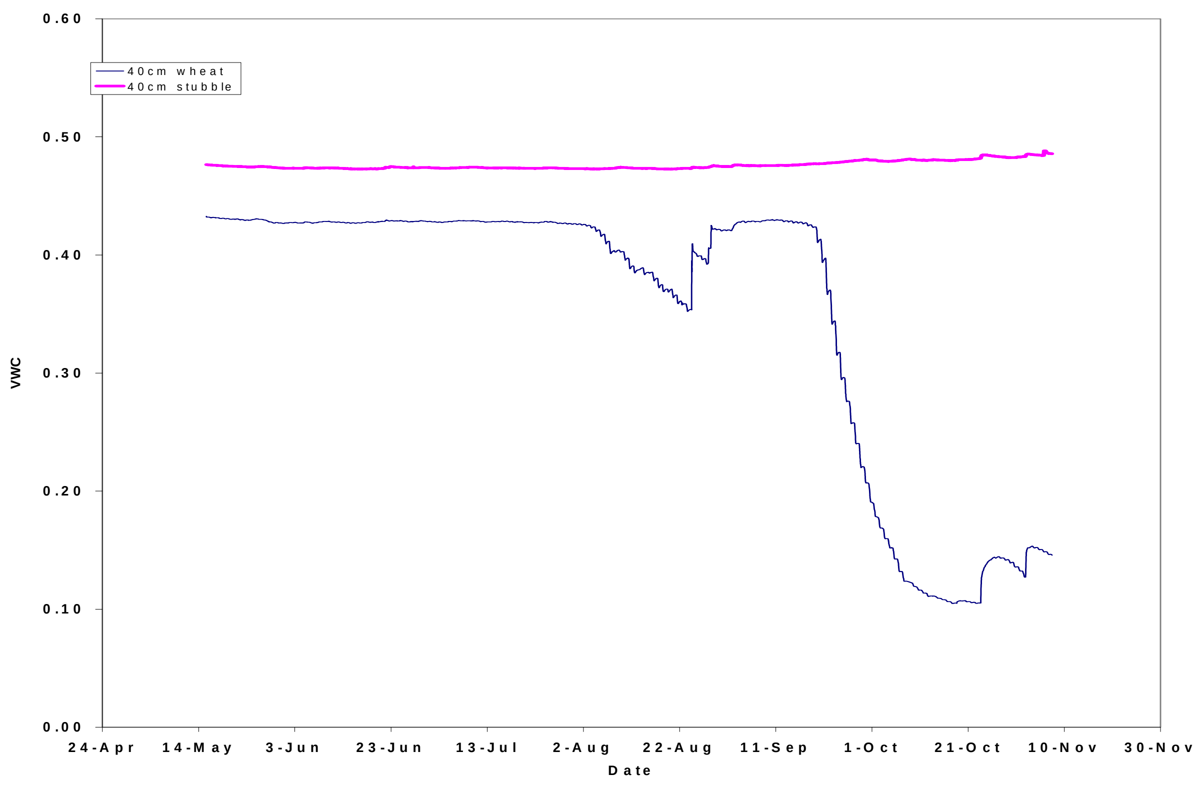


Fig. 13c. VWC @ 40cm for wheat and stubble



c) and d) Model calibration and validation

Predicted and observed grain yields for the six data sets are presented in Table 4. The yield range (3.4 to 5.9 t/ha) was lower than desirable for demonstrating the robustness of the models, however the range was limited by the availability of good quality data sets. Agreement between the model predictions and the field observations was excellent except for the Late 98 crop yield simulated by SWAGMAN® Destiny. Here the observed yield was 3.4 t/ha compared to the simulated yield of 1.9 t/ha due to water deficit stress as the season progressed. This difference may be due to the external effect of a rise in the regional watertable observed when an adjacent paddock was flooded for rice (25th Sept). Destiny simulated the soil profile to be a lot drier than the observed values during October and November which resulted in soil water deficit stress and the lower yield prediction. This effect did not occur with CERES Wheat and we can only conclude that one or both the models got it wrong to some degree.

Table 4. Observed and predicted grain yields

Soil Type	**Identifier**	**Grain yield (t/ha) (dry)**			
		Obs.	**CERES**	**Destiny**	**Cultivar**
Yooroobla Clay (Cal)	Coly93	4.0	4.1	4.0	Janz
Beelbangera Clay Loam (Ind)	Early98	4.2	4.3	4.1	Janz
Beelbangera Clay Loam (Ind)	Late98	3.4	3.4	1.9	Janz
Mundiwa Clay Loam(Cal)	L287	5.5	5.5	5.4	Yecora
Hanwood Loam (Cal) (Ind)	L186	5.9	5.7	5.7	Yecora
Mundiwa Clay Loam	L287	5.5	5.4	5.4	Yecora
Mundiwa Clay Loam (Cal)	Whit85	4.4	4.3	4.4	Bindawarra

Cal or Ind – Calibrated or independent data setsdata used for determining genetic coefficients

There was very good agreement between predicted and observed values for a wide range of parameters for both CERES Wheat and SWAGMAN® Destiny, including the time course of above ground biomass production, leaf area index, root length density, soil water content at different depths in the profile, and evapotranspiration (e.g. Figs 14-16). Further results of the model validations are provided in Smith et al. (2005).

Fig. 14. Observed and simulated soil volumetric water content at 10 cm for early wheat in 1998, independent data set

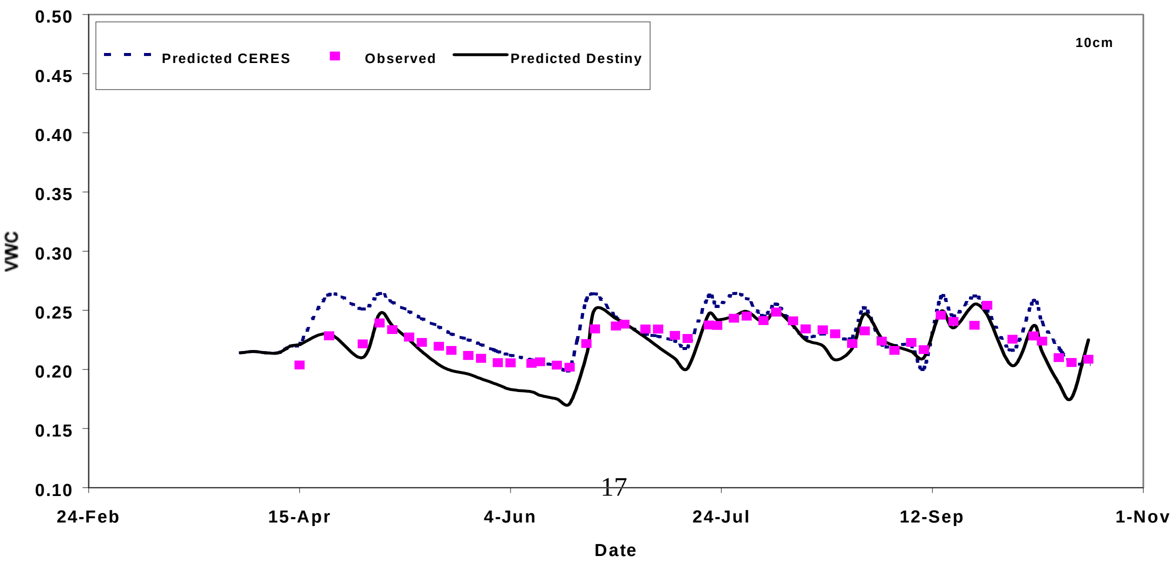


Fig. 15. Observed and simulated soil volumetric water content at 60 cm for early wheat in 1998, independent data set

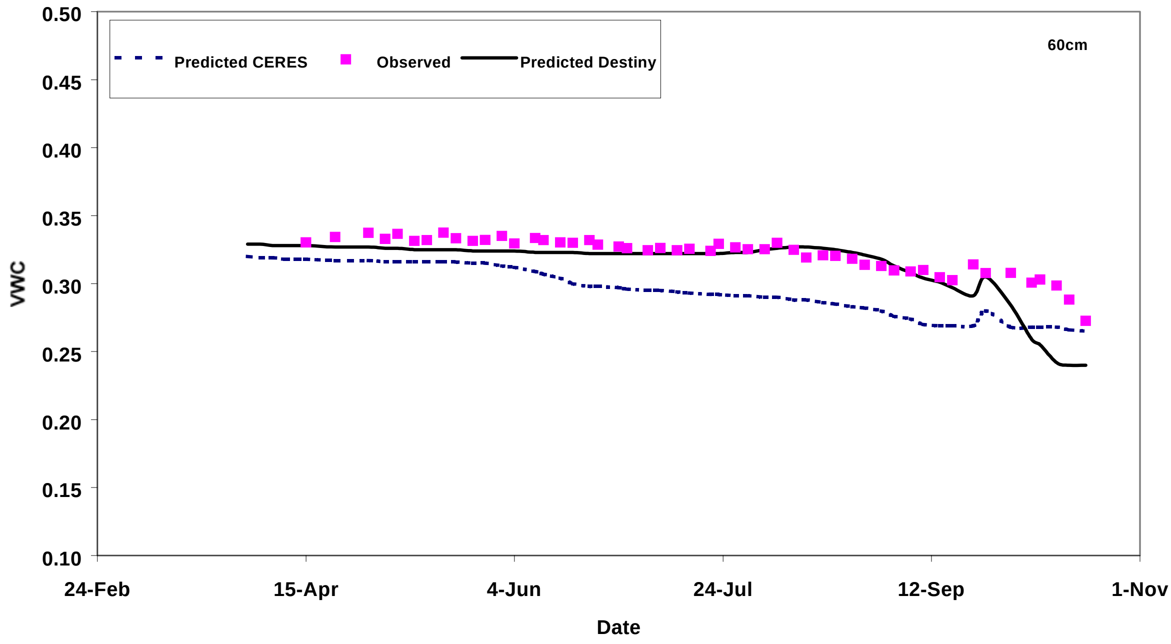
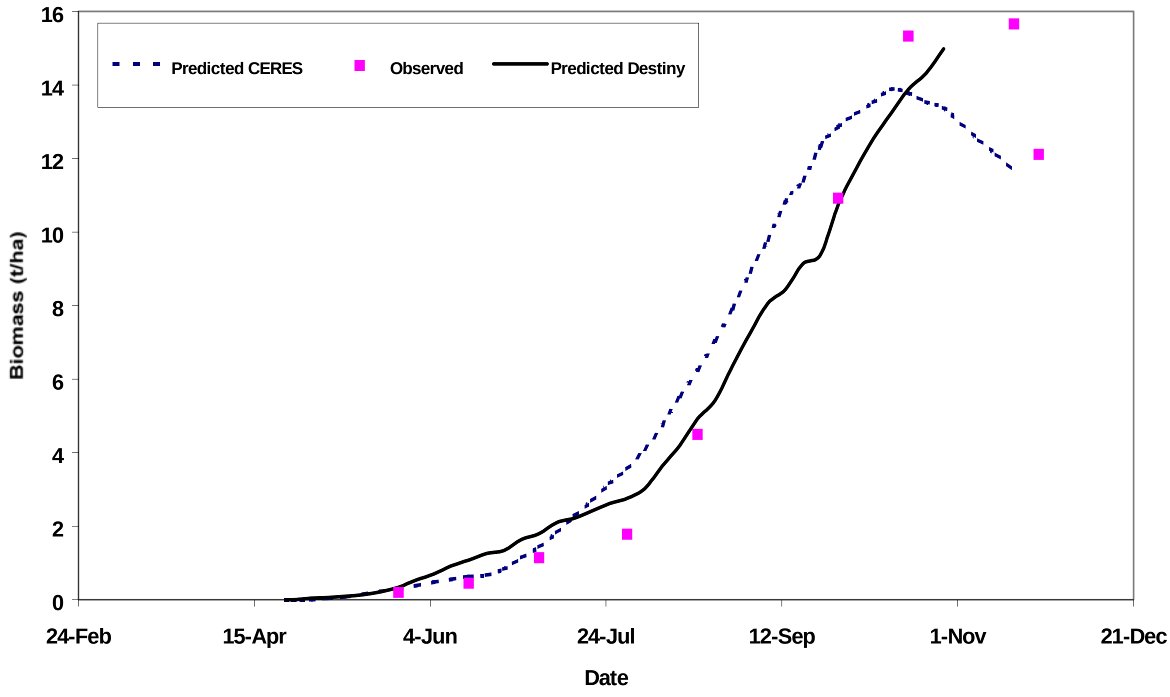


Fig. 16. Observed and simulated above ground biomass for early wheat in 1998, independent data set



e) Model simulations

Growing season rainfall and ETo

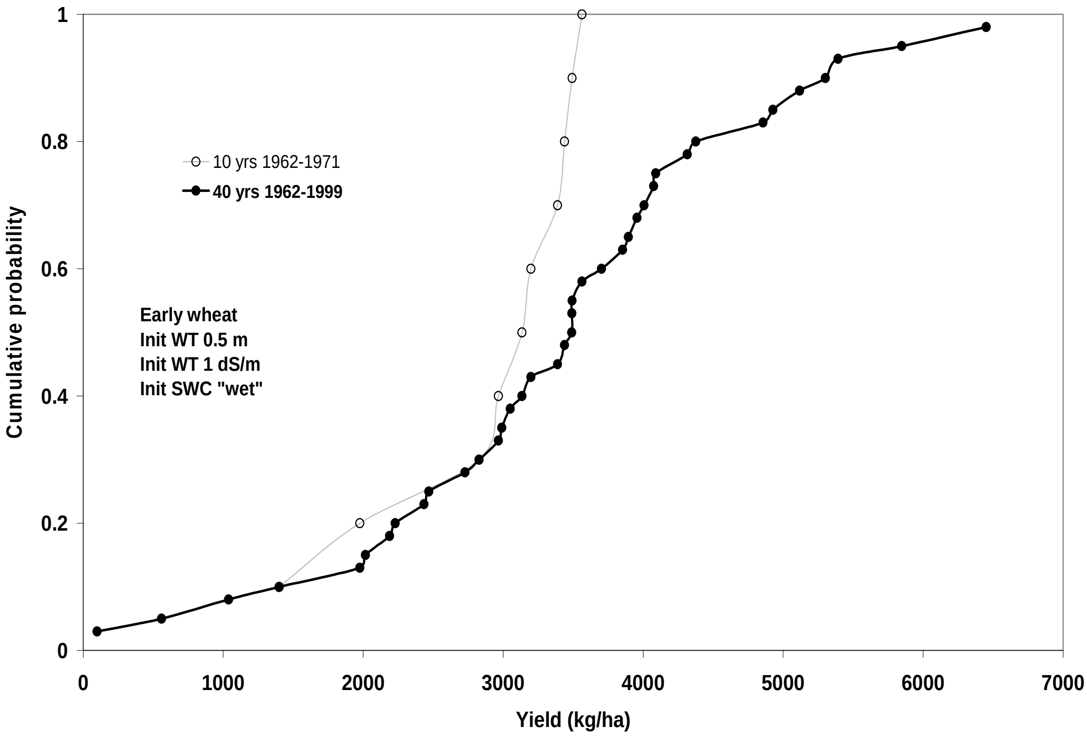
At the time this work commenced, SWAGMAN® Destiny was only capable of automatically running simulations for 10 years of weather data at a time. The data in Table 5 show that 10 consecutive years of weather data are not sufficient to cover the range of variability in total rain and reference evaporation (ETo) over the growing season. For example, growing season rainfall for early wheat in 1962-1971 ranged from 125-310 mm, whereas over the 40 years from 1962-2001 it ranged from 49- 353 mm. Similarly, ETo ranged from 508-580 mm in 1962-1971, and from 412- 660 mm over the 40 years. The yield probability distributions can be quite different when generated from data over one decade compared with over 39 years (e.g. Fig. 17). A Windows version of SWAGMAN® Destiny was completed in early 2001 with the capability of running the model for an unlimited number of years of weather data, enabling the simulations to be run using the 39 years of Griffith weather data available at that time to produce cumulative probability distributions. Therefore all simulations were repeated using 39 years of weather data.

Table 5. Mean total rain and potential evapotranspiration (ETo) for each decade from sowing to physiological maturity (dates of physiological maturity)

Early wheat sown 24 April								
Decade	**Rain (mm)**				**ETo (mm)**			
	Mean	Max	Min	Std Dev	Mean	Max	Min	Std Dev
1962-71	223	310	125	52	547	580	508	28
1972-81	229	353	105	83	455	563	382	55
1982-91	224	305	49	71	488	574	412	48
1992-01	225	337	58	80	513	660	456	59
Late wheat sown 29 June								
Decade	**Rain (mm)**				**ETo (mm)**			
	Mean	Max	Min	Std Dev	Mean	Max	Min	Std Dev
1962-71	181	239	89	43	709	782	660	32
1972-81	180	300	48	79	594	708	505	63
1982-91	168	239	14	63	679	743	602	41
1992-01	225	356	74	87	675	817	601	68

More detailed analysis of the data showed that ETo over the growing season for late sown wheat was always higher (by 123 to 157 mm) than for early sown wheat, while rain was usually less (by up to 36 mm) (Smith et al. 2005). Therefore, non-irrigated late sown wheat is likely to suffer greater water deficit stress than early sown wheat. Furthermore, the irrigation requirement to achieve yield potential was usually considerably higher for late sown wheat (by -63 to 377 mm, median difference 190 mm, difference >100 mm in 35 out of 39 years).

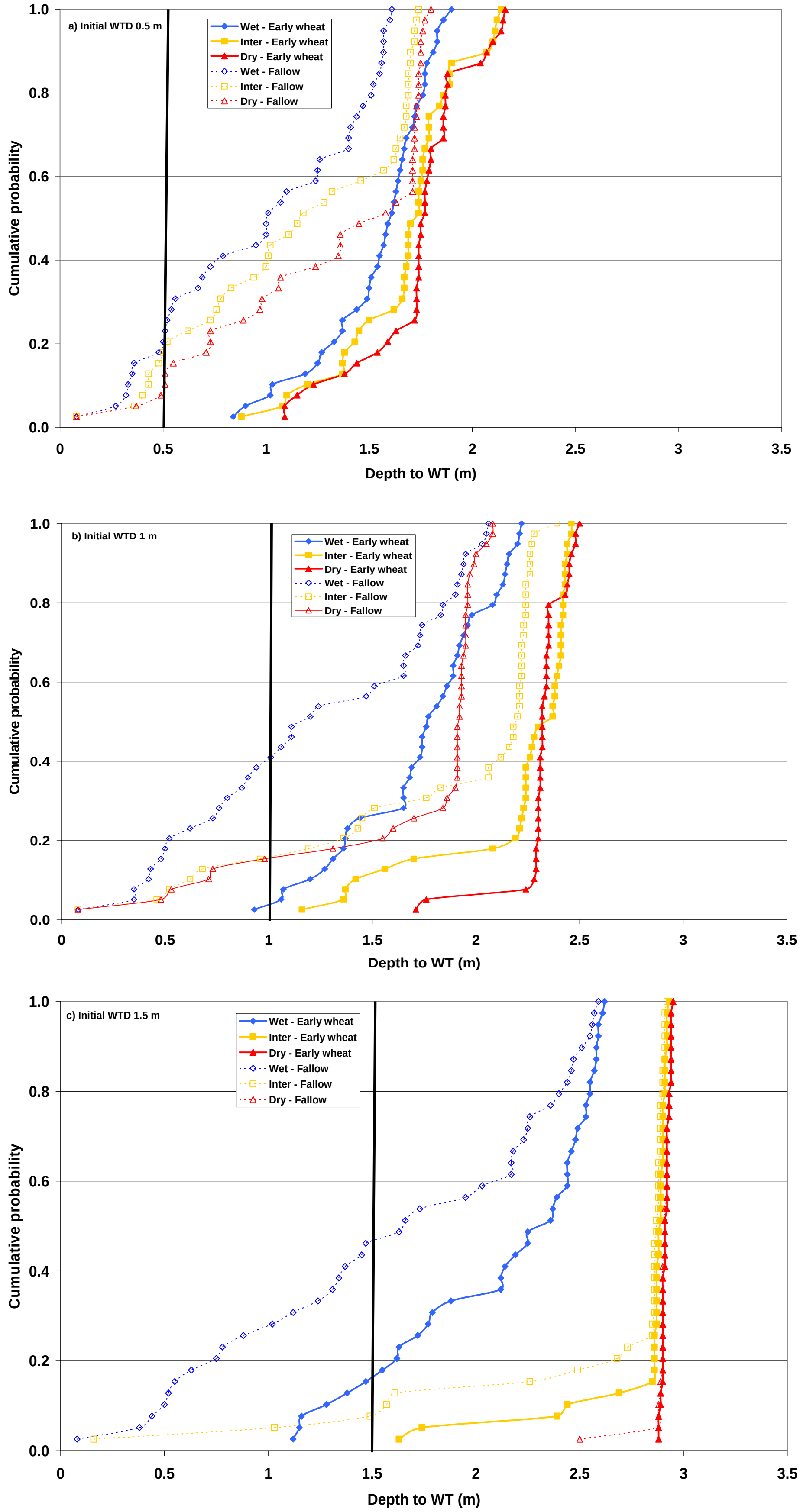
Fig. 17. Cumulative probability yield distributions for 10 and 39 years of Griffith weather for non-irrigated early wheat with initial WTD 0.5 m, 1 dS/m and wet soil.



Fallow vs early wheat

Changes in the depth to the watertable were affected by initial watertable depth (WTD) and initial soil water content (SWC) for both fallow and sown situations. With early wheat, the watertable at the end of the season was almost always lower than at the start of the season, regardless of the initial WTD and SWC. That is, there was almost always net discharge, due to the combined effects of both crop water use and deep drainage. Net recharge of the watertable only occurred in 0%, 3% and 15% of years with wet soil and initial WTD 0.5, 1 and 1.5 m respectively. In the few years where net recharge occurred it was relatively small and resulted in watertable rises of a few centimetres to about 0.4 m. In contrast, net recharge occurred more often in the fallow situation (especially when initial soil water content was high, as after rice) and the final WTD was often considerably lower (by up to 0.5m), and never higher, for early wheat compared with fallow (Figs 18a-c). In the fallow, net recharge (watertable rise of up to 0.4 m) occurred in 15-18% of years with wet or inter SWC and 0.5 m initial WTD. With 1 m initial WTD net recharge occurred in 38% of years with wet SWC (watertable rise of up to 0.9 m) and in 15% of years with dry and inter SWC. For an initial 1.5m WTD, net recharge (watertable rise of up to 1.4 m) occurred in 46% of years with wet SWC.

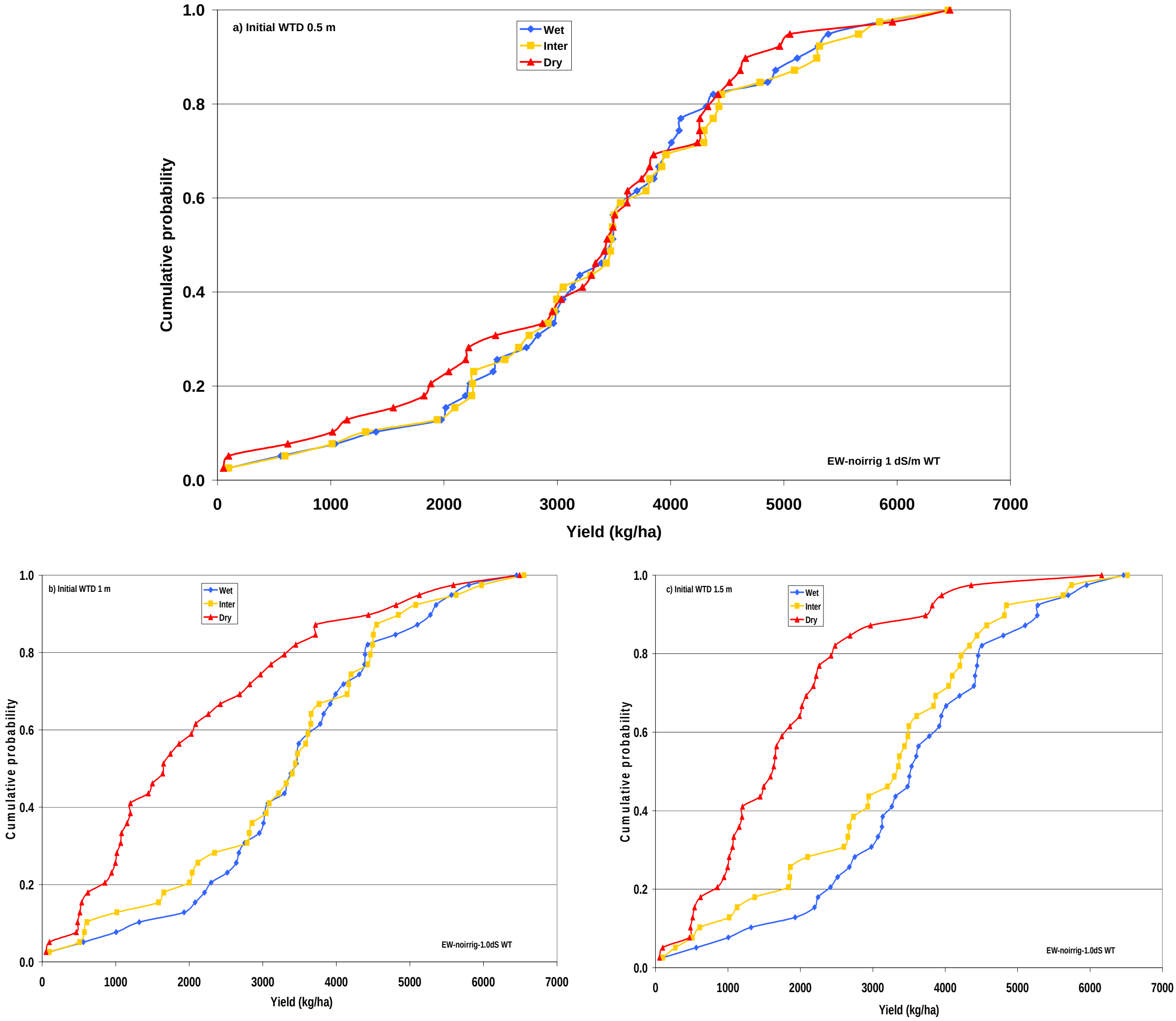
Figs 18a-c. Effect of initial SWC and WTD on final watertable depth for early wheat compared with fallow landuse (initial watertable salinity 1 dS/m, no irrigation)



Effect of initial soil water content, watertable depth and watertable salinity on yield of non-irrigated early wheat

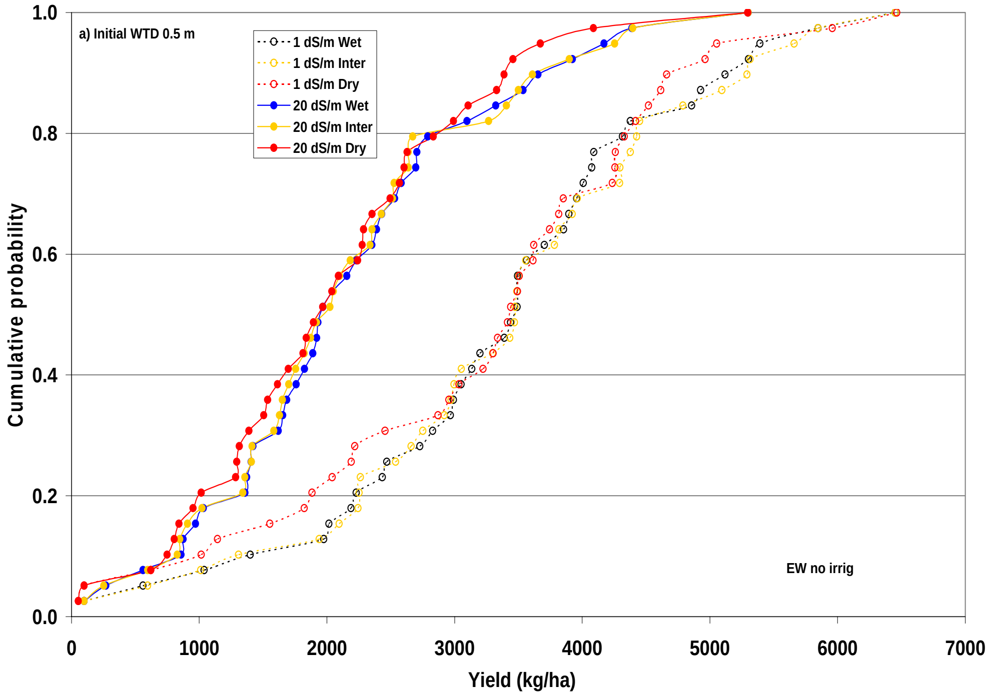
Yields of early wheat ranged from almost zero to about 6.5 t/ha for all starting conditions (Figs 19a-c), despite the lack of irrigation. Extremely low yields (all WTD and SWC) occurred in 1982 and 1994 when rain during the growing season was only 49 and 58 mm, respectively. With initial 0.5 m WTD, there was little effect of initial SWC on yield. Yields exceeded 3, 4 and 5 t/ha in 70%, 31% and 13% of years with 0.5 m WTD. The yield distribution for wet soil was similar for all initial WTD. However, as initial WTD increased, the effect of initial SWC on yield increased – with large yield declines of up to 2 t/ha when starting with a dry profile for WTD of 1 and 1.5 m. The data suggest that pre-irrigation of a dry soil will result in yield increases of 1-2 t/ha in all but the driest and wettest years for watertables of 1 m and deeper. If the watertable is shallow (0.5 m) and fresh, there is little benefit (but no yield penalty) of pre-irrigation. Yields with initial intermediate SWC were usually within 0-0.5 t/ha of yields with wet soil for all initial WTD, suggesting only a small benefit of preirrigation for wheat after rice.

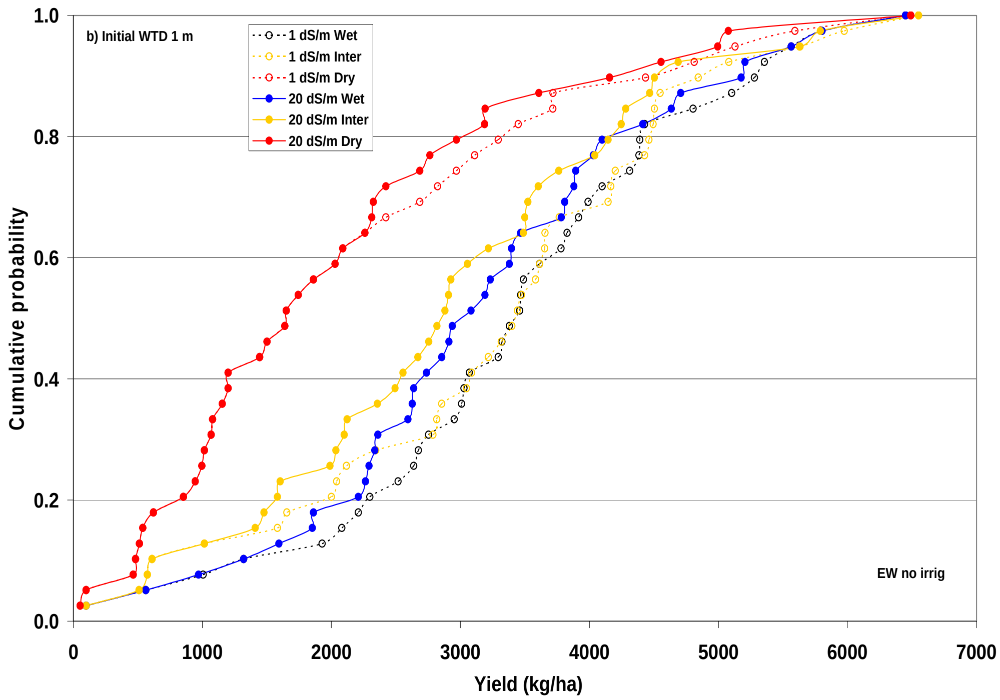
Figs 19a-c. Yield of early wheat as affected by initial SWC and WTD for 1 dS/m watertable, no irrigation



With a watertable salinity of 20 dS/m, yield reductions in excess of 1 t/ha were common for initial WTD 0.5 m compared with 1 dS/m watertable (Figs 20a,b). However, the effect of initial watertable salinity on yield was small to negligible for deeper initial WTD.

Figs 20a,b. Yield of early wheat as affected by initial watertable salinity

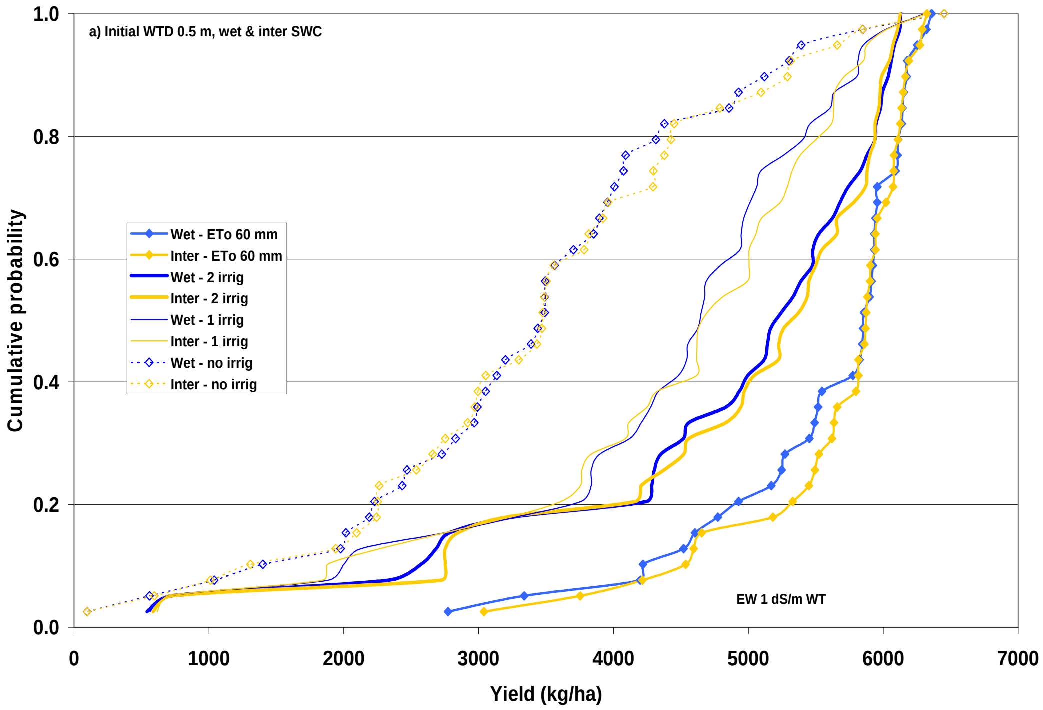


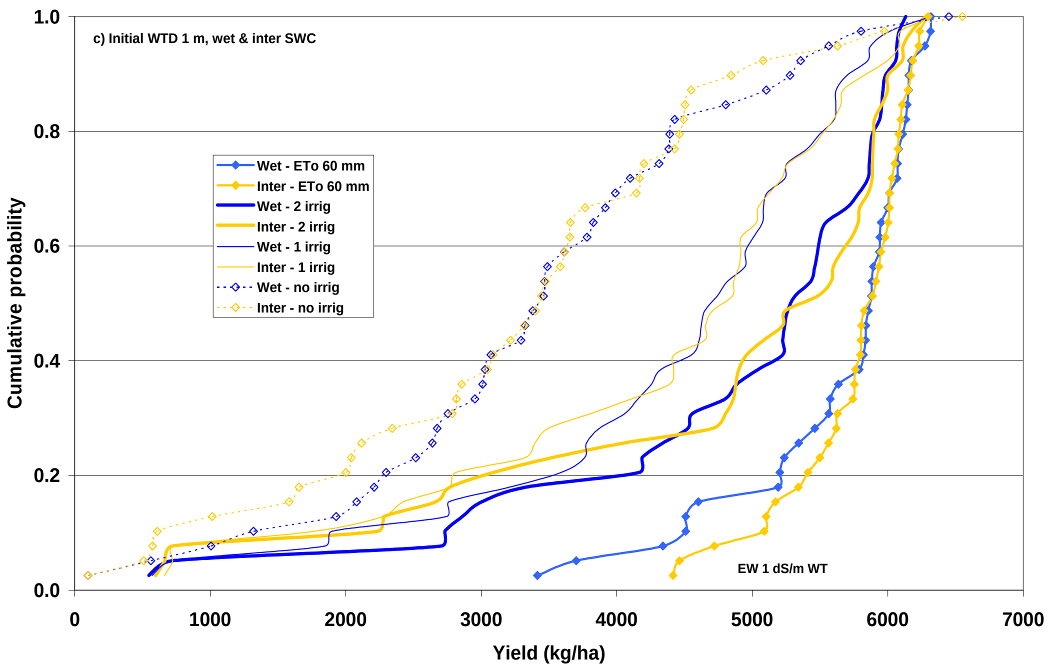


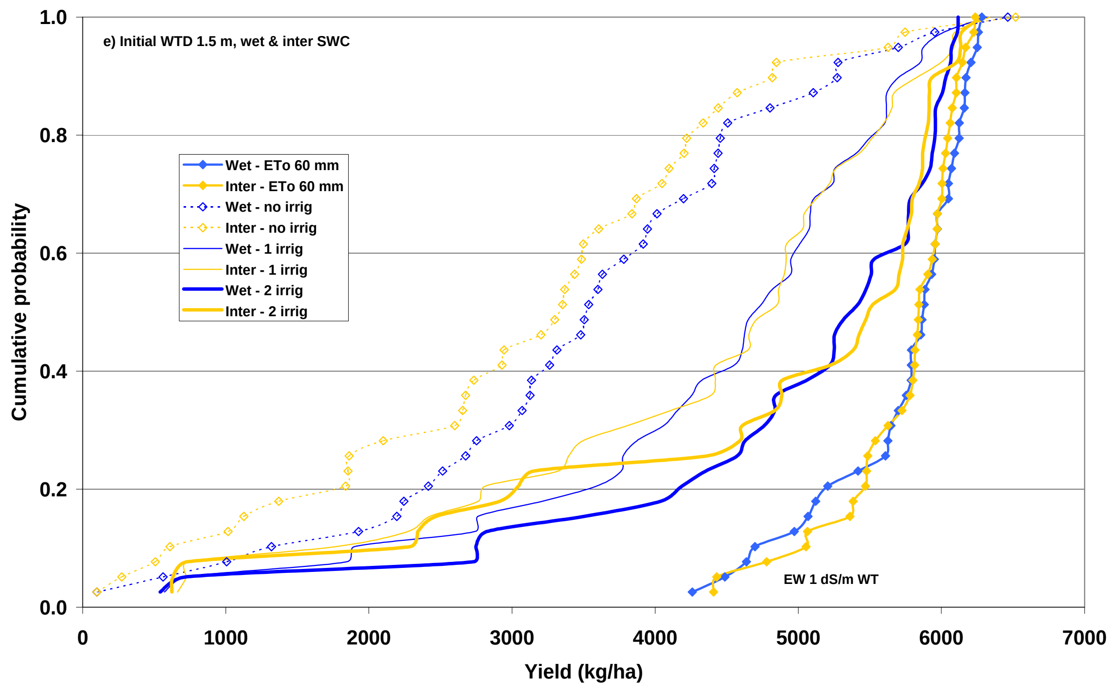
Effect of irrigation management on early wheat

For wheat sown after rice (wet soil), yields with one irrigation at the start of flowering or two irrigations at the start of flowering and grain filling were almost always higher than yields with no irrigation, and lower than yields with irrigation at ETo 60 mm, for all starting conditions (Figs 21a-c). Yields with two irrigations were higher than yields with one irrigation in 60-90% of years.

Figs 21a-c Effect of irrigation at key growth stages on yield of early wheat, 1 dS/m initial watertable salinity

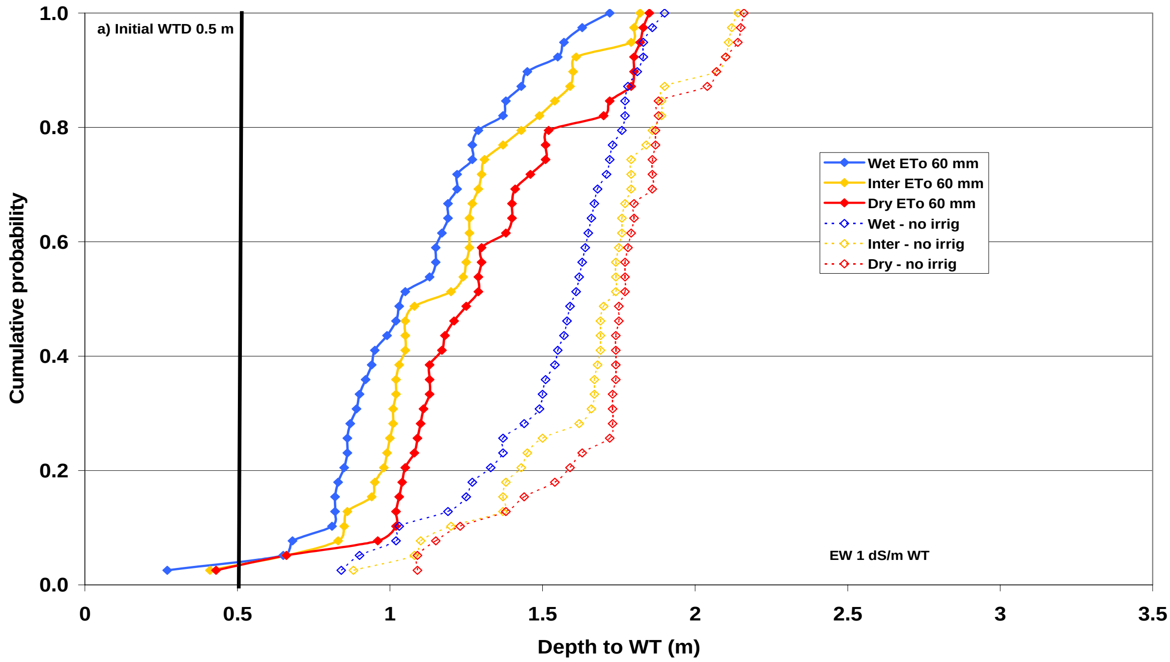


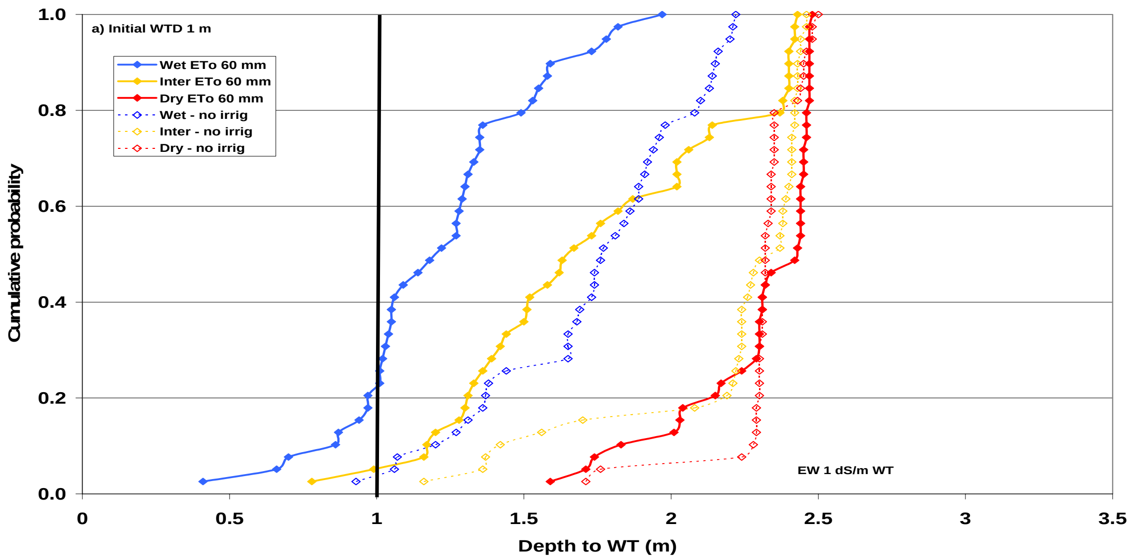


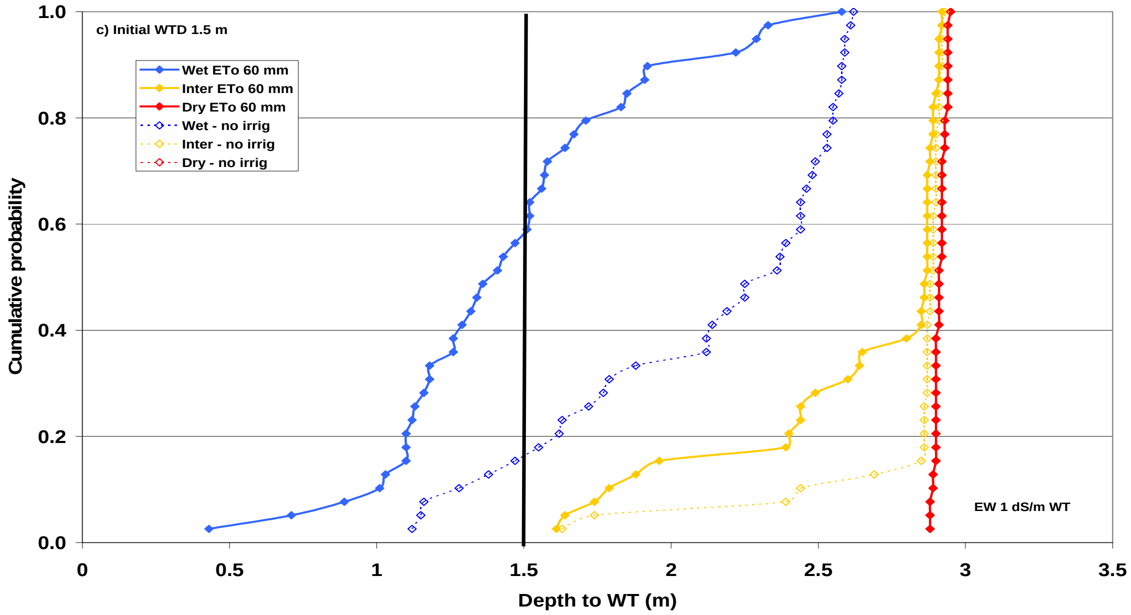


Final WTD was always higher for irrigated treatments than non-irrigated treatments with an initial WTD of 0.5 m, and for initial wet soil at all initial WTD (Figs 22a-c). The differencec was generally around 0.5 m for 0.5 m initial WRD for wet soil, but ranged from about 0.25 to 1 m. Even so, final WTD was almost always deeper than initial WTD for all irrigated crops, except when starting with dry soil and a deeper watertable. However the simulations assume that irrigation was very efficient - only enough water was applied to match ETo since the previous irrigation for the irrigations scheduled according to ETo. For flood irrigation recharge of watertables will be greater than simulated here i.e. final WTD is likely to be higher.

Figs 22a-c. Effect of irrigation frequency on final depth to watertable for early wheat





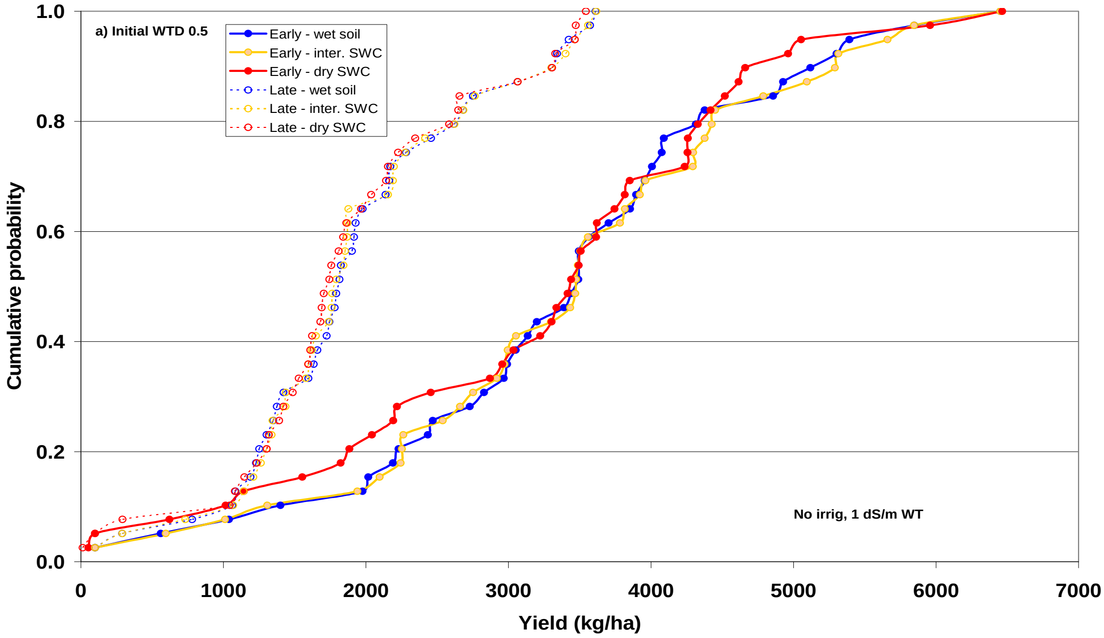


Effect of time of sowing

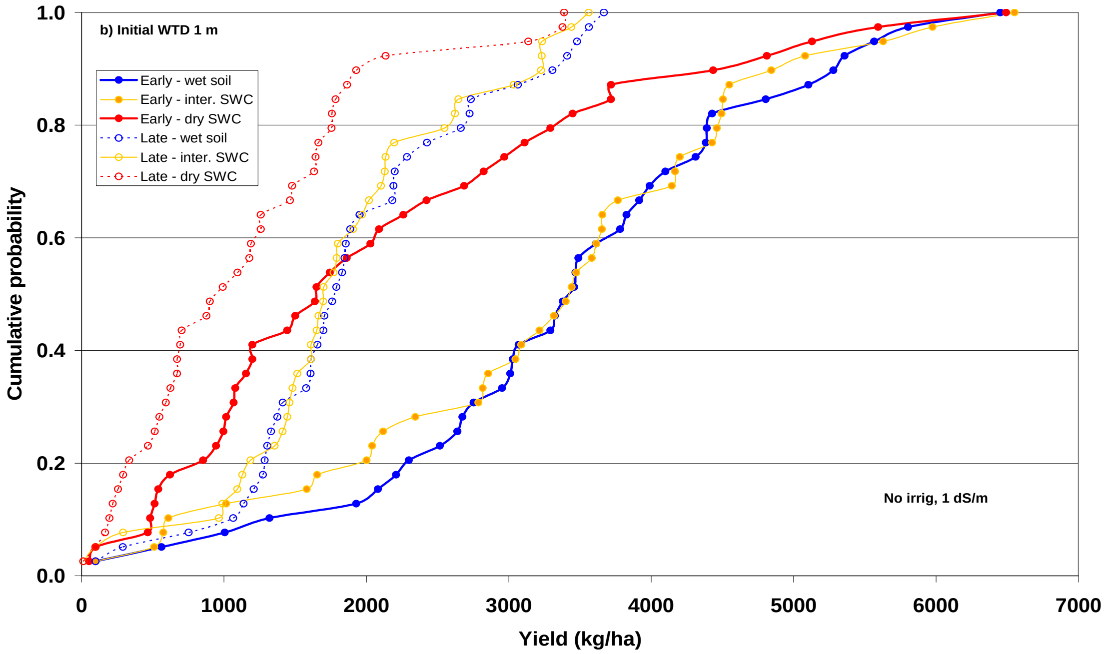
Yields of non-irrigated late wheat were much lower than for early wheat for all initial WTD and SWC (Figs 23a-c). For example, for initial wet soil, the yield range was 0.1-6.5 t/ha for early wheat, compared with 0.1-3.6 t/ha for late wheat, with median yields of 3.6 and 1.8 t/ha, respectively. The lower yields of late wheat were primarily due to water deficit stress at the end of the growing season.

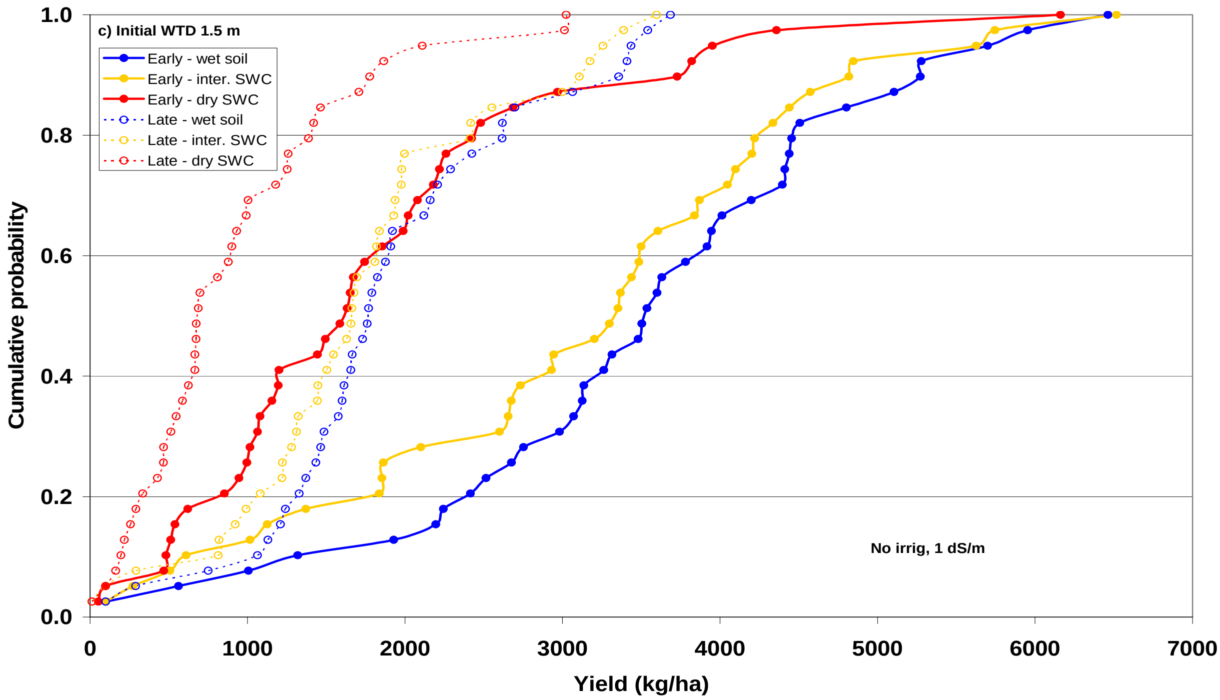
The effect of initial SWC on yield was smaller for late wheat than early wheat due to rain between the time of sowing early and late wheat, resulting in higher SWC before at sowing in late June compared with late April. As the starting WTD increased to 1.5 m, the yield penalty for lower initial SWC increased considerably. Yields for both inter and wet starting SWC were similar for all WTD, with maximum differences of less than 0.5 t/ha.

Figs 23a. Effect of sowing date on yield of non-irrigated late wheat after rice (wet soil), fresh watertable



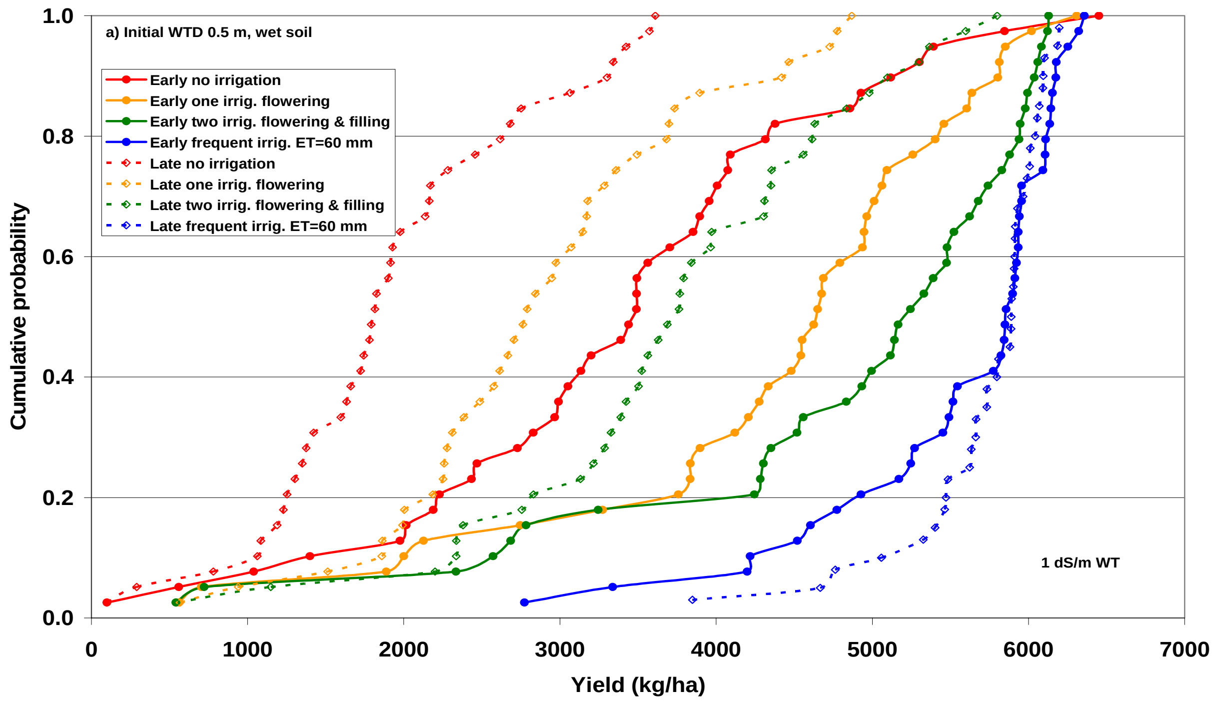
Figs 23b,c. Effect of sowing date on yield of non-irrigated late wheat after rice (wet soil), fresh watertable



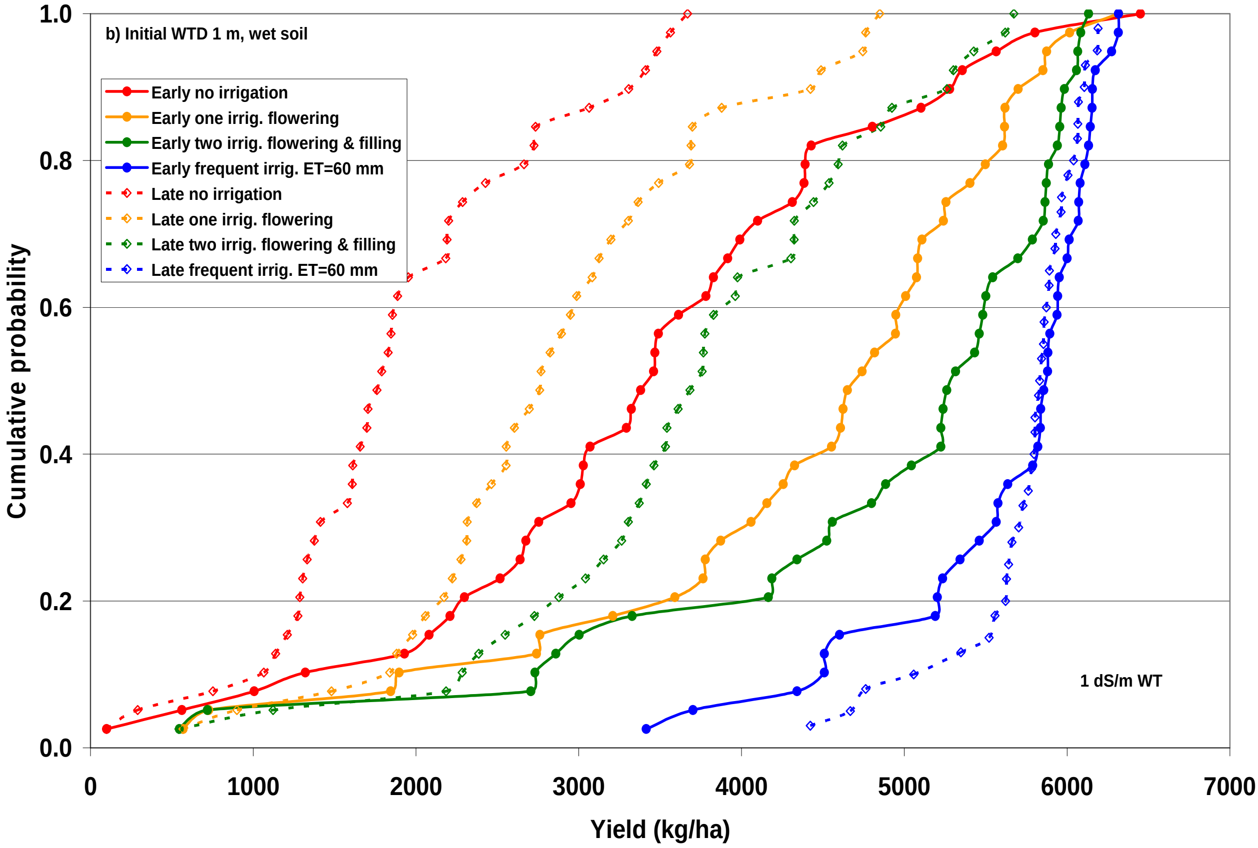


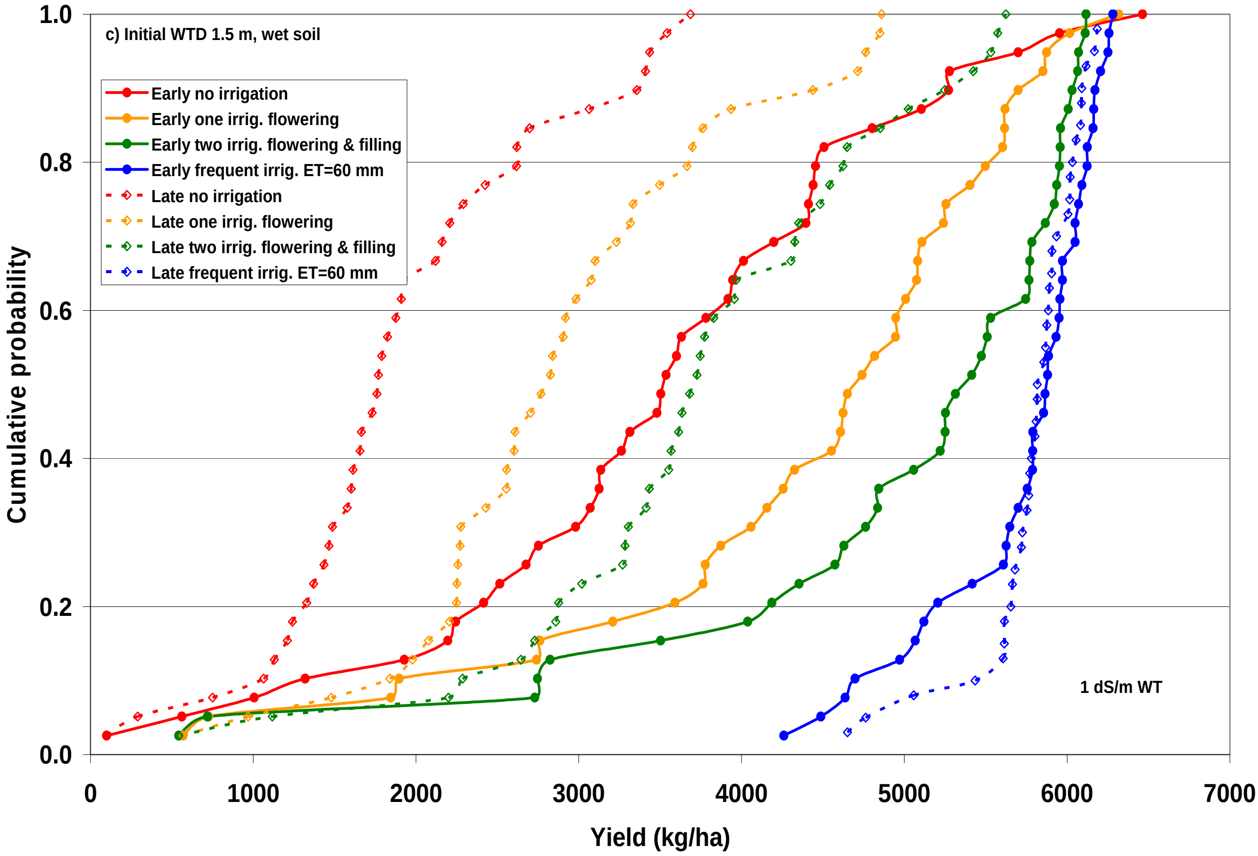
Yields of late wheat increased with frequency of irrigation from one at flowering to two (at start of flowering and grain filling) to frequent (ETo=60 mm) (Figs 24a-c). Frequent irrigation resulted in large yield increases of late wheat (4.5-6.2 t/ha) compared with no irrigation (0.1-3.8 t/ha). Yields with frequent irrigation were generally a little higher than with early wheat irrigated at ETo=60 mm for all initial SWC with 0.5 m WTD, possibly due to less waterlogging (aeration stress) with late wheat. However yields of late wheat with one or two irrigations were always less than yields of early wheat with the same number of irrigations, generally by 1-2 t/ha.

Fig. 24a. Yield of early and late wheat as affected by irrigation frequency and initial WTD and SWC (1 dS/m watertable)



Figs 24b,c. Yield of early and late wheat as affected by irrigation frequency and initial WTD and SWC (1 dS/m watertable)





6. Discussion of Results

a) determine knowledge of farmers' perceptions of:
(iv) *constraints to growing crops/pastures immediately after rice*
(v) *factors leading to successful production of crops after rice*
(vi) *impacts on sustainability (environmental, economic)*

The mail survey in May 1998 suggested that growing wheat (or other crops) after rice was regularly practised by many growers in the MIA and Benerembah, but much less common in other areas. It is likely that the practice has become more common since then, initially due to reductions in the availability of irrigation water and increasing price due to the water reforms, and more recently due to the drought (together with high wheat prices due to widespread drought in some years).

b) undertake field determinations and demonstrations of the impacts of growing wheat directly after rice on irrigation efficiency of the rice-wheat cropping system, additions to the watertable and distribution of salt in the rootzone

Rainfall during the wheat season was reasonably similar in all 3 years (270-318 mm) and a little higher than the mean (226 mm) between sowing and harvest (Table 5). Therefore the impact of wheat after rice under a range of seasonal conditions was not possible. However, rainfall was lower for the late sown wheat in 1998 (224 mm). Yield and biomass production of early sown (24 April) wheat was higher than yield of late wheat (29 June).

The field studies showed that, in the absence of irrigation, the soil profile remained wet in fallow areas, whereas there was considerable drying in areas planted to wheat. The degree of drying was greater for the late sown wheat in 1998. The drying created capacity in the soil profile to capture and use winter rainfall. There was a general increase in depth to the watertable during the first half of the season where non-irrigated wheat was grown after rice (except in a year where wheat establishment was late and crop growth was affected by early waterlogging and rust), but not in the fallow areas. However, in all situations, the watertable rose around the time of rice sowing each year due to a rise in the regional groundwater level. The lumped water balance studies suggested net discharge of about 1 ML/ha between the time of sowing and harvesting wheat after rice in each of the three years, mostly due to higher upflow due to crop water use. In the fallow, net discharge/recharge was close to zero.

c) compile existing data from rice-wheat cropping in southern Australia
&
d) validate and calibrate the CERES Wheat and SWAGMAN Destiny models for wheat in the rice growing areas of southern NSW

Six wheat data sets for wheat grown in the field and in lysimeters were compiled and used for model calibration and validation. The CERES Wheat and SWAGMAN® Destiny models performed very well in simulating a range of parameters including grain yield, time course of biomass production, leaf area index, root length density, soil water content in different layers and evapotranspiration. However the validation data sets were limited in that the yield range was smaller than desirable.

e) model simulations to predict impacts of wheat after rice on watertables and rootzone salinity for a range of seasonal conditions, watertable depths, soil types, sowing dates and irrigation management

The findings of model simulations were consistent with the findings of the field studies in that yield of non-irrigated early sown wheat (median 3.8 t/ha) was usually much higher than yield of late sown wheat (median 1.8 t/ha). With one or two irrigations at key growth stages (flowering, grain filling) yields of both early and late sown wheat almost always increased, by around 1 t/ha with one irrigation, and an additional 0.5 t/ha with the second irrigation. However, it was only with frequent irrigation (whenever cumulative ETo-rain since the previous irrigation reached 60 mm) that yields of late sown wheat matched (or surpassed) yields of early sown wheat. However the irrigation requirement for late wheat irrigated at ETo-rain 60 mm was almost always much higher than for early wheat with the same irrigation management (by >100 mm in most years). While irrigation increased yield, it also increased net recharge, with final watertables generally higher by 0.5 to 0.8 m for wheat after rice (wet initial soil) with irrigation at ETo-rain 60 mm compared with no irrigation.

The model simulations showed that with wheat after rice, there was net discharge in almost all years, regardless of initial watertable depth (0.5-1.5 m). In comparison, net recharge occurred in 18 to 48% years with fallow after rice, the amount of recharge increase as initial depth to the watertable increased.

For non-irrigated wheat after rice, salinity of the watertable was important where the watertable was shallow (0.5 m), with yield reductions in excess of 1 t/ha in most years. However for deeper watertables, there was no effect of watertable salinity for non-irrigated wheat. With irrigation, watertable salinity had no impact on yields.

7. Implications and recommendations

The results suggest that establishment of wheat shortly after rice harvest is beneficial in terms of net recharge management, capture and use of winter rainfall, and financially (see below). The results of the model simulations have potential application in the development of guidelines for growing wheat after rice. They can be used to indicate likely yields, and response to irrigation and sowing management, taking into account watertable depth and salinity at the time of sowing.

Singh et al. (2004) undertook an economic evaluation of the benefits and costs of the research on wheat after rice. They found an increase in Net Present Value (NPV) ranging from 31 to 126 $/ha/yr assuming that seasonal conditions would allow rice to be sown after harvest in 50% of years, for typical rotations (of 4 to 9 years duration) across the rice growing areas. NPV ranged from 31 to51 $/ha/yr for all rotations except for the low intensity rotations with one rice crop followed by 3 years of fallow or 2 years of fallow and one wheat crop (the 1:4 rotations common on larger farms in the Western Murray Valley). Assuming that the rate of adoption is doubled as a result of the project, the NPV of benefits was estimated to be $5.6 million compared with costs of $1.1 million, resulting in a benefit cost ratio of 5.3.

8. Description of Project Intellectual Property of any commercially significant developments arising from the Project.

The project IP is new knowledge of soil water and watertable dynamics for wheat grown after rice in comparison with fallow, and is publicly available. There are no commercially significant developments**.**

9. Recommendations

In collaboration with NSW DPI agronomists, develop guidelines (Agfact) for establishment and productivity of wheat sown after rice; interviews with successful farmers and possibly 1-2 focus groups to learn as much as possible about keys to success.

The guidelines should include information on the tradeoffs between yield and watertable control and how they are affected by management (e.g. time of sowing, frequency of irrigation, N application) and site conditions (e.g. soil type, depth and salinity of the watertable).

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11. Acknowledgements

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