Agronomic Options for Profitable Rice-based Farming System in Northern Australia

Siva Sivapalan

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Agronomic Options for Profitable Rice-based Farming System in Northern Australia

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Agronomic Options for Profitable Rice-based Farming System in Northern Australia

by Siva Sivapalan

September 2016
RIRDC Publication No 16/048
RIRDC Project No PRJ-007497
A rotation system based on rice and a legume crop appears highly suitable and profitable for the soil types in the tropical regions of Australia. Permanent raised-beds may provide a viable production system for the rice-based farming system in these regions. But many issues regarding suitable varieties, planting date, establishment technique, sowing rate, and fertiliser and irrigation requirements, remained unresolved.

The rice industry in NSW is looking for opportunities for quality rice production in northern Australia. Local industry groups are also keen to establish a commercially viable rice industry to provide speciality rices for niche markets. Rice is also considered a potential crop for the new farmlands to become available from the Ord irrigation expansion projects.

The major findings from this project provide guidance about variety selection that would have grain yield and quality advantages in potential regions and production systems. Results also serve as an agronomic package supported by industries which are economically and environmentally sound. The project created information about best pest, weed and disease management practices, and priorities for future research.

The report will be a useful basis for those growers and advisors looking for best agronomic options for a profitable rice-based farming system in northern Australia.

This project was funded by Rural Industries Research and Development Corporation (RIRDC) from industry revenue which is matched by funds provided by the Australian Government, and by Rice Research Australia Pty Ltd (RRAPL) through the Australian Centre for International Agricultural Research (ACIAR) who is funded by the Australian Government to conduct collaborative research projects concurrently in Australia and in developing nations.

This report is an addition to RIRDC’s diverse range of over 2000 research publications and it forms part of our Rice RD&E program, which aims to improve the profitability and sustainability of the Australian rice industry through the organisation, funding and management of a research, development and extension program that is aligned with industry reality and stakeholder needs.

Most of RIRDC’s publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

John Harvey
Managing Director
Rural Industries Research and Development Corporation
Acknowledgments

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### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ANOVA</td>
<td>analysis of variance</td>
</tr>
<tr>
<td>APSIM</td>
<td>Agricultural Production Systems Simulator</td>
</tr>
<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organisation</td>
</tr>
<tr>
<td>DAFWA</td>
<td>Department of Agriculture and Food, Western Australia</td>
</tr>
<tr>
<td>DAP</td>
<td>days after planting</td>
</tr>
<tr>
<td>DAP</td>
<td>di-ammonium phosphate</td>
</tr>
<tr>
<td>DP</td>
<td>deep percolation</td>
</tr>
<tr>
<td>DPI</td>
<td>Department of Primary Industries, NSW</td>
</tr>
<tr>
<td>DPIF</td>
<td>Department of Primary Industries and Fisheries, NT</td>
</tr>
<tr>
<td>DTPA</td>
<td>diethylenetriamine pentaacetic acid</td>
</tr>
<tr>
<td>E</td>
<td>evaporation</td>
</tr>
<tr>
<td>EPM</td>
<td>early pollen microspore</td>
</tr>
<tr>
<td>ET</td>
<td>evapotranspiration</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organisation</td>
</tr>
<tr>
<td>GAIA</td>
<td>graphical analysis for interactive aid</td>
</tr>
<tr>
<td>HBD</td>
<td>High basal dressing</td>
</tr>
<tr>
<td>IRRI</td>
<td>International Rice Research Institute</td>
</tr>
<tr>
<td>LBD</td>
<td>low basal dressing</td>
</tr>
<tr>
<td>l.s.d.</td>
<td>least significant difference</td>
</tr>
<tr>
<td>MCDM</td>
<td>multi-criteria decision methods</td>
</tr>
<tr>
<td>MCPA</td>
<td>2-methyl-4-chlorophenoxyacetic acid</td>
</tr>
<tr>
<td>NO</td>
<td>nitric oxide</td>
</tr>
<tr>
<td>NPI</td>
<td>nitrogen at panicle initiation</td>
</tr>
<tr>
<td>NSW</td>
<td>New South Wales</td>
</tr>
<tr>
<td>NT</td>
<td>Northern Territory</td>
</tr>
<tr>
<td>ORDCO</td>
<td>Ord River District Cooperative Ltd</td>
</tr>
<tr>
<td>ORIA</td>
<td>Ord River Irrigation Area</td>
</tr>
<tr>
<td>PI</td>
<td>panicle initiation</td>
</tr>
<tr>
<td>PROMETHEE</td>
<td>preference ranking organisation method for the enrichment of evaluations</td>
</tr>
<tr>
<td>QLD</td>
<td>Queensland</td>
</tr>
<tr>
<td>RRAPL</td>
<td>Rice Research Australia Pty Ltd</td>
</tr>
<tr>
<td>T</td>
<td>transpiration</td>
</tr>
<tr>
<td>WONS</td>
<td>Weeds of National Significance</td>
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</tbody>
</table>
Contents

Foreword ................................................................................................................................. iii
Acknowledgments ................................................................................................................... iv
Abbreviations ....................................................................................................................... v
Executive Summary ............................................................................................................. xi
1. Introduction ....................................................................................................................... 1
2. Objectives ......................................................................................................................... 4
3. Methodology .................................................................................................................... 5
   3.1 Aerobic system trials at Kununurra during 2012 dry season ........................................ 5
   3.2 Flooded system trials at Kununurra during 2012 dry season ....................................... 7
   3.3 Flooded system trials at Tortilla Flats during 2012 dry season .................................... 8
   3.4 Aerobic trials at Katherine during 2012/13 wet season ................................................. 10
   3.5 Planting date trials at Kununurra during 2013 dry season .......................................... 11
   3.6 Lysimeter trial at Kununurra during 2013 dry season .................................................... 12
   3.7 Evaluation of soybeans in rotation with rice on beds during 2013 dry season ............. 13
   3.8 Planting date trials at Tortilla Flats during 2013 dry season ........................................ 14
   3.9 Assessing grain quality at Kununurra during 2014 dry season ..................................... 15
   3.10 Lysimeter trial at Kununurra during 2014 dry season ............................................... 17
   3.11 Assessing fragrant lines at Tortilla Flats during 2014 dry season ............................... 17
4. Results and discussion .................................................................................................... 20
   4.1 Aerobic system trials at Kununurra during 2012 dry season ........................................ 20
       4.1.1 Varietal response to cold stress ............................................................................ 20
       4.1.2 Grain yields under cold stress ............................................................................. 22
       4.1.3 Sterility caused by cold stress ............................................................................. 23
   4.2 Flooded system trials at Kununurra during 2012 dry season .................................... 23
       4.2.1 High yields achieved despite cold stress ............................................................. 23
       4.2.2 Factors contributing to high yields ..................................................................... 24
   4.3 Flooded system trials at Tortilla Flats during 2012 dry season .................................... 25
       4.3.1 Agronomy trial .................................................................................................... 25
       4.3.2 Variety trial ......................................................................................................... 26
   4.4 Aerobic trials at Katherine during 2012/13 wet season ................................................. 26
       4.4.1 Phenology of varieties ....................................................................................... 26
       4.4.2 Grain yields ......................................................................................................... 27
   4.5 Planting date trials at Kununurra during 2013 dry season ........................................... 28
       4.5.1 Effect of different sowing rates .......................................................................... 28
       4.5.2 Aerobic system trials ......................................................................................... 28
       4.5.3 Flooded system trials ......................................................................................... 30
       4.5.4 Grain quality assessments .................................................................................. 31
   4.6 Lysimeter trial at Kununurra during 2013 dry season ................................................... 32
       4.6.1 Evaporation, transpiration and deep percolation losses ....................................... 32
       4.6.2 Total water use .................................................................................................... 33
4.6.3 Water productivity........................................................................................................ 34
4.7 Evaluation of soybeans in rotation with rice on beds during 2013 dry season .......... 35
4.8 Planting date trials at Tortilla Flats during 2013 dry season....................................... 36
  4.8.1 Grain yields .............................................................................................................. 36
  4.8.2 Harvest index............................................................................................................ 36
  4.8.3 Aromatic rice............................................................................................................ 37
4.9 Assessing grain quality at Kununurra during 2014 dry season.................................. 37
  4.9.1 Grain yields .............................................................................................................. 37
  4.9.2 Grain quality assessments ...................................................................................... 39
  4.9.3 Varietal differences for grain quality...................................................................... 40
  4.9.4 Preventing bird damage......................................................................................... 42
4.10 Lysimeter trial at Kununurra during 2014 dry season................................................ 43
  4.10.1 Evaporation losses ............................................................................................... 43
  4.10.2 Transpiration losses ............................................................................................. 44
  4.10.3 Deep percolation losses ....................................................................................... 44
  4.10.4 Total water use ..................................................................................................... 45
4.11 Assessing fragrant lines at Tortilla Flats during 2014 dry season.............................. 46
  4.11.1 Grain yields ............................................................................................................ 46
  4.11.2 Blast disease ......................................................................................................... 47

5. General discussion ............................................................................................................. 49

  5.1 Rice in the Ord River Irrigation Area ................................................................. 49
    5.1.1 Varieties ............................................................................................................... 49
    5.1.2 Planting date ........................................................................................................ 49
    5.1.3 Grain quality ....................................................................................................... 49
    5.1.4 Leakage losses .................................................................................................... 50

  5.2 Rice in the Northern Territory .................................................................................. 50

  5.3 Economics .................................................................................................................. 51
    5.3.1 Gross margins in 2012 ...................................................................................... 51
    5.3.2 Gross margins in 2013 ..................................................................................... 52

  5.4 Plant adaptation analysis—a case study ................................................................. 53

  5.5 Other constraints to the project .............................................................................. 56
    5.5.1 Hybrid rice evaluation ....................................................................................... 56
    5.5.2 Wet season trials ............................................................................................... 56
    5.5.3 Rice ratooning option ....................................................................................... 58
    5.5.4 Rice blast disease rating .................................................................................. 58

6. Implications ..................................................................................................................... 59

7. Recommendations ......................................................................................................... 60

8. Appendices ...................................................................................................................... 61

  8.1 Publications ............................................................................................................... 61
  8.2 In the media ............................................................................................................... 62
  8.3 Field days and review meetings held ....................................................................... 63

9. References ....................................................................................................................... 64
Tables

Table 3.1 Varieties tested at Kununurra during the dry season of 2012 ........................................5
Table 3.2 Scoring system for cold tolerance at different stages ......................................................6
Table 3.3 Composition of basal fertiliser mixture and application rates .....................................8
Table 3.4 Details of nitrogen regimes, establishment techniques and plant densities tested at Tortilla Flats during the dry season of 2012 ...................................................9
Table 3.5 Varieties tested at Tortilla Flats during the dry season of 2014 and their harvest dates ....18
Table 3.6 Visual score rating for blast disease and plant response .............................................19
Table 4.1 Critical temperatures of rice at different growth stages ..............................................21
Table 4.2 Average cold stress scores and grain yield of 19 varieties tested at Kununurra during the dry season of 2012 .................................................................22
Table 4.3 Machine harvested yield results for each variety in the flooded system ...................24
Table 4.4 Varietal characteristics and their resulting sowing rate .............................................28
Table 4.5 Results of analysis of variance of grain yields of 5 varieties tested with 3 planting dates ....30
Table 4.6 Quality analysis of rice harvested in 2013 ..................................................................31
Table 4.7 Results of soil analysis before and after soybeans .....................................................35
Table 4.8 Correlation matrix of six parameters associated with rice quality ...............................39
Table 5.1 A comparison of yield, revenue, growing costs and gross margins per hectare for rice ....52
Table 5.2 Gross margin sensitivity table .......................................................................................53
Table 5.3 Number of varieties used in each trial which created a unique environment .............54

Figures

Figure 3.1 Symptoms of cold stress on susceptible varieties .......................................................6
Figure 3.2 Evaluation of 17 varieties under flooded system .......................................................7
Figure 3.3 Evaluating two establishment techniques: (a) drill sown; (b) aerial sown ..............8
Figure 3.4 Evaluation of seven cultivars with different maturities ...........................................9
Figure 3.5 Upland trials at Katherine: (a) sowing rice with a vegetable planter; (b) solid set irrigation of trial area ..........................................................................................10
Figure 3.6 Evaluating 3–5 varieties under different planting dates: (a) raised-bed system; (b) flooded system .................................................................................................11
Figure 3.7 Harvesting trial plots for yield and quality analysis ..................................................12
Figure 3.8  Diagram of lysimeters to measure evaporation (E), transpiration (T) and deep percolation (DP) losses in a paddy field (the arrows indicate combined water losses)  
Figure 3.9  Set up of lysimeters and evaporation pan to measure leakage losses under flooded rice system  
Figure 3.10  Soybeans ready for desiccation  
Figure 3.11  Varieties Viet 4 and NTR 587 under two planting dates  
Figure 3.12  Planting variety Yunlu 29 on raised-beds  
Figure 3.13  Harvesting variety NTR 587 for yield and quality analysis  
Figure 3.14  Set up of lysimeters and evaporation pan to measure leakage losses for variety NTR 587  
Figure 3.15  Infection of blast disease in variety Opus: (a) 52 DAP; (b) 59 DAP; (c) 100 DAP  
Figure 4.1  Observed minimum air temperatures at the trial site and average cold stress scores obtained on eight occasions  
Figure 4.2  Grouping of varieties based on cold stress scores obtained on eight occasions  
Figure 4.3  Spikelet fertility of 19 varieties tested at Kununurra during the dry season of 2012  
Figure 4.4  The effect of planting technique, plant population and timing of nitrogen applications on harvested grain yield  
Figure 4.5  Grain yield of seven varieties tested at Tortilla Flats during the 2012 dry season (error bars indicate standard deviation)  
Figure 4.6  Grain yield of 20 varieties tested at Katherine during 2012-13 wet season (error bars indicate standard deviation)  
Figure 4.7  Mean yield of Yunlu 29 under three planting dates (error bars indicate standard error)  
Figure 4.8  Fluctuation of soil moisture at 10 and 20 cm depths in the aerobic trial  
Figure 4.9  Mean yields of 5 varieties tested under 3 planting dates in a flooded system (error bars indicate standard error)  
Figure 4.10  Daily maximum and minimum air temperatures prior to harvest in 2013  
Figure 4.11  Evaporation, transpiration and deep percolation losses as measured by the lysimeters  
Figure 4.12  Total water losses from flooded rice system within lysimeters and outside in the field  
Figure 4.13  Grain yield of two varieties as influenced by the date of planting (1st planting=24 April, 2nd planting=31 May; error bars indicate standard deviation)  
Figure 4.14  Harvest index of two varieties as influenced by the date of planting (1st planting=24 April, 2nd planting=31 May)  
Figure 4.15  Grain yield of three varieties tested during the dry season of 2014 (LBD=low basal dressing, HBD=high basal dressing, error bars indicate standard deviation)  
Figure 4.16  Minimum air and water temperatures during the growing season of 2014
Figure 4.17  Observed air temperature fluctuations prior to harvest ..........................................................40
Figure 4.18  Relationship between quality parameters and moisture at sampling/harvest for variety
NTR 426 ...............................................................................................................................................41
Figure 4.19  Relationship between quality parameters and moisture at sampling/harvest for variety
NTR 587 ...............................................................................................................................................41
Figure 4.20  Relationship between quality parameters and moisture at sampling/harvest for variety
Yunlu 29 ...............................................................................................................................................42
Figure 4.21  In-situ measurements of evaporation from Lysimeter A and Class A Evaporation Pan .....43
Figure 4.22  Crop transpiration losses for variety NTR 587 under the growing conditions in 2014 ......44
Figure 4.23  Estimated deep percolation losses using data from Lysimeters A and B .......................45
Figure 4.24  Total water use (i.e. sum of evaporation, transpiration and deep percolation losses) as
measured in the lysimeters and in the surrounding field .........................................................................46
Figure 4.25  Grain yield of 15 varieties tested at Tortilla Flats during the dry season of 2014 (error
bars indicate standard deviation) ...........................................................................................................47
Figure 4.26  Blast disease rating of Quest and Opus at Tortilla Flats during 2014 dry season ..........48
Figure 5.1  GAIA plots of varieties and environments for aerobic system (green=environments,
yellow=temperate varieties, grey=tropical varieties, red=decision axis) ..............................................55
Figure 5.2  GAIA plots of varieties and environments for flooded system (brown= environments,
yellow=temperate varieties, grey=tropical varieties, red=decision axis) ..............................................55
Executive Summary

What the report is about

This report contains the results of a series of experiments evaluating the best agronomic options for a profitable rice-based farming system in the tropical north Western Australia and the Northern Territory. This project aimed to develop a suitable rice-based farming system in order to establish a viable industry based on production of high quality exportable produce. The emerging rice industry in tropical northern Australia has new challenges to increase production over the next few years.

Who is the report targeted at?

The main beneficiaries of this research are primary producers who are interested in incorporating rice as part of their farming system in the tropical regions of Australia. Farm consultants, extension workers, agronomists, scientists, researchers, irrigation distribution companies, land and water management plan implementers operating in these areas will gain the technical knowledge of growing rice in the tropical environments from this report.

Where are the relevant industries located in Australia?

Primary producers in the Ord River Irrigation Area (ORIA), Adelaide River and Katherine regions, and other interested farmers elsewhere in the tropical Australia will get basic information on tropical rice production and will become familiar with the research priorities for tropical rice-based farming systems from the results and findings presented in this report.

Background

Suitable soil types, warm climate and availability of irrigation water make the ORIA and parts of NT ideal for growing rice. Due to lack of irrigation water availability for rice production associated with recent droughts in NSW and to ensure stable production to satisfy the demand of its export customers, the Riverina Rice Industry is looking for opportunities for quality rice production in northern Australia. Local industry groups, such as ORIA Industry Development Committee, are keen to establish a commercially viable rice industry to provide speciality rice for niche markets. Rice is also considered a potential crop for the new farmlands to become available from future expansion of the Ord irrigation project in WA and NT.

A range of field crops such as chia, chickpeas, sorghum, maize, culinary beans, hay, millet, sweetcorn, sunflower, peanuts and small seeds is currently grown in these regions. Many growers have shown a keen interest in growing rice. However, they faced a lack of information about tropical rice growing that is required to make sound decisions in these regions. Therefore, this project was designed to carry out research along these lines and to develop guidelines for the management of rice-based farming systems in the tropical WA and NT regions.

Aims/objectives

The overall aim of this project was to identify the best agronomic options for a profitable rice-based farming system in northern Australia. The research described in this report had the following objectives:

- To identify locally adapted rice varieties (including hybrid and blast disease-tolerant rice) with required quality characteristics for wet and dry seasons on raised-bed system compared with flood and upland conditions
- To identify ideal establishment technique, sowing time, optimum sowing rate and plant population for each variety
• To identify crop nutrition (amount and strategy) requirements, to determine irrigation requirements and weed/pest/disease control strategies
• To evaluate the potential of rice rationing
• To assess leakage losses under flooded systems

Methods used

A range of temperate and tropical rice varieties showing potential for high yield in a tropical climate were evaluated in a series of field experiments at Kununurra in WA, and Katherine and Tortilla Flats in NT, for three years commencing in 2012. Rice was planted on raised-bed (aerobic) system and compared with flooded system and upland conditions. Direct seeding method was compared with aerial sowing techniques at sites where establishment problems occurred with direct seeding. Different seeding rates (100-200 kg/ha) were tested with selected varieties to identify the optimum plant density for maximum yield.

Different planting dates were tested to identify the optimum sowing time for best grain quality and to avoid cold/heat stress during critical growth stages. A split fertiliser application strategy (different rates of initial basal application at seeding followed by different rates of nitrogen application at different growth stages) was also tested. By continuous soil moisture monitoring on beds using EnviroScan system, irrigation scheduling was adjusted to provide optimum soil moisture conditions for the aerobic system. Leakage trials were conducted using a set of lysimeters and lockup bay tests under flooded system in Kununurra Clay soil during the dry seasons of 2013 and 2014.

The study generated information on air/water temperatures, soil moisture, establishment counts, flowering data, biomass sampling at different stages, harvest index, grain yield, grain quality (chalk, amylose and protein), milling assessment, gross margin analysis, deep percolation losses, and total water use. Statistical analysis included multi–criteria decision methods (MCDM) such as PROMETHEE and GAIA.

Results/key findings

Rice growing under an aerobic system will better fit rotation options, require less irrigation water and minimise bird pressure in the higher rainfall areas of northern Australia. The production systems need to be efficient, environmentally sustainable, and responsive to market needs. The results of this project provided options for growing rice in Australia’s north to guarantee food security for important export markets. This was achieved by: (1) demonstrating the most appropriate production system; (2) establishing the most suitable varieties; and (3) ensuring that grain quality standards are maintained under geographic pressure.

Minimum air temperatures less than 15°C had biggest impact on varietal performance. Cold damage during the months of June and July warrants selection of varieties with cold tolerance for this environment, especially for the aerobic rice system. Ponded water has 4-8°C advantage over the air temperature, thus providing some protection against such cold damage. This has resulted in higher yields under flooded system.

Planting dates, varying from late-February to late-May, were found to play a crucial role for plants to escape the low temperature damage at critical growth stages. The results also indicated that late planting ensures high yields, but the grain quality suffered due to extreme weather conditions prior to harvest. High percentage of millout can be achieved by harvesting at high grain moisture levels but high amount of chalk in harvested grains remains an issue.

Among the varieties tested, selected tropical varieties yielded higher than the temperate varieties. Variety Yunlu 29 has been identified as the best variety adapted for aerobic rice systems. NTR 426 and NTR 587 were found to outperform all other tested varieties under the flooded system.
Rice is a semi-aquatic plant and considered as heavy user of water. Thus, for the aerobic system, it is necessary to maintain the soil moisture levels closer to drained upper limit to avoid water stress. The results of this project suggest that irrigation scheduling based on 7 days of irrigation interval achieves the best results for the aerobic system in the tropical environment.

Leakage measurements in the flooded system revealed that the deep percolation losses in Cununurra Clay soil were either negligible or less than 1 mm/day, which is within acceptable limits of groundwater recharge. The results also indicated that the total water use, varied from 9.7 ML/ha for NTR 587 in 2014 to 13 ML/ha for IR 72 in 2013, is efficient for a rice production system in the tropical environment.

**Implications for relevant stakeholders**

Varieties that are suitable for aerobic production and flooded system in northern environments of Australia have been identified. Knowledge of varietal performance under critical environmental factors, such as cold, heat, water stress, and blast disease, has been created. This information will help growers in the region to adopt best practice in their rice-based farming system.

An understanding of the critical balance between plant, water, nutrient and temperature which are both economic and environmentally sustainable has been ascertained. The grain yield and quality parameters collected will provide basic information for the introduction of new varieties targeting the domestic and international markets.

This report provides general guidelines for the management of rice-based farming system in the ORIA and NT regions. This information is also available to anyone interested in growing rice on a raised-bed or flooded systems in the tropical environment.

**Recommendations**

The major findings from this project will benefit primary producers in several ways:

1. guidance about variety selection that would have grain yield and quality advantages in potential regions and production systems
2. agronomic package supported by industries which are economically and environmentally sound
3. information about best pest, weed and disease management practices, and priorities for future research.

The broader benefits of implementing the results will be better food security for Australia and its near neighbours, and maintenance of an important export industry that is currently suffering from climate change and water security concerns.
1. Introduction

Rice was grown commercially in the ORIA from 1973 to 1983 in both the dry season and wet season. Production peaked in 1982, with 3500 tonnes of rice paddy at an average yield of 7.1 t/ha in the dry season and 3.7 t/ha in the wet season. However commercial production ceased in 1983 due to: bird damage to crops by ducks and magpie geese; cold stress in June and July and heat stress in October and November for the dry season crop; low returns to farmers; declining demand in local markets; high recharge rates of Cununurra clay soils under flooded systems; and unavailability of locally adapted rice varieties with good mill-out rates (Burt 2002). The average yield potential of paddy rice in the ORIA was around 7.5–8.0 t/ha. Higher yields above 9 t/ha could be achieved under optimum conditions (Burt 2002).

The extensive floodplains of various river systems in the NT stimulated interest in rice production as early as the 1950s with the Humpty Doo attempt at large scale commercialisation and a concerted research effort in the Adelaide River region by CSIRO. These ventures ceased in the 1960s for a range of reasons including unsuitable varieties, improper agronomic practices suited to the climate, and pest pressure (Chapman et al. 1985). Small scale production recommenced in the early 1970s around Tortilla Flats, until the initiation of another research program in early 1980s. Varietal improvement, better establishment techniques, crop rotations and market development were the main focus (McDonald 1985). This program ceased in 1987, mainly due to agronomic issues, lack of industry development, and poor market access.

After a successful 240 ha commercial planting in 2010 in the ORIA, about 650 ha of crop was planted by three growers in 2011. Rice blast disease (Magnaporthe grisea) infected the commercial rice crops in the Ord Valley in 2011 with devastating effects on harvestability, grain yield, quality and marketability. Blast is a serious disease of rice and can cause crop failure up to 100%. A gross margin analysis indicated the blast disease in the ORIA caused total losses of up to $1.2 million in farm business (Sivapalan et al. 2012a). In addition, economic losses were felt by the associated activities in the region. The social impact of the blast disease prevailed in the next few years. Identification of a blast tolerant rice variety suitable for this region is a priority research need for the emerging Ord rice industry. The importance of identifying resistant varieties is also considered as an important spin off to the traditional rice growing areas elsewhere in Australia. Rice production on the Adelaide River floodplains provides an option for producers to utilise land that remains relatively unproductive over the wet season, and to increase cattle productivity from grazing the rice stubble over the dry season—a time of traditionally low feed availability. Pastoralism is the major industry in the Adelaide River area, and development of a rice production system would allow diversification and spread of risk for local producers.

Suitable soil types, warm climate and availability of irrigation water make the ORIA and parts of NT ideal for growing rice. Due to lack of irrigation water availability for rice production associated with recent droughts in NSW and to ensure stable production to satisfy the demand of its export customers, the Riverina Rice Industry is looking for opportunities for quality rice production in northern Australia. There is potential to export rice from the Wyndham Port to Papua New Guinea where ‘SunRice’ operates a processing facility. Local industry groups, such as ORIA Industry Development Committee, are keen to establish a commercially viable rice industry to provide speciality rices for niche markets. The Ord River District Cooperative Ltd (ORDCO) and Pacific Seeds have both offered access to their infrastructure in the initial stages of development. Rice is also considered a potential crop for the new farmlands to become available from the Ord irrigation expansion project.

A range of field crops such as chia, chickpeas, sorghum, maize, culinary beans, hay, millet, sweetcorn, sunflower, peanuts and small seeds is currently grown in these regions. Many growers have shown a keen interest in rice. However, they currently face a lack of information about rice growing that is required to make sound decisions in these regions. Among the new crops trialled in the ORIA, rice has been demonstrated as a potentially suitable high-return crop. Yields of up to 13.6 t/ha (2009) and gross
margins of up to $2,442/ha (based on 7.5 t/ha at $550/t in 2010) have been demonstrated. Plot yields of 11.5 t/ha were achieved at Tortilla Flats in the 2010 dry season. A research program commenced in the Adelaide River region in 2009-10 wet season. Higher yields from better suited varieties, better adapted agronomic practices and the potential for export markets have provided increased confidence in the future development of a rice industry in the NT. However, trials in 2010–2011 at Frank Wise Institute of Tropical Agriculture in WA (Sivapalan et al. 2011; 2012b) and Katherine and Tortilla Flats in NT (Eastick et al. 2012) and the experience of local commercial growers (Ord Valley and Adelaide River region) have shown that many issues regarding suitable varieties, planting date, establishment technique, sowing rate, fertiliser and irrigation requirements remained unresolved, especially when rice was grown in rotation with other crops. A rotation system based on rice and a legume crop appears highly suitable and profitable for the soil types in these regions and permanent raised-beds may provide a viable production system.

Rice growing in Australia is a progressive industry that recognises the importance of development of new production areas in northern Australia. Protecting the crop from weeds, pests and diseases in a changing natural and regulatory environment is an ongoing challenge for rice growers in both Riverina and northern Australia. Expansion of the industry into northern Australia exposes production to new bio-security threats. The occurrence of blast disease in the Ord Valley in 2011 prompted several initiatives to identify tolerant rice varieties which could be used in breeding to develop varieties suitable for Riverina and other regions—this will prepare the local rice industry in the event of blast disease outbreaks for the industry to survive and continue production.

High yielding good quality rice could significantly increase farm gross margins and viability. Trials at Frank Wise Institute of Tropical Agriculture in 2009 demonstrated that yields up to 13.6 t/ha are possible in this environment. This compares well with maximum yields of 11.6 t/ha in NT (2010/11) and 7.9 t/ha in QLD (2008/09). In 2010, SunRice paid a record farm gate price of $550/t for medium grain rice produced by NSW and Ord growers. In the Ord Valley, a gross margin analysis indicated that a 7.5 t/ha crop at $550/t generated gross margins of $2,442/ha which was very competitive compared with many other field crops grown in this region. The major market to be targeted is export to Papua New Guinea, in conjunction with SunRice’s marketing strategies for northern Australia. There is also the opportunity for the domestic market—ideally for higher value human consumption, or for use as stock feed (from $200/t in WA to $300/t in NT was offered for local rice grain for stockfeed in 2009). Rice is a preferred source of grain for intensive cattle feed-lotting, or to use in livestock pellets/cubes. In addition, rice produces about 12 t/ha of hay and an opportunity exists for baling rice stubble as cattle feed which brings an extra $150/ha to growers in the Ord Valley and possibly to growers in the NT.

There is a market for rice stubble as stockfeed in these regions which results in reduced stubble burning and environmental pollution. The 2010 commercial crop in the Ord Valley took just over three months to reach maturity which in turn reduced the amount of irrigation water usage by 3.5 ML/ha. Lower water usage has less environmental impact in terms of rising watertables and salinity. Generally, different crops in rotation (for example, rice with a shallow root system and chickpeas with a deeper root system) can result in better utilisation of nutrients and avoid leaching losses and groundwater pollution. A legume in the rotation can reduce nitrogen fertiliser requirements of other crops. Crop rotation also allows for better weed, pest and disease control. Farmer uptake of rice production on the Adelaide River floodplains allows for an economically feasible method for the control of mimosa (Mimosa pigra). This is the major weed of northern Australian floodplains, and a Weed of National Significance (WoNS).

Rice is a new crop to these regions with potential for high returns to growers. As a new industry, this can attract significant additional employment opportunities. Rice also allows crop diversification, therefore less financial risk to the farmers. Statistics from southern NSW show that, in terms of employment, for every person directly employed by the industry, there are four jobs created in associated activities. Similarly, for every dollar earned by the industry $6 is generated in associated
activities. These figures highlight the social benefits that could result to these regions by establishing a successful rice industry locally.

About 15,000 hectares of new lands suitable for irrigated agriculture became available in the Ord Valley (Stage II) in November 2011. The two major soil types present in the Ord Valley—Cununurra Clays and Aquitaine Soils—have high clay content (49–57%) and are ideally suited to rice cultivation. The potential area for rice growing on the Adelaide River floodplains is estimated as 5,000 ha in the Upper Adelaide River and 40,000 ha in the Lower Adelaide River regions (Airey et al. 1981). It is expected that rice grown on the raised-bed system will have minimal impact on ecological sustainability similar to other field crops grown in these regions. However, rice under a flooded system might contribute to greater biodiversity of aquatic life. For example, hundreds of millions of spotted grass frogs (*Limnodynastes tasmaniensis*) were produced annually from rice bays in the Riverina Bioregion of NSW, and these frogs probably represent the highest biomass of any vertebrate on rice farms. This highlighted the possibility that these frogs, which consume insects, may be controlling economically important pests of rice crops. Although the establishment of rice cultivation in new land developments will lead to an altered landscape, it will result in the seasonal availability of extensive aquatic habitats in a previously drier landscape. Consequently, these rice-farming areas will be of considerable importance to a range of vertebrate fauna. Vertebrate diversity will be underpinned by two major factors—flooded rice bays and remnant vegetation patches. The former are important drivers of abundance of frogs, snakes, turtles and waterbirds, while the latter are critical for richness of reptiles, frogs, mammals and woodland birds.
2. Objectives

The emerging rice industry in tropical northern Australia has new challenges to increase production over the next few years. In order to establish a viable industry based on production of high quality exportable produce, a suitable rice-based farming system needs to be developed. This project aimed to establish the best agronomic options for a profitable rice-based farming system in tropical north Western Australia and the Northern Territory. Major outcomes are the guidelines for potential rice growers in tropical Australia.

The research described in this report had the following objectives:

1. To identify locally adapted rice varieties (including hybrid and blast disease-tolerant rice) with required quality characteristics for wet and dry seasons on raised-bed system compared with flood and upland conditions
2. To identify ideal establishment technique, sowing time, optimum sowing rate and plant population for each variety
3. To identify crop nutrition (amount and strategy) requirements, to determine irrigation requirements and weed/pest/disease control strategies
4. To evaluate the potential of rice rationing
5. To assess leakage losses under flooded systems
3. Methodology

The WA component of the research was conducted at the Frank Wise Institute of Tropical Agriculture, Department of Agriculture and Food, Western Australia, Kununurra, WA. This research station is located in the ORIA in the East Kimberley Region with a tropical climate. Kununurra is within the Federal electorate of Durack. Main trial sites were located at the Research Station Farm. Various trials were conducted during the dry season from 2012 to 2014, inclusive. Raised-bed system at this site followed the recommendations of Beecher et al. (2007). A total of 19 varieties (5 temperate and 14 tropical) were tested during this period. These trials created 11 unique environments for this site. In addition, lysimeter trials were also carried out during the dry seasons of 2013 and 2014.

The NT component was conducted mainly at the Tortilla Flats (ex-NTG Research Station, currently farmer-owned) facility with a ‘bird cage’ to protect trials from damage. It is located in the Adelaide River region. Only flooded system trials were undertaken at this site. Trials were conducted during the dry seasons from 2012 to 2014. In addition, trials were also conducted at Katherine Research Station during the wet season of 2012/13 under upland conditions (aerobic system). Up to 30 varieties (including fragrant lines) were evaluated in various trials in NT.

3.1 Aerobic system trials at Kununurra during 2012 dry season

The purpose of the trial was to evaluate the grain yield potential of 5 temperate and 14 tropical rice varieties (Table 3.1) grown under raised-beds (aerobic) system in the dry season of 2012 in the ORIA. These varieties were selected based on their potential adaptation characteristics to the tropical environment in Australia. All 19 varieties were grown with two replicates at Frank Wise Institute of Tropical Agriculture in Kununurra. Varieties in each replicate were arranged in a randomized complete block design. Plot size was 100 m long by 0.9 m wide which included six rows of plantings with 15 cm spacing between rows. Long plots were used for the purpose of seed increase while maintaining pure seed status at sowing and harvesting. A seeding rate of 182 kg/ha was used.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperate</strong></td>
<td></td>
</tr>
<tr>
<td>Langi</td>
<td>NSW, Australia</td>
</tr>
<tr>
<td>Kyeema</td>
<td>NSW, Australia</td>
</tr>
<tr>
<td>Doongara</td>
<td>NSW, Australia</td>
</tr>
<tr>
<td>Quest</td>
<td>NSW, Australia</td>
</tr>
<tr>
<td>Illabong</td>
<td>NSW, Australia</td>
</tr>
<tr>
<td><strong>Tropical</strong></td>
<td></td>
</tr>
<tr>
<td>Yunlu 29</td>
<td>Yunnan, China</td>
</tr>
<tr>
<td>Viet 5</td>
<td>Vietnam</td>
</tr>
<tr>
<td>Tachiminori</td>
<td>Japan</td>
</tr>
<tr>
<td>Viet 4</td>
<td>Vietnam</td>
</tr>
<tr>
<td>Fin</td>
<td>QLD, Australia</td>
</tr>
<tr>
<td>IR 72</td>
<td>IRRI, Philippines</td>
</tr>
<tr>
<td>Takanari</td>
<td>Japan</td>
</tr>
<tr>
<td>B6144F-MR-6</td>
<td>Indonesia</td>
</tr>
<tr>
<td>NTR 587</td>
<td>IRRI, Philippines</td>
</tr>
<tr>
<td>Lemont</td>
<td>Texas, USA</td>
</tr>
<tr>
<td>NTR 426</td>
<td>IRRI, Philippines</td>
</tr>
</tbody>
</table>
The crop was planted into dry soil on 30 April and watered on 2 May to initiate germination. Scheduling of furrow irrigations was based on continuous soil moisture monitoring using an EnviroScan system. Cold stress (Figure 3.1) was assessed using a scoring system (Table 3.2) adopted from the International Rice Research Institute (IRRI) (2002).

**Figure 3.1  Symptoms of cold stress on susceptible varieties**

**Table 3.2  Scoring system for cold tolerance at different stages**

<table>
<thead>
<tr>
<th>Score</th>
<th>Visual symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>For seedlings</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Seedlings dark green</td>
</tr>
<tr>
<td>2</td>
<td>Seedlings light green</td>
</tr>
<tr>
<td>4</td>
<td>Seedlings yellow</td>
</tr>
<tr>
<td>6</td>
<td>Seedlings orange</td>
</tr>
<tr>
<td>8</td>
<td>Seedlings brown</td>
</tr>
<tr>
<td>10</td>
<td>Seedlings dead</td>
</tr>
<tr>
<td>From tillering to maturity</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Plants have a normal colour; rate of growth and flowering normal</td>
</tr>
<tr>
<td>2</td>
<td>Plants slightly stunted; growth slightly retarded</td>
</tr>
<tr>
<td>4</td>
<td>Plants moderately stunted, leaves yellowish and development delayed</td>
</tr>
<tr>
<td>6</td>
<td>Plants severely stunted, leaves yellow and development delayed, and panicles poorly exerted</td>
</tr>
<tr>
<td>8</td>
<td>Plants severely stunted, with leaves brown, development much delayed and panicles not exerted</td>
</tr>
<tr>
<td>10</td>
<td>Plants dead</td>
</tr>
<tr>
<td>Spikelet fertility</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>More than 80%</td>
</tr>
<tr>
<td>2</td>
<td>71–80%</td>
</tr>
<tr>
<td>3</td>
<td>61–70%</td>
</tr>
<tr>
<td>Score</td>
<td>Visual symptoms</td>
</tr>
<tr>
<td>-------</td>
<td>-----------------</td>
</tr>
<tr>
<td>4</td>
<td>51–60%</td>
</tr>
<tr>
<td>5</td>
<td>41–50%</td>
</tr>
<tr>
<td>6</td>
<td>31–40%</td>
</tr>
<tr>
<td>7</td>
<td>21–30%</td>
</tr>
<tr>
<td>8</td>
<td>11–20%</td>
</tr>
<tr>
<td>9</td>
<td>Less than 11%</td>
</tr>
</tbody>
</table>

(adopted from IRRI, 2002)

The final short stature of most varieties did not allow machine harvest of the entire crop. Hence one-metre row samples cut at ground level were obtained between 15 and 23 November. Key measurements included daily minimum air temperatures, cold stress scores on 21, 34, 54, 70, 86, 103, 119 and 131 days after planting (DAP), and grain yield at harvest. Panicle samples from each variety were obtained to assess the floret sterility through spikelet fertility as in Table 3.2. Grain yields were calculated based on the weight of grain in the samples and adjusted for 14% moisture. Results were subjected to ANOVA and Cluster Analysis. The values of cold stress scores and grain yields reported here are the mean of two replicates.

3.2 Flooded system trials at Kununurra during 2012 dry season

Five temperate and 12 tropical rice varieties (Table 3.1, except for Takanari and B6144F-MR-6) were evaluated for grain yield under flooded conditions (paddy system) (Figure 3.2) during the dry season of 2012 at the Frank Wise Institute of Tropical Agriculture. These varieties were planted on 28 April and watered (flushed) on 2 May and again on 16 May. Permanent water was applied on 30 May and maintained until lockup (that is, remaining water being used up by the crop with no further additions or drainage of water) on 28 September. A basal fertiliser mixture (Table 3.3) was applied prior to sowing, followed by an aerial application of urea at the rate of 150 kg/ha on 6 August.

![Figure 3.2 Evaluation of 17 varieties under flooded system](image-url)
### Table 3.3 Composition of basal fertiliser mixture and application rates

<table>
<thead>
<tr>
<th>Fertiliser</th>
<th>Content</th>
<th>Application rate (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Di-ammonium phosphate (DAP)</td>
<td>18% N and 20% P</td>
<td>100</td>
</tr>
<tr>
<td>Sulphate of potash (K₂SO₄)</td>
<td>41% K and 18% S</td>
<td>25</td>
</tr>
<tr>
<td>Single superphosphate (SSP)</td>
<td>8.8% P and 11% S</td>
<td>20</td>
</tr>
<tr>
<td>Zinc sulphate (ZnSO₄)</td>
<td>21% Zn and 15% S</td>
<td>15</td>
</tr>
<tr>
<td>Urea (CO(NH₂)₂)</td>
<td>46% N</td>
<td>150</td>
</tr>
</tbody>
</table>

Stomp® was sprayed on 1 May to control weeds. Plot size was 200 m long (except for Tachiminori and Yunlu 29, which were 100 m long due to lack of seeds) by 0.9 m wide which included six rows of plantings with 15 cm spacing between rows and a seeding rate of 182 kg/ha was used. Temperature probes were installed to monitor air and water temperatures. The crop was machine harvested between 30 October and 5 November.

### 3.3 Flooded system trials at Tortilla Flats during 2012 dry season

A trial was conducted at Tortilla Flats in the NT during 2012 dry season using lowland production system. Seed was obtained from Biloela Genetic Resource Centre at IRRI and SunRice. Variety Viet 4 was used to compare five top dress nitrogen regimes, two establishment techniques (Figure 3.3), and two plant densities under paddy conditions (Table 3.4).

![Figure 3.3 Evaluating two establishment techniques: (a) drill sown; (b) aerial sown](image-url)
Table 3.4  Details of nitrogen regimes, establishment techniques and plant densities tested at Tortilla Flats during the dry season of 2012

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Top dress nitrogen regimes</strong></td>
<td></td>
</tr>
<tr>
<td>NO</td>
<td>no top dress nitrogen</td>
</tr>
<tr>
<td>NR</td>
<td>recommended nitrogen rate with split application of 20 units at mid-tillering and 30 units at panicle initiation</td>
</tr>
<tr>
<td>NMT</td>
<td>50 units of nitrogen at mid-tillering</td>
</tr>
<tr>
<td>NPI</td>
<td>50 units of nitrogen at panicle initiation</td>
</tr>
<tr>
<td>NB</td>
<td>50 units of nitrogen at early/mid-booting</td>
</tr>
<tr>
<td><strong>Establishment techniques</strong></td>
<td></td>
</tr>
<tr>
<td>Drill</td>
<td>drill sowing</td>
</tr>
<tr>
<td>Flood</td>
<td>aerial sowing into flooded plots</td>
</tr>
<tr>
<td><strong>Target plant populations</strong></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>low intended population at 400 plants/m²</td>
</tr>
<tr>
<td>VL</td>
<td>population at hindsight at 200 plants/m²</td>
</tr>
<tr>
<td>H</td>
<td>high population at 800 plants/m²</td>
</tr>
</tbody>
</table>

In a separate trial, seven cultivars (BIRGA, Doongara, IR64, Sen Pidao, Tachiminori, Takanari and ULP R17) were evaluated (Figure 3.4). The date of sowing was 23–24 May and the plots were harvested during 4–23 October.

Figure 3.4  Evaluation of seven cultivars with different maturities

Land preparation consisted of 1-3 rotary hoe cultivations depending on soil conditions. Basal fertiliser was applied prior to sowing using a twin-box drill seeder at 30 cm row spacing, consisting of 150 kg/ha urea (46:0:0) at 8 cm depth, and 200 kg/ha NPKS blend (Nitrophoska Blue) (4:12:7:9) at 3 cm. Seed was sown in 30 cm rows using a single row vegetable drill. Stam® (480 g/L propanil) was applied for weed control one month after sowing. Permanent flood irrigation was applied within two days. Top dressing application of urea was hand spread according to the experimental design described in Table 3.4 and assuming that one unit of nitrogen is about two kg of urea. Insect infestation was sporadic, so chlorpyrifos was applied as necessary. The experimental site was under bird netting.
3.4 Aerobic trials at Katherine during 2012/13 wet season

The site was situated at Katherine Research Station (14°27′56″ S, 132°18′40″E). Soil type found within this area is a Tippera clay loam (red earth Kandosol). The area was predominantly an established Sabi grass (*Urochloa mosambicensis*) stand, which was freshened up with irrigation, sprayed out with glyphosate on 19 December 2012, then mowed and ploughed in on 27 December. The site was found to have a hardpan at 5 cm depth, so 5 mm of irrigation (2 hours) was applied overnight and was disced again the following day. The site had another cultivation with the rotary hoe to break up remaining Sabi grass clumps on 7 January, then fertiliser was applied using the Nordsten® twin boxes; consisting granulated urea (57 kg/ha) to a depth of 10-12 cm and 133 kg/ha of 19:13 CropLift® to a shallow depth. Rustica® was applied (192 kg/ha) to the experimental area to a depth of 10-12 cm the next day prior to sowing.

Twenty varieties (Azucena, B6144F-MR-6, BIRGA, Ceysvoni, Cica 6, IR 45, IR 64, Labonnet, NTR 426, NTR 587, PSBRC 9, Pandan Wangi 10, Pandan Wangi 7, Sen Pidao, Tachiminori, Takanari, ULP R17, Viet 1, Viet 4, and Yunlu 29) were tested. Plots were hand-sown with a vegetable planter (Figure 3.5a) on 9 January 2013, using the Beet/Okra seed plate to sow at equivalent 200 kg/ha. Due to compaction from the tractor used for pre-plant fertiliser application, varying sowing depths were observed and as such affected emergence. Plots were 11 rows (30 cm) by 4 m length (13.20 m²).

Experimental design was a Randomised Complete Block, with cultivars as the main treatment, replicated four times, over 5 bays. The harvest period was from 22 April (104 DAP) until 9 May (120 DAS).

![Figure 3.5](image)

**Figure 3.5** Upland trials at Katherine: (a) sowing rice with a vegetable planter; (b) solid set irrigation of trial area

Solid set irrigation (Figure 3.5b) was applied every evening during 9–12 January for approximately an hour, equivalent to 18 mm daily to fill soil profile. Plots were continued to be watered every evening for approximately an hour, however the amount varied. Irrigation was then calculated to replace evaporative losses on a daily basis to keep a full moisture profile available. Seed viability did not appear to be effected. The nitrogen fertiliser schedule intended that 70 units of nitrogen be applied at pre-sowing, followed by 20 units at time of sowing, with 20 units being applied via top dressing at mid-tillering and 30 units at panicle initiation (PI) stages. The top-dressing schedule was: 23 kg N/ha (50 kg/ha urea) on 1 February (23 DAP), 23 kg N/ha (50 kg/ha urea) on 20 February (43 DAP), and 23 kg N/ha (50 kg/ha urea) on 7 March (57 DAP).

Weeds were of a concern in the trial until the point in which a sufficient canopy had formed. Hand weeding was done every morning, primarily for sabi grass, however other weeds such as phasey bean (*Phaseolus macroptilium*), cavalcade (*Centrosema pascuorum*) as well as pigweed (*Amaranthus spp.*) were also present within the trial area. Due to the amount of weeds present, Kamba 500® was applied on 22 January in conjunction with a Trace 8 Mix application. Stam® (propanil) was applied on 14 February, however due to poor rice seedling growth, only major weed areas were sprayed.
3.5 Planting date trials at Kununurra during 2013 dry season

The purpose of the trial was to evaluate the yield potential and the grain quality parameters of selected temperate and tropical rice varieties grown under raised-bed and flooded conditions with three planting dates during the 2013 dry season at Frank Wise Institute of Tropical Agriculture in Kununurra. Three varieties (Langi, Viet 5 and Yunlu 29) were tested in aerobic (raised bed) conditions (Figure 3.6a) and five varieties (Doongara, Pandan Wangi 7, Viet 1, NTR 426 and NTR 587) were tested under a flooded (paddy) production system (Figure 3.6b). Three planting dates, a fortnight apart, on 22 April, 8 May and 21 May were used for both systems. Three replicates were used for each planting date.

(a)  
(b)  

Figure 3.6 Evaluating 3–5 varieties under different planting dates: (a) raised-bed system; (b) flooded system

The raised-bed system and the flooded system were treated as separate experiments. In each case, a split-plot design was used with blocks representing three planting dates, whole plots representing three replicates and subplots representing 3-5 varieties. A plot size of 100 m × 0.9 m was used for all plantings in the aerobic system and for the third planting in the flooded system. A plot size of 200 m × 0.9 m was used for the first and second plantings in the flooded system. A seeding rate of 152 kg/ha was used. A basal fertiliser consisting DAP 100 kg/ha, Sulphate of Potash 25 kg/ha, Single Super Phosphate 20 kg/ha, Zinc Sulphate 15 kg/ha and Urea 150 kg/ha was applied prior to planting. A top dressing of Urea at the rate of 150 kg/ha was applied closer to panicle initiation stage.

The aerobic system was furrow irrigated once every 12-17 days (average 14.3 days). A fixed irrigation scheduling adjusted according to water availability was used to determine whether the rice plants can utilise the subsoil moisture. An EnviroScan system was installed to monitor soil moisture status of the aerobic system from 21 May to 29 October. Flooded system was flushed twice before applying the permanent water after 28 days, and the ponded water was maintained until the paddy was drained to prepare for harvest. Two herbicides, Stomp just after sowing, and MCPA 4-5 weeks after sowing, were used to control weeds. Temperature loggers were installed to monitor air and water temperatures at 30 minute intervals.

Aerobic trials were hand harvested (3 m samples from each replicate) and the flooded system trials were machine harvested (whole of plot) (Figure 3.7). Yield (t/ha at 14% moisture) of each variety and quality parameters (millout, chalk, amylose and protein) of selected varieties were determined. Results were subjected to analysis of variance (ANOVA) and mean results are reported here.
3.6 Lysimeter trial at Kununurra during 2013 dry season

The study was conducted on Cununurra Clay soil (Self-mulching Vertosol) at Frank Wise Institute of Tropical Agriculture in Kununurra under ponded rice culture (flooded system) during the period from 10 June to 2 October (90 days). ‘Lockup bay tests’ as proposed by Humphreys (1992) together with a modified lysimeter experiment (Bethune et al. 2001) were used in this study. Three lysimeters (two with open-end and one with closed-end) were used. Each lysimeter was 50 cm across and 70 cm high and driven 35 cm into the ground and sealed. One lysimeter (open-end) was installed in the cropped area with other two in adjacent bare land. By comparing losses from each lysimeter, it was possible to measure the evaporation, transpiration and deep percolation components (Figure 3.8). The side valve on each lysimeter was opened during each irrigation event (that is, topping up the bay) to allow water inside.

![Figure 3.7 Harvesting trial plots for yield and quality analysis](image)

![Figure 3.8 Diagram of lysimeters to measure evaporation (E), transpiration (T) and deep percolation (DP) losses in a paddy field (the arrows indicate combined water losses)](image)

US Class A Pan evaporimeter was also installed at experimental site to measure actual evaporation losses in paddy field situation under FAO recommended standard conditions. Automatic water level
recorders were used to monitor changes in water level within lysimeters, evaporation pan and outside surrounding field (Figure 3.9). Lateral seepage from the test bay was prevented by undertaking ponded rice culture in adjacent bays in both sides. The tail-end bank was sealed using a plastic barrier just before commencing the experiment. Lockup bay tests were conducted once the permanent water had been applied to the rice crop (10 June) and continued until the bay was drained to prepare for harvest (2 October). A lockup bay test involves preventing water flow between the bays (that is, no inflow or outflow within the bay in this situation) and recording the change in water depth each day over a period of several days.

![Figure 3.9](image)

**Figure 3.9** Set up of lysimeters and evaporation pan to measure leakage losses under flooded rice system

The data for water height from each logger showed variations within a 24 hour period. Therefore an average height was calculated for the 24 hour period. The average height after an irrigation event was considered as the initial height of water column. Similarly the average height before the next irrigation event was considered as the final height of water column. The difference in height between these two readings was the total amount of water loss during that time period. Water losses are expressed as loss per day (mm/day) or total loss (mm) over the period of measurement (days). For the evaporation pan, these measurements correspond to water level after and before filling the pan with water, respectively.

### 3.7 Evaluation of soybeans in rotation with rice on beds during 2013 dry season

The aim of this trial was to determine how a nitrogen fixing crop would grow on land which had dry land rice last season as part of this rice research project. Paddock rotation was as follows: fallow (2007); chickpeas (2008); wheat (2009); rice (2010); fallow (2011); rice (2012); soybeans (2013); rice (2014). Soil samples were collected on 28 March 2013 and again on 5 May 2014 and analysed by CSBP Ltd for nutrient contents in soil, before and after soybeans. Soybean variety Leichhardt was planted in an area of 1.4 ha (42 beds). Land preparation included one pass to pull up beds and one pass to cultivate the middle of the bed. The block required two passes with the power harrows to break down the clods because the ground was quite hard after continuous watering for the rice during the previous season. The block was fertilised with 150 kg DAP/Zinc mixture supplying 27 units of nitrogen, 30 units of phosphorous and 15 units of zinc.

Seed was treated with peat based inoculum using a concrete mixer just before planting. The block was planted on 7 May 2013 aiming at a plant population of 300,000 plants/ha using the Maxi Merge precision planter with the settings at 64 cell corn plates, high range (driver 29 / driven 28), and vacuum of 8 using the long brushes. An application of 3L Stomp was applied after planting and the block was watered up. This was not the best method for soybean but was done to incorporate the Stomp evenly across the block. A crop inspection on 15 May noted a low germination with rotting seed found in the
seeded rows and decision was made to re-plant to increase plant population. The block was re-planted on 17 May into the moisture from the original planting. By 21 May, the crop had emerged very well gaining the required plant population.

The block was inter-row cultivated on 10 June mainly to remove a big population of Wild Gooseberry which grew through the application of Stomp. The block started flowering around the end of June. Very little insect pressure was observed so the block had not required a spray. Desiccation was held off to 19 September to cater for the rice field walk. Ideally the plants needed to desiccate around 10 September (Figure 3.10). The plants remaining from the original planting had shattered to some extent but the later planting was looking good. The crop was harvested on 25 September.

![Figure 3.10 Soybeans ready for desiccation](image)

### 3.8 Planting date trials at Tortilla Flats during 2013 dry season

A trial was conducted at Tortilla Flats in Adelaide River region during the 2013 dry season. This trial was designed to compare the effects of planting time, using Viet 4—an early maturing cultivar (shorter season), and NTR 587—a late maturing (longer season) cultivar. These two varieties were planted on 24 April and again on 31 May (that is, five weeks apart) and replicated three times. Both varieties were aerial sown and grown under paddy conditions (Figure 3.11).
Figure 3.11 Varieties Viet 4 and NTR 587 under two planting dates

Early planted crop was harvested on 27 August for Viet 4, and 10 September for NTR 587. Harvesting of second planting occurred on 16 October for Viet 4, and 22 October for NTR 587. Thunderstorm activities deposited 50 mm of rain on 14 October and again 37 mm of rain on 21 October before harvest of the later planted (31 May) crop. Grain yield and harvest index were determined for each treatment and the data was subjected to analysis of variance. Mean values of three replicates are reported here.

3.9 Assessing grain quality at Kununurra during 2014 dry season

The aim of these trials was to determine whether the preferred rice quality parameters, that is, high millout percentage and low chalk, could be achieved by harvesting early at the recommended grain moisture level of 22-24%. The trials also focused on establishing crops which mimic commercial plantings as a management tool against waterbirds’ attack at ripening stages.

Based on grain yields achieved in previous years, the variety Yunlu 29 was selected for the raised-bed system as upland or aerobic rice. It was sown in an area of 1.5 ha on 12 May (Figure 3.12) at a seeding rate of 148 kg/ha, immediately after the application of basal fertiliser mixture (Table 3.3) at the rate of 320.4 kg/ha. First watering occurred on 17 May. EnviroScan was installed on 29 May to set up an ideal irrigation scheduling system for optimum growth. MCPA was sprayed on 24 June, topdressing urea was applied on 16 July, manual weeding was performed during 22–24 July, plant sampling commenced on 14 October, and the crop was machine harvested on 27 October (164 days after planting).
Varieties NTR 587 and NTR 426 were selected for the traditional flooded system. Two rates of basal dressings, 310 kg/ha and 524.9 kg/ha of fertiliser mixture (Table 3.3), were tested. Four separate bays were used to test two varieties and two rates of basal dressings. The varieties were planted in total area of 7.3 ha during 19–20 May at a seeding rate of 198.4 kg/ha. For weed control, Stomp was sprayed on 21 May and MCPA on 12 June. First and second flushings occurred during 21–22 May and 4–5 June, respectively. Permanent water was applied during 17–18 June. Topdressing urea at the rate of 150 kg/ha was applied on 15 July. Lock-up of all bays was carried out on 1 October. Plant sampling commenced on 7 October and continued until harvest. NTR 587 was harvested on 22 October (155 DAP) and NTR 426 on 27 October (160 DAP) (Figure 3.13).

All three varieties (Yunlu 29, NTR 587 and NTR 426) were sampled or harvested and milled at different grain moisture conditions, thus generating 30 samples. The grain samples were sent to Yanco Agricultural Institute in NSW for quality analysis. They were evaluated for grain quality parameters—per cent millout, amylose content, chalk percentage and protein content. Grain yield and quality results were subjected to ANOVA and the mean results are reported here.
3.10 Lysimeter trial at Kununurra during 2014 dry season

This study was undertaken again in 2014 to estimate evaporation, transpiration and deep percolation losses from a flooded rice crop (ponded rice culture) using variety NTR 587 in Kununurra Clay soil using a set of three lysimeters and lockup bay tests (Figure 3.14).

![Figure 3.14 Set up of lysimeters and evaporation pan to measure leakage losses for variety NTR 587](image)

The experiment was conducted at the Frank Wise Institute of Tropical Agriculture in Kununurra between 18 June and 9 October (114 days). Three lysimeters (two with open-end and one with closed-end) were used (Figure 3.8). Each lysimeter was 50 cm in diameter and 70 cm high, and was driven 35 cm into the ground. All three lysimeters were installed within the cropped area. The side valve on each lysimeter was opened during each irrigation event (that is, topping up the bay at weekly intervals) to allow water inside. A US Class A Pan evaporimeter was also installed at the experimental site. Automatic water level recorders were used to monitor changes in water level within lysimeters, the evaporation pan and the outside surrounding field. Lateral seepage from the test bay was minimised by undertaking ponded rice culture in adjacent bays. The tail-end bank was sealed using a plastic barrier just before commencing the experiment. Lockup bay tests commenced with the application of permanent water to the rice crop on 18 June.

Evaporation was estimated from the water loss measured in Lysimeter A and the Class A pan. Deep percolation was estimated as the difference in water loss measured in Lysimeters A and B. Water moving downward from the open-end of the lysimeters at 35 cm depth was considered as deep percolation in this experiment. Transpiration was estimated as the difference in water loss measured in Lysimeters B and C. Total water use (that is, evaporation + transpiration + deep percolation) as measured in the lysimeters was compared with losses measured in the surrounding field.

3.11 Assessing fragrant lines at Tortilla Flats during 2014 dry season

The 2014 dry season trial at Tortilla Flats was planted on 12 April. This experiment had 17 varieties (Table 3.5) and was replicated seven times. A large number of these cultivars were fragrant lines. Cultivars that were susceptible to blast disease were also selected and were monitored for any disease incursions throughout the cropping period. All varieties were drill sown under minimum tillage conditions. The trial was conducted under traditional paddy conditions. The crop was harvested during 23 July–11 September (Table 3.5). Varieties Opus and Quest were infected badly with rice blast disease and therefore failed to produce any harvestable grain (Figure 3.15).
Table 3.5  Varieties tested at Tortilla Flats during the dry season of 2014 and their harvest dates

<table>
<thead>
<tr>
<th>Variety</th>
<th>Harvest date</th>
<th>DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opus</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Quest</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Amber 33</td>
<td>23 July</td>
<td>103</td>
</tr>
<tr>
<td>Yunlu 29</td>
<td>28 July</td>
<td>108</td>
</tr>
<tr>
<td>PHKA-Rumduol</td>
<td>1 August</td>
<td>112</td>
</tr>
<tr>
<td>Basmati</td>
<td>5 August</td>
<td>116</td>
</tr>
<tr>
<td>Hum Mal New</td>
<td>12 August</td>
<td>123</td>
</tr>
<tr>
<td>Kyeema/Basmati Stepheny</td>
<td>18 August</td>
<td>129</td>
</tr>
<tr>
<td>Kyeema</td>
<td>19 August</td>
<td>130</td>
</tr>
<tr>
<td>Pandan Wangi 7</td>
<td>21 August</td>
<td>132</td>
</tr>
<tr>
<td>YRF 209 SMITH</td>
<td>26 August</td>
<td>137</td>
</tr>
<tr>
<td>IR 64</td>
<td>26 August</td>
<td>137</td>
</tr>
<tr>
<td>Doongara</td>
<td>26 August</td>
<td>137</td>
</tr>
<tr>
<td>Pandan Wangi 10</td>
<td>4 September</td>
<td>146</td>
</tr>
<tr>
<td>Viet 8</td>
<td>9 September</td>
<td>151</td>
</tr>
<tr>
<td>Jefferson/Azucena Evangeline</td>
<td>9 September</td>
<td>151</td>
</tr>
<tr>
<td>Viet 1</td>
<td>11 September</td>
<td>153</td>
</tr>
</tbody>
</table>

Figure 3.15  Infection of blast disease in variety Opus: (a) 52 DAP; (b) 59 DAP; (c) 100 DAP

During a routine inspection on 27 May, blast disease (*Pyricularia oryzae*) was identified on the variety Quest in this trial. Ratings were then taken regularly on four occasions (27 May, 30 May, 2 June and 10 June) on the severity of blast disease on Quest and Opus varieties, while also inspecting all other varieties. The rating system adopted by IRRI (Table 3.6) was used in this trial. Plant samples were collected of both infected varieties and sent to the Pathology Division at Berrimah Agricultural Research Centre where isolates were taken from the infected samples and the specimens were preserved in the Plant Pathology Herbarium. All other varieties were monitored through the season and were found unaffected.
<table>
<thead>
<tr>
<th>Scale</th>
<th>Type of lesions</th>
<th>Host behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No lesions observed</td>
<td>Highly resistant</td>
</tr>
<tr>
<td>1</td>
<td>Small brown specks of pin-point size or larger brown specks without sporulating centre</td>
<td>Resistant</td>
</tr>
<tr>
<td>2</td>
<td>Small roundish to slightly elongated, necrotic grey spots, about 1–2 mm in diameter, with a distinct brown margin</td>
<td>Moderately resistant</td>
</tr>
<tr>
<td>3</td>
<td>Lesion type is the same as in scale 2, but a significant number of lesions are on the upper leaves</td>
<td>Moderately resistant</td>
</tr>
<tr>
<td>4</td>
<td>Typical susceptible blast lesions 3 mm or longer, infecting less than 4% of the leaf area</td>
<td>Moderately susceptible</td>
</tr>
<tr>
<td>5</td>
<td>Typical blast lesions infecting 4–10% of the leaf area</td>
<td>Moderately susceptible</td>
</tr>
<tr>
<td>6</td>
<td>Typical blast lesions infection 11–25% of the leaf area</td>
<td>Susceptible</td>
</tr>
<tr>
<td>7</td>
<td>Typical blast lesions infection 26–50% of the leaf area</td>
<td>Susceptible</td>
</tr>
<tr>
<td>8</td>
<td>Typical blast lesions infection 51–75% of the leaf area and many leaves are dead</td>
<td>Highly susceptible</td>
</tr>
<tr>
<td>9</td>
<td>More than 75% leaf area affected</td>
<td>Highly susceptible</td>
</tr>
</tbody>
</table>

(adopted from IRRI, 2002)
4. Results and discussion

4.1 Aerobic system trials at Kununurra during 2012 dry season

4.1.1 Varietal response to cold stress

The results of these trials indicated that air temperatures were the most critical factor for a successful crop. During germination and establishment, the minimum air temperatures were well above the critical minimum temperatures (that is, 10°C for germination and 12-13°C for establishment) and therefore did not affect germination or establishment. Plants reached the 5-leaf stage and started to produce tillers (early tillering stage) by 23 May (21 DAP). During 16-20 May, the minimum air temperatures were below 15°C (varied from 9.9 to 14.2°C) (Figure 4.1). The critical low temperature range for rice at this stage is 9-16°C. Minimum temperatures below the critical temperature can cause cold damage to plants. Visible symptoms such as yellowing of leaves, stunted growth, partially dead leaves and completely dead plants were used to assess the cold damage. Score varied from 0–no visible signs, to 10–severe damage (Table 3.2). Only varieties NTR 426 and Pandan Wangi 7 showed the signs of severe cold damage (score of 7) on 23 May (21 DAP).

![Figure 4.1 Observed minimum air temperatures at the trial site and average cold stress scores obtained on eight occasions](image)

Minimum temperatures again dropped below 15°C from 26 May to 1 June, the lowest temperature was 6.8°C on 27 May (Figure 4.1). The crop was monitored for cold stress again on 5 June (34 DAP) when the crop was at mid-tillering stage. Signs of further cold damage to plants (average score of all varieties 3.3) were observed. Minimum air temperatures remained below 15°C during 4-16 June and from 19 June to 11 July and the lowest temperature recorded was 6.1°C during this time. Cold stress scores taken on 25 June (54 DAP) showed an average of 4.8. From 20 June to 9 July, the minimum air temperatures remained below 11.7°C and averaged just 8.7°C, causing further cold stress. Cold stress
scores recorded on 11 July (70 DAP) indicated an average score of 6.0. The threshold temperatures for each growth stage are given in Table 4.1.

**Table 4.1** Critical temperatures of rice at different growth stages

<table>
<thead>
<tr>
<th>Growth stage</th>
<th>Low</th>
<th>High</th>
<th>Optimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germination</td>
<td>10</td>
<td>45</td>
<td>20–35</td>
</tr>
<tr>
<td>Establishment</td>
<td>12–13</td>
<td>35</td>
<td>25–30</td>
</tr>
<tr>
<td>Tillering</td>
<td>9–16</td>
<td>33</td>
<td>25–31</td>
</tr>
<tr>
<td>Panicle initiation</td>
<td>15</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Panicle differentiation</td>
<td>15–20</td>
<td>38</td>
<td>-</td>
</tr>
<tr>
<td>Anthesis</td>
<td>22</td>
<td>35</td>
<td>30–33</td>
</tr>
<tr>
<td>Ripening</td>
<td>12–18</td>
<td>30</td>
<td>20–25</td>
</tr>
</tbody>
</table>

(adapted from Yoshida 1981)

From 17 July to 24 August, the minimum temperatures were below 15°C which caused further cold stress to the crop (Figure 4.1). Thereafter, the minimum temperatures were within the favourable range and some varieties gradually showed signs of recovery. Rate of recovery varied vastly between varieties and this was reflected by the grain yield achieved. An attempt was made to classify varieties based on cold stress scores obtained at eight different times (Figure 4.2) to assess the varietal differences for cold tolerance.

![Figure 4.2 Grouping of varieties based on cold stress scores obtained on eight occasions](image)

The average of eight scores for each variety is also presented in Table 4.2 for comparison. Varieties NTR 426, Pandan Wangi 7 and NTR 587 had scores greater than 6, indicating their susceptibility to cold stress compared to the other varieties. This is also evident from their grouping together at a high similarity level as shown in Figure 4.2. Varieties Illabong, Tachiminori, Yunlu 29, Quest and Viet 1 indicated high cold tolerance (score between 3.2 and 3.4) relative to the other tested varieties. These varieties are grouped together at a lower similarity level in Figure 4.2. Varieties with similar cold tolerance levels can be identified from their grouping in Figure 4.2.
4.1.2 Grain yields under cold stress

Of the cold sensitive varieties as identified in Figure 4.2 such as Pandan Wangi 7, NTR 426, NTR 587, IR 64 and Takanari, they yielded lower than most other varieties (Table 4.2). These low yielding varieties showed severe cold damage and failed to recover under favourable conditions at the end of the season. It is obvious that these varieties when grown under an aerobic system would fail to produce economic yields in a cold year such as the dry season of 2012. Of the cold tolerant varieties identified in Figure 4.2, such as Illabong, Tachiminori, Yunlu 29, Quest and Viet 1, only Yunlu 29 achieved a high yield at 9.9 t/ha, while Viet 1 yielded lowest at 0.8 t/ha. While these varieties also suffered cold damage (average score 3.2–3.4), it appears that they also failed to recover (except for Yunlu 29) and produce economical yields. It is evident that out of the 19 varieties tested, not a single variety escaped the cold damage. There is no correlation between cold stress scores and grain yields. It is the recovery of plants after the cold damage that determined the final grain yield. Rate and degree of recovery after the cold damage varied between the varieties. If economic yield is considered for an aerobic system, then Yunlu 29 is the most preferred variety. Among the tested varieties, it has a rapid recovery from cold damage and has the ability to produce high yields.

Table 4.2 Average cold stress scores and grain yield of 19 varieties tested at Kununurra during the dry season of 2012

<table>
<thead>
<tr>
<th>Variety</th>
<th>Origin</th>
<th>Cold stress score (scale 0–10)</th>
<th>Grain yield (t/ha at 14% moisture)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yunlu 29</td>
<td>Yunnan, China</td>
<td>3.3</td>
<td>9.9</td>
</tr>
<tr>
<td>Langi</td>
<td>NSW, Australia</td>
<td>4.1</td>
<td>5.5</td>
</tr>
<tr>
<td>Viet 5</td>
<td>Vietnam</td>
<td>4.7</td>
<td>4.9</td>
</tr>
<tr>
<td>Tachiminori</td>
<td>Japan</td>
<td>3.3</td>
<td>3.7</td>
</tr>
<tr>
<td>Viet 4</td>
<td>Vietnam</td>
<td>4.8</td>
<td>3.7</td>
</tr>
<tr>
<td>Fin</td>
<td>QLD, Australia</td>
<td>5.1</td>
<td>3.7</td>
</tr>
<tr>
<td>IR 72</td>
<td>IRRI, Philippines</td>
<td>5.6</td>
<td>3.4</td>
</tr>
<tr>
<td>Kyeema</td>
<td>NSW, Australia</td>
<td>4.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Doongara</td>
<td>NSW, Australia</td>
<td>4.1</td>
<td>2.8</td>
</tr>
<tr>
<td>Takanari</td>
<td>Japan</td>
<td>5.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Quest</td>
<td>NSW, Australia</td>
<td>3.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Illabong</td>
<td>NSW, Australia</td>
<td>3.2</td>
<td>2.0</td>
</tr>
<tr>
<td>B6144F-MR-6</td>
<td>Indonesia</td>
<td>4.5</td>
<td>2.0</td>
</tr>
<tr>
<td>NTR 587</td>
<td>IRRI, Philippines</td>
<td>6.4</td>
<td>2.0</td>
</tr>
<tr>
<td>Lemont</td>
<td>Texas, USA</td>
<td>4.3</td>
<td>1.5</td>
</tr>
<tr>
<td>NTR 426</td>
<td>IRRI, Philippines</td>
<td>8.6</td>
<td>1.0</td>
</tr>
<tr>
<td>IR 64</td>
<td>IRRI, Philippines</td>
<td>5.8</td>
<td>0.9</td>
</tr>
<tr>
<td>Viet 1</td>
<td>Vietnam</td>
<td>3.4</td>
<td>0.8</td>
</tr>
<tr>
<td>Pandan Wangi 7</td>
<td>Indonesia</td>
<td>7.7</td>
<td>0.8</td>
</tr>
<tr>
<td>l.s.d. (5%)</td>
<td></td>
<td>0.04</td>
<td>3.76</td>
</tr>
</tbody>
</table>

There is no clear separation of temperate varieties (that is, Quest, Langi, Illabong, Kyeema and Doongara) from the tropical varieties for cold stress and grain yield. For example, Quest associated with Yunlu 29 for cold tolerance yielded much lower than Yunlu 29. Langi, on the other hand, achieved a modest grain yield of 5.5 t/ha and did not show any association with Yunlu 29 in Figure 4.2. Illabong had the lowest score of cold stress but yielded only 2.0 t/ha. A comparison of Figure 4.2 and Table 4.2 demonstrates that factors other than cold stress might be important to achieve high grain yield for some varieties.
4.1.3 Sterility caused by cold stress

Spikelet fertility varied significantly (P<0.001) between the tested varieties (Figure 4.3). As expected, the correlation between grain yield and spikelet fertility was found significant (P<0.001). Among the tested varieties, the spikelet fertility varied from 3.5% for Viet 1 to 29.0% for Viet 4. These spikelet fertility values correspond to fertility scores of 9 and 7, respectively (Table 3.2). This suggests the extent of cold damage caused by minimum air temperatures during the critical stages of the crop. Even the highest yielding variety Yunlu 29 had only 28.2% of spikelet fertility.

![Figure 4.3 Spikelet fertility of 19 varieties tested at Kununurra during the dry season of 2012](image)

Since there is no correlation between cold stress scores and grain yields, factors such as phenology (vigour), weed competition, high maximum air temperatures, water stress, etc. might have played a significant role in the recovery of plants during the later stages of the crop. It appears that factors other than cold stress may be important for the recovery of the identified cold tolerant varieties to achieve high yields. It is the rate and extent of recovery from cold damage that matters here for high or economic yield.

4.2 Flooded system trials at Kununurra during 2012 dry season

4.2.1 High yields achieved despite cold stress

Grain moisture at harvest varied from 12.2 per cent (Langi) to 22.8 per cent (Viet 1) (Table 4.3). Grain yields are reported at 14 per cent moisture. Grain yields of the 17 varieties tested varied from 4.2 t/ha (Langi) to 11.5 t/ha (NTR 587) with an overall average of 7.9 t/ha. This was achieved despite a cold year when minimum air temperatures dropped below 15°C at critical stages of the crop—tillering, panicle initiation, early pollen microspore, and flowering. In 2009, one replicate plot of Doongara (temperate variety) achieved the highest yield of 13.6 t/ha. However, this year, four tropical varieties (NTR 587, NTR 426, Viet 1, and Pandan Wangi 7) yielded more than Doongara’s average yield of 9.0 t/ha. One thing that is common for 2009 and 2012 is the late planting (15 May and 2 May, respectively) compared to the preferred February to April planting. In a normal season, early planting might help the crop to avoid low temperatures at critical stages during June and July and enable the crop to mature in mild weather conditions in August and September. However, the 2012 dry season experienced lower temperatures from May to September caused the crop to grow slowly. The crop took longer to reach maturity (harvesting commenced 180 days after planting) and this extended growing period might have contributed to the high yields achieved this year.
Table 4.3  Machine harvested yield results for each variety in the flooded system

<table>
<thead>
<tr>
<th>Variety</th>
<th>Origin</th>
<th>Grain yield (t/ha)</th>
<th>Moisture at harvest (%)</th>
<th>Blast disease rating*</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTR 587</td>
<td>IRRI, Philippines</td>
<td>11.5</td>
<td>16.8</td>
<td>MR</td>
</tr>
<tr>
<td>NTR 426</td>
<td>IRRI, Philippines</td>
<td>10.7</td>
<td>16.9</td>
<td>MR</td>
</tr>
<tr>
<td>Viet 1</td>
<td>Vietnam</td>
<td>10.1</td>
<td>22.8</td>
<td>MR</td>
</tr>
<tr>
<td>Pandan Wangi 7</td>
<td>Indonesia</td>
<td>9.5</td>
<td>13.0</td>
<td>MS</td>
</tr>
<tr>
<td>Doongara</td>
<td>Australia</td>
<td>9.0</td>
<td>13.4</td>
<td>-</td>
</tr>
<tr>
<td>Kyeema</td>
<td>Australia</td>
<td>8.9</td>
<td>13.0</td>
<td>MS</td>
</tr>
<tr>
<td>Viet 4</td>
<td>Vietnam</td>
<td>8.7</td>
<td>19.0</td>
<td>MR</td>
</tr>
<tr>
<td>IR 72</td>
<td>IRRI, Philippines</td>
<td>8.4</td>
<td>14.8</td>
<td>MR</td>
</tr>
<tr>
<td>Viet 5</td>
<td>Vietnam</td>
<td>8.3</td>
<td>13.1</td>
<td>-</td>
</tr>
<tr>
<td>Illabong</td>
<td>Australia</td>
<td>7.9</td>
<td>14.9</td>
<td>-</td>
</tr>
<tr>
<td>IR 64</td>
<td>IRRI, Philippines</td>
<td>7.9</td>
<td>15.4</td>
<td>MR</td>
</tr>
<tr>
<td>Lemont</td>
<td>Texas, USA</td>
<td>6.6</td>
<td>16.0</td>
<td>-</td>
</tr>
<tr>
<td>Fin</td>
<td>Australia</td>
<td>6.6</td>
<td>12.4</td>
<td>-</td>
</tr>
<tr>
<td>Quest</td>
<td>Australia</td>
<td>5.6</td>
<td>13.4</td>
<td>HS</td>
</tr>
<tr>
<td>Tachiminori</td>
<td>Japan</td>
<td>5.5</td>
<td>13.8</td>
<td>-</td>
</tr>
<tr>
<td>Yunlu 29</td>
<td>Yunnan, China</td>
<td>4.6</td>
<td>12.6</td>
<td>MR</td>
</tr>
<tr>
<td>Langi</td>
<td>Australia</td>
<td>4.2</td>
<td>12.2</td>
<td>-</td>
</tr>
</tbody>
</table>

* based on NT trials; MR-moderately resistant; MS-moderately susceptible; HS-highly susceptible; -data not available.

Varieties NTR 587, NTR 426, Viet 1, and Pandan Wangi 7 are late maturing (long season) varieties, while varieties such as Yunlu 29, Quest, and Langi are early maturing. The early maturing varieties suffered heavy losses due to bird damage prior to the harvest, hence, some of the lower yields reported do not represent the actual/potential yield of those varieties. Late maturing varieties survived the bird attack at the expense of early maturing ones. It should be noted that NTR 426 was also the highest yielding variety (yield 7.8 t/ha) under the flooded system in 2011. On the other hand, Pandan Wangi 7 in previous trials in 2010 and 2011 yielded between 3.2 and 4.6 t/ha under the flooded system.

4.2.2 Factors contributing to high yields

Considering the factors that contributed to the high yields, first of all, it was the water management that provided protection against cold damage. Minimum air temperatures dropped below 15°C for most days during May to September. Ponded water helped to raise the minimum temperatures by an average of 5°C and up to 9.4°C, maintaining a more favourable temperature profile within part of the crop canopy. It should be noted here that NTR 426, NTR 587 and Pandan Wangi 7 were the worst affected varieties by cold damage in this year’s aerobic trial (see results of the aerobic trials reported in Section 4.1). The application timing of permanent water and maintaining adequate depth of water during the critical stages of the crop proved to be important measures to protect the crop from cold damage. Other factors that contributed to the high yields included excellent weed control, pest and disease free status and adequate supply of nutrition. One thing which requires further investigation is the time of planting and the effect of growth duration of each variety to reach maturity. It appears that a late planting helped late maturing (long season) varieties to respond to increasing day light hours from June 21 onwards by accumulating greater biomass and hence achieving high yields. This aspect was explored in greater detail in 2013.
4.3 Flooded system trials at Tortilla Flats during 2012 dry season

4.3.1 Agronomy trial

Planting technique, plant population and timing of nitrogen applications are critical factors for successful rice cultivation. Trials conducted at Tortilla Flats during the dry season of 2012 aimed at solving these puzzles. Results from these trials are presented in Figure 4.4. Variety Viet 4 was selected for this trial because Viet 4 has provided the most promising results under all production systems in previous NT trials. The overall treatment effects on harvested grain yield was not significant (P>0.45) indicating that the interaction between the treatments had greater influence. Among the two establishment techniques, drill versus flood, the difference between them was not significant (P>0.25). The crop was grown under ponded culture and therefore the effect of different establishment techniques on growth and yield was negligible. This suggests that crop could be established either way depending on soil and climatic conditions. For example, if the ground is wet, aerial sowing can be undertaken and vice versa.

Figure 4.4 The effect of planting technique, plant population and timing of nitrogen applications on harvested grain yield

(NO—no top dress nitrogen; NR—recommended nitrogen rate with split application of 20 units at mid-tillering and 30 units at panicle initiation; NMT—50 units of nitrogen at mid-tillering; NPI—50 units of nitrogen at panicle initiation; NB—50 units of nitrogen at early/mid-booting; Drill—drill sowing; Flood—aerial sowing; L—low intended population at 400 plants/m²; VL—population at hindsight at 200 plants/m²; and H—high population at 800 plants/m²; error bars indicate standard deviation)

The differences between the three planting densities were significant (P>0.018). Very low (VL) and high (H) population densities produced lesser grain compared with low (L) population density. VL resulted in lower than expected preferred plant density. On the other hand, H resulted in high plant population where individual plants competed for resources such as light and nutrients. Even though rice plants are capable of adjusting for available space by producing less or more tillers, the situation existed in this trial was the extreme case.
The differences between the five nitrogen treatments were not significant (P>0.17). The highest weight of harvested grain was achieved when nitrogen was applied at panicle initiation stage (NPI). As expected, nil top dress nitrogen treatment (NO) produced the lowest grain yield. Rice plants are heavy users of nitrogen nutrient. Top dressing nitrogen ensures a high nitrogen use efficiency of rice plants. Rice plants were grown under ponded rice culture in this trial and the urea fertiliser applied as top dressing readily dissolves in water. Thus the effect of applying the fertiliser at different times had smaller effect on growth and yield of rice plants.

4.3.2 Variety trial

Seven varieties were evaluated for their grain yield in a separate trial conducted at Tortilla Flats during the dry season of 2012. The results are presented in Figure 4.5. The differences in grain yield for these varieties are significant (P>0.0082). Among the tested varieties, Takanari produced the highest yield and BIRGA produced the lowest. These results relate to days after sowing to harvest the crop. For example, Takanari took 153 days and BIRGA took 134 days to harvest. BIRGA was harvested on 4 October and Takanari on 23 October. A variety with longer duration enables better utilisation of the increasing day length associated with longer duration of sunlight.

![Figure 4.5 Grain yield of seven varieties tested at Tortilla Flats during the 2012 dry season (error bars indicate standard deviation)](image)

Late finish of Takanari in this instance predisposed the maturing crop to adverse environmental conditions such as high day time temperature and onset of wet season thunderstorms. This could be avoided by early planting but probably the variety will not achieve its yield potential. This aspect (the effect of planting date on growth and yield) was tested in a trial at Tortilla Flats during the dry season of 2013.

4.4 Aerobic trials at Katherine during 2012/13 wet season

4.4.1 Phenology of varieties

Field observations suggest that Pandan Wangi 10 was slow to establish. The earliest cultivars from sowing to harvest were IR 64, Viet 4 and Takanari, which required only 104 days. The time taken for panicle emergence varied between cultivars, with Tachiminori being the earliest (58DAP), and Pandan Wangi 10 the longest. The majority of the cultivars had panicle emergence during 70-80 DAP. The length of the growing season ranged from 104 days after sowing for Viet 4 to 120 days for Pandan Wangi 10. IR 45 and Azucena produced the fastest growth rate over the duration of the growing season. Although IR 45 was shorter than Azucena, it had slightly higher growth rate due to its earlier
maturity. Generally, there was a good correlation between final height at harvest and growth rate. These trends indicate that overall height and maturity of the individual varieties have an effect on the growth rate of the cultivars and that some growth rates may have slowed or quickened during certain parts of the season. This has implications for the timing of critical physiological stages such as early pollen microspore (EPM), panicle initiation (PI) and anthesis, in terms of susceptibility of different cultivars to cold temperatures.

Sen Pidao had the highest number of tillers, but this did not result in the highest yield. NTR587 had 30% less tillers but produced roughly 1.5 t/ha of grain more than Sen Pidao. Sen Pidao had higher harvest index (0.41) than NTR 587 (0.39) indicating that Sen Pidao produced less biomass as well as less grain than the other varieties. The relationship between tillers/m² and final grain yield resulted in a poor correlation. There are obviously other components which contribute to yield, but number of tillers may not be an important precursor to achieving high biomass and grain yields. This highlights the importance that high number of tillers may not necessarily be responsible for high yielding varieties.

4.4.2 Grain yields

Grain yields for the varieties are presented in Figure 4.6. Yields were confounded by different levels of plant establishment, subsequent weed infestation, and as well as wheel tract effect. Using 6 t/ha grain yield as the benchmark, only six varieties averaged higher in the trial. Tachiminori produced results close to 7 t/ha. The high yield, however, may be attributed to this variety being planted consistently (due to it being a guard row) in the wheel tract area which led to better emergence and establishment. Viet 4 was the highest yielder, producing 7.5 t/ha. Both Viet 4 and Tachiminori had high harvest index (0.52 and 0.50, respectively) leading to the conclusion that both were efficient producers of grain.

![Figure 4.6](image)

**Figure 4.6** Grain yield of 20 varieties tested at Katherine during 2012-13 wet season (error bars indicate standard deviation)

Rice producers in the NT are likely to have an integrated cattle enterprise (unlike the Ord and the Burdekin which are primarily irrigated cropping). Consequently, they are interested in a variety which produces both high grain and high biomass yields. Increase in cattle weight gains by grazing rice
stubble compared to native pasture may highlight the importance of selecting a variety which has the higher biomass production with only a small penalty for grain yield. NTR 587 has been the industry standard for the NT and is described as a dual purpose variety with good grain yields and low harvest index producing effective biomass levels. Pandan Wangi 10 produced less grain than NTR 587 (4.6 t/ha compared to 6.5 t/ha, respectively) and had a lower harvest index (0.30 compared to 0.39, respectively) leading to more biomass and the assumption that it may be a more effective dual purpose variety.

4.5 Planting date trials at Kununurra during 2013 dry season

4.5.1 Effect of different sowing rates

The seeding equipment used for this trial was calibrated using variety Quest (medium grain, seed weight 25.7 mg) to sow seed at the rate of 152 kg/ha, aiming at a total plant density of 200-300 plants/m². However, the grain characteristics were different for the varieties used and calibrating the seeder using the Quest variety resulted in applying varying amounts of seed for the other varieties (Table 4.4). However, correlation analysis between sowing rate and grain yield resulted in a coefficient of 0.063 which indicated that the different sowing rates did not impact on the grain yield of these varieties. It is well known that the rice plant has remarkable ability to compensate for less plant density by producing more tillers and vice versa. Therefore varying plant densities resulting from different sowing rates have no effect on grain yield. This phenomenon has been observed in previous trials at Kununurra (Sivapalan et al. 2012) and by other workers in NSW (Smith & Ford 2012).

<table>
<thead>
<tr>
<th>Varieties</th>
<th>Grain size</th>
<th>Seed weight (mg)</th>
<th>Sowing rate (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doongara</td>
<td>Long</td>
<td>21.9</td>
<td>152</td>
</tr>
<tr>
<td>NTR 426</td>
<td>Long</td>
<td>24.2</td>
<td>163</td>
</tr>
<tr>
<td>NTR 587</td>
<td>Long</td>
<td>28.4</td>
<td>181</td>
</tr>
<tr>
<td>Pandan Wangi 7</td>
<td>Long</td>
<td>27.0</td>
<td>171</td>
</tr>
<tr>
<td>Viet 1</td>
<td>Medium</td>
<td>24.3</td>
<td>182</td>
</tr>
</tbody>
</table>

4.5.2 Aerobic system trials

The Langi and Viet 5 plot plantings failed to produce any significant yields in the aerobic system for all three planting dates. Therefore it was decided not to harvest these varieties from this aerobic trial. However, variety Yunlu 29 was hand harvested and it produced low yields which were not significantly different (P > 0.23) between the three planting dates (Figure 4.7). It should be noted that this variety in the 2011 and 2012 trials yielded 11.7 and 9.9 t/ha, respectively. Cold stress did not seriously affect the yields from the 2013 aerobic trials. The number of days when the minimum air temperature dropped below 15ºC was 74 days in 2013, whereas it was 115 and 118 days in 2011 and 2012, respectively. Water stress was the main factor which contributed to the failure of the aerobic trials in 2013.
Figure 4.7 Mean yield of Yunlu 29 under three planting dates (error bars indicate standard error)

Data from the EnviroScan system showed that the soil moisture dropped below the desired critical soil moisture level (that is, the refill point at 50% depletion of plant available water) at 10 and 20 cm depths (Figure 4.8). While the root system has grown down to 40 cm, 70% of the absorbed water is extracted from the top 20 cm of the root zone. This means that the soil moisture data at both the 10 cm and the 20 cm depths are important for irrigation scheduling purposes. Rice is a semi-aquatic plant and considered as heavy user of water. Soil moisture levels closer to the drained upper limit are necessary to avoid water stress leading to reduced yields. The data on Figure 4.8 suggests that the soil moisture at 10 cm depth reached the refill point in approximately 7 days.

Figure 4.8 Fluctuation of soil moisture at 10 and 20 cm depths in the aerobic trial

A delay in commencing the next irrigation will subject the crop to water stress, especially in the root zone within the first 10 cm which absorbs 40% of total water uptake. The irrigation intervals for the 2013 trials varied from 12 to 17 days (average 14.3 days) and this caused severe water stress to plants. The ideal irrigation interval for rice in Kununurra soil has been estimated to be 7 days. This is
supported by the trials in 2011 when a yield of 11.7 t/ha was achieved with an average irrigation interval of 7.0 days. Similarly in 2012, a yield of 9.9 t/ha was achieved with an average irrigation interval of 7.7 days.

### 4.5.3 Flooded system trials

The ANOVA of grain yields of five flooded rice varieties over three planting dates indicated significant differences ($P < 0.001$) between the varieties and between the planting dates (Table 4.5). The interaction between the varieties and the planting dates is also significant ($P = 0.00105$) which means that certain varieties preferred certain planting dates. Average yields of five varieties for the first, second and third plantings were 3.9, 9.7 and 5.6 t/ha, respectively. This indicates that the second planting date (8 May) is the preferred time for sowing the tested varieties. Average yields over three planting dates for each variety varied from 4.4 t/ha (Doongara) to 8.3 t/ha (NTR 587).

#### Table 4.5 Results of analysis of variance of grain yields of 5 varieties tested with 3 planting dates

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting dates</td>
<td>272.7504058</td>
<td>2</td>
<td>136.3752029</td>
<td>102.7583319</td>
<td>3.77E-14</td>
</tr>
<tr>
<td>Varieties</td>
<td>84.0795347</td>
<td>4</td>
<td>21.0198836</td>
<td>15.8384232</td>
<td>4.50E-07</td>
</tr>
<tr>
<td>Interaction</td>
<td>48.2464811</td>
<td>8</td>
<td>6.0308101</td>
<td>4.54E-08</td>
<td>0.00105</td>
</tr>
<tr>
<td>Within</td>
<td>39.8143489</td>
<td>30</td>
<td>1.3271449</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>444.8907707</td>
<td>44</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean grain yields of each variety for each planting date are shown in Figure 4.9. Significantly higher yields were achieved with the second planting date (8 May) compared with first planting (22 April) and third planting (21 May). Crop planted on 8 May might have been more exposed to increasing daylight hours after 21 June compared to that planted on 22 April. Greater exposure to sunlight enables more photosynthesis and hence higher grain yields. This trend was not observed with the third planting date (21 May) and this may be due to severe crop damage caused by Brologas during establishment time. Note, that NTR 587 was the highest yielding variety in both first and third plantings and equal highest at the second planting. Viet 1 produced new record yields of 11.4, 12.3 and 14.3 t/ha for the 3 replicates of the second planting. Based on grain maturity, Viet 1 took about 2-4 weeks longer than the other varieties and this phenomenon might be a disadvantage for this variety when the additional costs of extended bird damage control and extra water and nutritional requirements for Viet 1 are considered. Alternatively, the equal highest yielding variety NTR 587 looks promising for the ORIA.
The three replicates for NTR 587 with the second planting date yielded close to each other (12.4, 12.6 and 12.4 t/ha) indicating less variability under high yields. In 2012, it achieved the highest yield of 11.5 t/ha for a planting date of 2 May. Based on previous studies (2012 dry season) at Kununurra, NTR 587 is very sensitive to cold temperatures (refer to Sections 4.1 and 4.2). However ponding water within the anaerobic production system helped to minimise the cold damage by maintaining a water temperature above 15ºC while the air temperature dropped below 15ºC on 74 days.

4.5.4 Grain quality assessments

Rice harvested from all three varieties in 2013 was subjected to quality analysis. Results (Table 4.6) indicate that the amylose content of NTR 587 was high. This is preferred for rice which tends to cook firm and dry. On the other hand, the amylose content of NTR 426 was medium, indicating this rice tends to be softer and stickier. Amylose content of Yunlu 29 was low, indicating a high level of stickiness.

Table 4.6  Quality analysis of rice harvested in 2013

<table>
<thead>
<tr>
<th></th>
<th>Moisture at harvest (%)</th>
<th>Moisture at dehulling (%)</th>
<th>Millout (%)</th>
<th>Chalk (%)</th>
<th>Amylose (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTR 426</td>
<td>17.9</td>
<td>10.5</td>
<td>43</td>
<td>39.0</td>
<td>19.9</td>
</tr>
<tr>
<td>NTR 587 (a)*</td>
<td>15.5</td>
<td>10.8</td>
<td>32</td>
<td>53.8</td>
<td>31.6</td>
</tr>
<tr>
<td>NTR 587 (b)*</td>
<td>16.8</td>
<td>10.5</td>
<td>24</td>
<td>67.2</td>
<td>31.7</td>
</tr>
<tr>
<td>Yunlu 29</td>
<td>15.0</td>
<td>10.3</td>
<td>12</td>
<td>-</td>
<td>14.1</td>
</tr>
<tr>
<td>Preferred</td>
<td>22-24</td>
<td>18</td>
<td>&gt;55</td>
<td>&lt;5</td>
<td>15-30</td>
</tr>
</tbody>
</table>

*Sample (a) was from a crop planted on 22 April; sample (b) was from a crop planted on 21 May

Quality analysis also indicated poor millout percentages and high chalk for the harvested grain. Yunlu 29 has coloured grain and therefore chalk does not apply. Prior to harvest, the maturing grain had experienced high fluctuations in diurnal temperatures (Figure 4.10) and this is likely to have caused cracking of the grains and a high amount of chalk in grains. Adverse weather conditions after physiological maturity and up to the time of harvest will be the most significant factor in reducing the % whole grain.
The harvesting of the 2013 trials was delayed to enable the grain moisture to drop to lower levels (15-18%). This practice was adopted to reduce drying costs and keep the seed for planting next year while maintaining high viability of the seed. The recommended grain moisture for harvesting commercial crops is 22-24%, which is then milled at 18% moisture. The harvested grain in these trials was milled at 10-11% moisture. Therefore the low grain moistures both at harvest and milling is likely to have contributed to lower millout percentages. It is believed that the preferred rice quality parameters, high millout percentage and low chalk, can be achieved by harvesting early at the recommended grain moisture level. These aspects were tested in trials during the dry season in 2014.

4.6 Lysimeter trial at Kununurra during 2013 dry season

4.6.1 Evaporation, transpiration and deep percolation losses

Results for evaporation, transpiration and deep percolation calculated from the lysimeter data are shown in Figure 4.11. Evaporation is the water loss measured in Lysimeter A. Deep percolation is the water loss measured in Lysimeter B minus water loss measured in Lysimeter A. Transpiration is the water loss measured in Lysimeter C minus water loss measured in Lysimeter B. Data points in Figure 4.11 are the average water losses within an irrigation cycle.
Figure 4.11  Evaporation, transpiration and deep percolation losses as measured by the lysimeters

There was general agreement for evaporation losses between that measured by the lysimeter A and Class A Pan. Total evaporation losses from Lysimeter A over a period of 90.5 days were 375.7 mm and from Class A Pan over a period of 91.2 days were 377.9 mm. Therefore, for the purpose of reporting evaporation losses from a flooded rice bay, data from Lysimeter A could be used. The data shows that evaporation losses were high at the beginning when the rice plants were small. But it decreased as the crop developed to full canopy which provided a shading effect to reduce the evaporation losses. When the air temperature increased in August and September, the evaporation was not affected. It appears that the shading effect was much greater than the air temperature effect on evaporation.

As expected, transpiration losses were much lower when the rice plants were small. The crop was planted on 8 May and it was 35 days old when the experiments started on 12 June with the application of permanent water. Transpiration losses increased rapidly as the plants reached full canopy and then started to decline when the plants approached full maturity. At full canopy, transpiration losses were almost double of evaporation losses. Over the period of 90.5 days, the total transpiration losses were 523 mm. The transpiration losses reported here is applicable to variety IR 72 at a population density of 200-300 plants/m² as maintained within Lysimeter C. It might be different for another variety and for different plant population.

The amount of deep percolation losses fluctuated approximately between 0 and 2 mm/day over the period and this may be due to the nature of measurements performed in Lysimeters A and B. The total deep percolation losses over a period of 90.5 days were 87.9 mm. Hence the average deep percolation loss over the period was 0.97 mm/day. This was less than previously reported in Kununurra, reflecting the improved crop and water management used on modern rice varieties. It also suggests that if this rate can be scaled up to a paddock and farm area, it is predicted that recharge of groundwater under extensive rice cultivation using the traditional flooded system in Kununurra clay soils should be within manageable limits given existing infrastructure.

4.6.2 Total water use

The total water losses (that is, the sum of evaporation, transpiration and deep percolation losses) as measured by the lysimeters were compared with the total field losses as measured outside the
lysimeters (that is, field water level) in Figure 4.12. The lysimeter measurements indicated that the total water loss can reach a value of 14 mm/day whereas the field losses reached a maximum of 10 mm/day. This is mainly because the lysimeter had 100% cropped area while the field had only 33.1% cropped area. This difference in cropped area had direct effect on the amount of transpiration losses only. In other words, the total transpiration losses from the field were only a third of that measured in the lysimeters. Another effect will be the difference in water level within lysimeters (open-end type only) and outside, thus creating a hydraulic difference. The implication of this effect is over estimation of deep percolation losses and under estimation of transpiration losses in these experiments.

![Graph showing total water losses from flooded rice system within lysimeters and outside in the field](image)

Figure 4.12 Total water losses from flooded rice system within lysimeters and outside in the field

The total water losses as measured by the lysimeters over the period of 90.5 days were 986.6 mm. The rice crop had ponded water for 110 days. Therefore the above measurements were extrapolated to cover the entire duration of ponding and the result is 1198.7 mm. Using a conversion of 100 mm of water depth equals to 1 ML/ha, the total water loss would be approximately 12 ML/ha. Assuming a further 1 ML/ha is used for two flushings carried out before the permanent water, the total water usage amounts to 13 ML/ha for the 2013 rice crop. This compares well with the rice crop water use of 18.4 ML/ha for conventional ponded rice grown on a flat layout at Coleambally in New South Wales in Australia (Dunn et al. 2004). Compared with other crops such as sugar cane in the ORIA which requires approximately 18 ML/ha of water, that is, 12 ML/ha during dry seasons and 6 ML/ha during wet seasons (Kinhill 1995), rice appears to require less water.

4.6.3 Water productivity

In the present study, water productivity as calculated with respect to the amount of water evaporated and transpired was 0.73 t/ML and with respect to total water input was 0.74 t/ML. A value from 0.42 to 0.60 t/ML has been cited for rice water productivity in Australia (Christen & Jayewardene 2005). In contrast, a trial in south-eastern Australia found that the water use efficiency of conventional ponded rice was 0.68 t/ML (Dunn et al. 2004). The value for water productivity reported in this study was significantly higher than those reported in those references. Hence the conventional ponded rice culture similar to that adopted in this trial was highly efficient for rice production on Cununurra Clay soil in the tropical environment, specifically for the variety IR 72 and for the environmental conditions experienced during the dry season of 2013.
The results reported here are only applicable for 110 days of ponding, for variety IR 72 and for 100% cropped area at 200-300 plants/m². As mentioned before, the crop water usage might be different for a different variety and for different climatic conditions where ponding duration is dependent on growth duration. Therefore it was decided to repeat this experiment in 2014 for a different variety such as NTR 587 with 100% cropped area within lysimeters and outside field. This is necessary to conform that the deep percolation losses are, in fact, less than 1 mm/day and to determine the rice crop water requirement for a different variety in another season.

4.7 Evaluation of soybeans in rotation with rice on beds during 2013 dry season

Soybeans (variety Leichardt) was grown on raised-beds during the dry season of 2013. The aim of this trial was to determine how a nitrogen fixing crop (soybeans) would grow on land which had rice last season as part of rotational cropping system. Paddock rotation was fallow (2007), chickpeas (2008), wheat (2009), rice (2010), fallow (2011), rice (2012), soybeans (2013), and rice (2014). Soil samples were collected from the trial area before planting soybeans (28 March 2013) and again before planting next year’s rice crop (5 May 2014). The results of soil analysis for nutrient contents are shown in Table 4.7. There was no significant change in nutrient contents occurred due to planting soybeans. Visual observations suggested slight improvements in soil structure after soybeans. Based on these results, it can be concluded that the effect of soybeans on the following rice crop was minimal in influence. This could be due to the 2013/14 wet season rainfall and high temperatures which might have promoted rapid decomposition of organic matter which was left in the soil after soybeans. In addition, leaching and runoff losses of nutrients might have occurred during the wet season.

Table 4.7 Results of soil analysis before and after soybeans

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>2013 Before soybeans</th>
<th>2014 After soybeans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium Nitrogen</td>
<td>mg/Kg</td>
<td>&lt;1</td>
<td>3</td>
</tr>
<tr>
<td>Nitrate Nitrogen</td>
<td>mg/Kg</td>
<td>20</td>
<td>17</td>
</tr>
<tr>
<td>Phosphorus Colwell</td>
<td>mg/Kg</td>
<td>66</td>
<td>75</td>
</tr>
<tr>
<td>Potassium Colwell</td>
<td>mg/Kg</td>
<td>275</td>
<td>251</td>
</tr>
<tr>
<td>Sulphur</td>
<td>mg/Kg</td>
<td>6.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Organic Carbon</td>
<td>%</td>
<td>0.83</td>
<td>0.55</td>
</tr>
<tr>
<td>Conductivity</td>
<td>dS/m</td>
<td>0.088</td>
<td>0.061</td>
</tr>
<tr>
<td>pH Level (CaCl₂)</td>
<td>pH</td>
<td>6.8</td>
<td>6.7</td>
</tr>
<tr>
<td>pH Level (H₂O)</td>
<td>pH</td>
<td>7.7</td>
<td>7.7</td>
</tr>
<tr>
<td>DTPA Copper</td>
<td>mg/Kg</td>
<td>0.86</td>
<td>0.97</td>
</tr>
<tr>
<td>DTPA Iron</td>
<td>mg/Kg</td>
<td>12.27</td>
<td>16.76</td>
</tr>
<tr>
<td>DTPA Manganese</td>
<td>mg/Kg</td>
<td>12.65</td>
<td>9.09</td>
</tr>
<tr>
<td>DTPA Zinc</td>
<td>mg/Kg</td>
<td>6.01</td>
<td>7.69</td>
</tr>
<tr>
<td>Exch. Aluminium</td>
<td>meq/100g</td>
<td>0.062</td>
<td>0.074</td>
</tr>
<tr>
<td>Exch. Calcium</td>
<td>meq/100g</td>
<td>19.96</td>
<td>20.81</td>
</tr>
<tr>
<td>Exch. Magnesium</td>
<td>meq/100g</td>
<td>12.42</td>
<td>13.06</td>
</tr>
<tr>
<td>Exch. Potassium</td>
<td>meq/100g</td>
<td>0.71</td>
<td>0.64</td>
</tr>
<tr>
<td>Exch. Sodium</td>
<td>meq/100g</td>
<td>0.64</td>
<td>0.66</td>
</tr>
<tr>
<td>Boron Hot CaCl₂</td>
<td>mg/Kg</td>
<td>0.69</td>
<td>0.66</td>
</tr>
</tbody>
</table>
The yield of soybean (variety Leichardt) was low (0.72 t/ha) which is well below the average for the region. Major problems were encountered during the growing season: (1) low germination with rotting seed found in the seeded rows and decision was made to re-plant to increase plant population; (2) delayed desiccation to cater for the rice field walk; and (3) the plants remaining from the original planting had shattered to some extent. Yield would be a determinant of a successful crop.

4.8 Planting date trials at Tortilla Flats during 2013 dry season

4.8.1 Grain yields

Two planting dates (24 April and 31 May) and two varieties (Viet 4 and NTR 587) were tested under paddy conditions. The hot dry season resulted in quick, early growth, and a short growing period, which may have contributed to lower yields (Figure 4.13). Panicle emergence for Viet 4 and NTR 587 occurred at 86 and 107 DAP and the harvest commenced on 128 and 142 DAP, respectively. The yields of Viet 4 and NTR 587 from first planting were just under 6 t/ha and just over 7 t/ha, respectively, and from second planting were both just over 5.5 t/ha. This year, lodging was a problem in both plantings, second planting had a greater problem than first planting. Strong winds for the second half of the growing season and heavy storms prior to the second harvest reduced final yields.

![Figure 4.13 Grain yield of two varieties as influenced by the date of planting (1st planting=24 April, 2nd planting=31 May; error bars indicate standard deviation)](image)

Warmer weather with strong winds and late season rains were conducive to high levels of late lodging and lower than normal yields. This effect was more pronounced in the late planting treatment. Results have shown that optimum planting time is early to mid-April (weather permitting) to allow enough time to drain bays and give a larger window of opportunity at the end of the season to avoid early storms at harvest. In previous experiments conducted at this site has shown that planting techniques, plant population, and correct timing of nitrogen applications are all critical factors. This trial has shown that timing of planting is also a priority for this site.

4.8.2 Harvest index

Results of harvest index for the two varieties tested under the two planting dates are shown in Figure 4.14. Harvest index of Viet 4 and NTR 587 were almost similar when these varieties were planted on 24 April (first planting). Since NTR 587 produced more grain than Viet 4 for this planting date, it can
be concluded that NTR 587 must have produced more biomass than Viet 4. Therefore NTR 587 is more suited as a dual purpose variety than Viet 4. Dual purpose varieties are preferred for their high yield and their ability produce greater biomass as hay. There is high demand for rice hay to feed the cattle industry in NT.

![Harvest index of two varieties as influenced by the date of planting (1st planting=24 April, 2nd planting=31 May)](image)

**Figure 4.14** Harvest index of two varieties as influenced by the date of planting (1st planting=24 April, 2nd planting=31 May)

### 4.8.3 Aromatic rice

Basmati variety was also planted in a separate bay for observation and also suffered from high levels of lodging and was rain affected. Yields of 2 t/ha were recorded for Basmati. Future work in northern Australia has been re-evaluated and screening a greater range of fragrant and aromatic rice lines initiated in NT for 2014. These lines have an opportunity for import substitution in Australian markets and are suited to the tropical environment.

### 4.9 Assessing grain quality at Kununurra during 2014 dry season

#### 4.9.1 Grain yields

The trials during the dry season of 2014 were established to evaluate the grain quality parameters of three rice varieties as influenced by the tropical environmental conditions that prevailed in 2014 in the ORIA. The grain yield achieved for all three varieties (Figure 4.15) was average than what was expected. This was mainly due to a high percentage of floret sterility which was observed during the harvest in all three varieties. Differences in grain yield between varieties were significant (P<0.001). NTR 587 was the highest yielding variety in this trial. High basal dressing (HBD) of 524.9 kg/ha of fertiliser mixture failed to achieve significant increase in grain yield than low basal dressing (LBD) at 310 kg/ha. A higher rate of fertiliser may not be required by the rice plants or part of the fertiliser might have been lost before the plants could absorb them.
Figure 4.15 Grain yield of three varieties tested during the dry season of 2014 (LBD=low basal dressing, HBD=high basal dressing, error bars indicate standard deviation)

Minimum air temperatures (Figure 4.16) during August dropped below 15°C. This occurred continuously for 43 days. The lowest temperature was 3.0°C on 16 August. The most critical stages of crop growth—panicle initiation (PI) and early pollen microspore (EPM)—might have coincided with this period. This was the case especially with Yunlu 29 which was grown as aerobic rice with no ponded water. In the flooded system, minimum water temperatures during this period dropped slightly below 15°C on six occasions. A high degree of cold damage (browning of leaves) was observed in NTR 587 and NTR 426 above the water level in the bays. Even deep water (up to 25 cm) failed to protect the crop from such cold damage.

Figure 4.16 Minimum air and water temperatures during the growing season of 2014
4.9.2 Grain quality assessments

The recommended grain moisture for harvesting commercial crops in New South Wales is 22-24%, and the harvested rice is dehulled at 18% moisture and then milled at 12% moisture. This study evaluated the grain quality parameters of three rice varieties—NTR 587, NTR 426 and Yunlu 29—as influenced by the tropical environmental conditions that prevailed in 2014 in the ORIA. Grain moisture at sampling/harvest varied from 11.9% to 22.9% for the 30 samples generated in this study. Grain moisture at dehulling varied from 10.5% to 17.6%. Grain moisture at milling varied from 9.8% to 10.5%. Low moisture at milling was due to the delay in processing the samples for quality analysis at Yanco Agricultural Institute. The results of a correlation analysis between the six parameter associated with quality are shown in Table 4.8. As expected, moisture at sampling/harvest had significant (P<0.001) effect on millout percentage suggesting a high moisture at harvest enables high millout percentage. On the other hand, high moisture at harvest enables low chalk (preferred quality characteristic) (P<0.001). Grain moisture at dehulling had minimum impact on the quality parameters.

Table 4.8  Correlation matrix of six parameters associated with rice quality

<table>
<thead>
<tr>
<th></th>
<th>Moisture at sampling / harvest (%)</th>
<th>Moisture at dehulling (%)</th>
<th>% millout</th>
<th>Chalk (%)</th>
<th>% protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture at dehulling (%)</td>
<td>0.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% millout</td>
<td>0.83</td>
<td>-0.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chalk (%)</td>
<td>-0.62</td>
<td>-0.41</td>
<td>-0.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% protein</td>
<td>0.38</td>
<td>0.10</td>
<td>0.15</td>
<td>-0.30</td>
<td></td>
</tr>
<tr>
<td>% amyllose</td>
<td>-0.24</td>
<td>-0.12</td>
<td>-0.06</td>
<td>0.12</td>
<td>-0.85</td>
</tr>
</tbody>
</table>

Prior to harvest, the maturing grain experienced high fluctuations in diurnal temperatures (Figure 4.17) and this might have caused cracking of the grains (hence low millout percentage) and a high amount of chalk in grains. Such adverse weather conditions after physiological maturity and up to the time of harvest were the most significant factor in reducing the per cent whole grain. However, the preferred millout percentage of >55 was achieved by harvesting at high moisture level greater than 19.4%. On the other hand, the preferred chalk percentage <5 was not achieved by harvesting at high grain moisture level. The temperature fluctuations prior to harvest might have played a major role in creating high amount of chalk in the grain. Therefore it is clear that the crop must mature in mild weather (mid-August–mid-September) to achieve high quality grain. This would prompt early planting (February–March) of the crop in this environment.
4.9.3 Varietal differences for grain quality

Variety NTR 426 achieved high millout percentages when the grain was harvested at more than 19.4% moisture (Figure 4.18) except for one sample which was dehulled at high moisture compared with all other samples. At high moisture, the grain may not be strong enough to withstand the stress imposed on grain during the dehulling process thus may breakdown into pieces. Chalk remained high and increased when the grain was left in the field for longer period. Protein and amylose content were not affected by harvest conditions. Amylose content of NTR 426 was medium (21.63%) indicating this rice tends to be softer and stickier.
Variety NTR 587 achieved high millout percentage when harvested at 19.5% or higher grain moisture (Figure 4.19). This variety tends to develop more chalk than NTR 426. Protein and amylose content were not influenced by the harvest conditions. Amylose content of NTR 587 was high (29.63%) and this is preferred for rice which tends to cook firm and dry.
Reasonably good millout percentage was achieved when the grain was harvested at high moisture greater than 20% for variety Yunlu 29 (Figure 4.20). Average protein content (8.74%) of Yunlu 29 was higher than that of NTR 587 and NTR 426. But average amylose content (13.71%) of Yunlu 29 was much lower than that of NTR 587 and NTR 426. Low amylose content indicates a high level of stickiness of cooked rice. This may be a preferred characteristic for speciality uses in traditional cooking by Asian communities. Since Yunlu 29 has red coloured grain, chalk is not an issue.

![Figure 4.20](image)

**Figure 4.20**  Relationship between quality parameters and moisture at sampling/harvest for variety Yunlu 29

The results of this trial indicate the influence of the harvest conditions upon grain quality characteristics, especially millout and chalk percentages. Protein and amylose contents were not affected by the harvest conditions. A high millout percentage can be achieved by harvesting at higher grain moisture levels. However, except for Yunlu 29, high amount of chalk will remain as a limiting factor to achieve high quality grain. Therefore it is important to ensure that the crop will mature in mild weather. This can be achieved by early planting in the growing season.

### 4.9.4 Preventing bird damage

The flooded system trials at the Frank Wise Institute of Tropical Agriculture at Kununurra in 2014 also focussed on varieties—NTR 587 and NTR 426—for their ability to produce tall, dense crops at maturity. Grain eating waterbirds are attracted to poor, patchy, uneven crops and experimental crops where the crop edge to area ratio is very high. Crop attack is most likely in areas of low tiller density, ‘holey’ areas, tiller lodgement and crop edges. Trials in 2014 were established to mimic commercial crops. The rice crop in 2014 was well grown and had formed a closed canopy which restricted the entry of the birds. The overall management of the crop produced an even, tall, dense, standing crop, and waterbird attack was restricted to bay edges and usually only the glossy ibis was involved. Under such situations, the rice crop generally sustained very little damage. It can be concluded that if ripening crops are tall, dense and even, no flock management will generally be required. If such crops are produced, most growers may not need to implement any control management strategies at the crop ripening stage.
4.10 Lysimeter trial at Kununurra during 2014 dry season

4.10.1 Evaporation losses

Average evaporation losses from Lysimeter A and from the evaporation pan are shown in Figure 4.21. Readings from Lysimeter A were obtained within an irrigation cycle (that is, between topping-up the bay) and readings from the evaporation pan were obtained between two consecutive re-filling processes which coincided with the irrigation events. There was general agreement for evaporation losses between that measured by Lysimeter A and the Class A Pan. Analysis of variance of data obtained from Lysimeter A and Class A Pan indicated no significant differences (P>0.64) between the data obtained from them. Results obtained from Lysimeter A were highly correlated with the measurements made in evaporation pan (correlation coefficient 0.87; significant at P<0.001).

![Evaporation losses graph](image)

**Figure 4.21** In-situ measurements of evaporation from Lysimeter A and Class A Evaporation Pan

The evaporation losses were high at 6 mm/day at the beginning when the rice plants were small. Losses decreased to 3-4 mm/day as the crop developed to full canopy, which provided a shading effect. Total evaporation losses from Lysimeter A over a period of 114 days were 428 mm and from Class A Pan over the same period were 406 mm. This difference could be attributed to higher evaporation losses observed in Lysimeter A during the early stages of the experiment. Differences in materials used for construction, diameter of the cylinder and height above ground level between Lysimeter A and evaporation pan might have contributed to the disparity in measurements. This effect was minimised when the surrounding plants became tall and deep water was applied to the field.

4.10.2 Transpiration losses

Transpiration was estimated from the water loss measured in Lysimeter C minus water loss measured in Lysimeter B and the results are shown in Figure 4.22. The first two negative values for transpiration in Figure 4.22 were unexpected. During this period of time, the transpiration losses were small and the evaporation and deep percolation losses were common for both lysimeters. Therefore accurate measurement of transpiration losses at this point in time was not possible and the negative values could be attributed to experimental error.
As expected, transpiration losses were much lower when the rice plants were small. The crop was 23 days old when the experiments started on 18 June 2014 with the application of permanent water. Transpiration losses progressively increased as the plants reached full canopy. At full canopy, transpiration losses were almost twice the evaporation losses. Over the period of 114 days, the total transpiration losses were 286 mm. The transpiration losses reported here are specific for (1) rice variety NTR 587; (2) agronomic practices (sowing rate, fertiliser rate, water management, etc.) used in this study; and (3) the environmental conditions that prevailed in 2014.

4.10.3 Deep percolation losses

Deep percolation is the water loss measured in Lysimeter B minus water loss measured in Lysimeter A and the results are shown in Figure 4.23. The estimated deep percolation losses are controversial and only 6 data points of the total 16 resulted in a positive value. Lysimeters A and B are identical in shape, size and material and therefore evaporation losses from these two lysimeters must be the same. A negative value for deep percolation can result only if water moved into Lysimeter B through the valve or through the open end under the ground. This cannot happen as the water level of the surrounding field was lower than the water level inside the lysimeter for most of the time (except at the end of an irrigation event when water levels were the same). This aspect needs further investigation.
It should be noted that the estimated deep percolation values in this experiment were small and they fluctuated approximately between +0.5 and -0.5 mm/day over the period (except two data points). Thus regardless of the nature of measurements performed in Lysimeters A and B, it can be concluded that the deep percolation losses are negligible in Cununurra Clay soil at this trial site.

4.10.4 Total water use

The total water use (that is, the sum of evaporation, transpiration and deep percolation losses) as measured in the lysimeters was compared with that measured in the surrounding field (Figure 4.24). Analysis of variance indicated no significant differences (P>0.30) between the two data sets. In addition, correlation coefficient between the two data sets was 0.628; significant at P<0.01. The cumulative total water use for the period of 114 days in the lysimeters was 693 mm and that in the surrounding field was 766 mm. The difference of 73 mm between these two measurements could be due to underestimation of deep percolation in the lysimeters. If this is the case, then the average deep percolation losses over the measurement period of 114 days could be 0.64 mm/day.
Total water use (i.e. sum of evaporation, transpiration and deep percolation losses) as measured in the lysimeters and in the surrounding field

The measurements in this trial ended on 9 October 2014 when the water levels dropped below the recorders. The crop was harvested on 22 October 2014. Usually water use drops as the ground dries prior to harvest. Hence a moderate water use of 8 mm/day can be assumed during the last 13 days and this is equivalent to a total water use of 104 mm. Another 100 mm of water (equal to 1 ML/ha) could be attributed to the two flushings carried out before the permanent water was applied. Therefore, the total water use for the variety NTR 587 in 2014 trial was 970 mm or 9.7 ML/ha. This compares well with the rice crop water use of 18.4 ML/ha for conventional ponded rice grown on a flat layout at Coleambally in New South Wales (Dunn et al. 2004).

4.11 Assessing fragrant lines at Tortilla Flats during 2014 dry season

The trial at Tortilla Flats for the 2014 season focussed on fragrant/aromatic lines. Aromatic rice is highly prized by rice consumers globally, and countries that produce aromatic rice obtain high financial returns in the international rice market. Northern Australia could be a key participant in that market, therefore there is potential in the future to expand on the research work that has already been done in Northern Australia on Jasmine style aromatic rice lines.

4.11.1 Grain yields

Grain yield results are presented in Figure 4.2. Varieties are arranged in order of their maturity, that is, from Amber 33 which took 103 days to Viet 1 which took 153 days to reach maturity from planting (Table 3.5). It was expected that longer season varieties could achieve higher yields than shorter season varieties. This was not established by the results from this trial. The correlation between grain yield and days to maturity was not significant. The difference in maturity between the short season variety Amber 33 and long season variety Viet 1 was 50 days. If water is a limiting factor, then shorter season varieties are preferred. Another advantage of using shorter season varieties is that the crop could be harvested before the onset of harsh climatic conditions. This will help to achieve high quality (high millout percentage and low chalk) of the harvested grain.
There were significant differences in yield (P<0.001) between the varieties tested in this trial. Overall yield performance of all 15 varieties was below average. Highest yielding variety was Yunlu 29, followed by Kyeema, Doongara, YRF 209 SMITH and Amber 33. Grain yield of these five varieties varied from 3.8 t/ha to 4.6 t/ha which was considerably higher than the yields of the rest of the varieties. Depending on the quality of the harvested product and therefore the market price it could attract, cultivation of these varieties could be profitable at these yield levels.

### 4.11.2 Blast disease

Blast disease has been documented in previous flood plain rice trials grown at Tortilla Research Farm in the 60’s and recently in an upland rice trial grown at Coastal Plains during the wet season of 2011/12. Quest is very susceptible to blast disease (Sivapalan et al. 2012a) and for that reason it was planted in the trial at Tortilla Flats during the dry season of 2014 to monitor the blast disease infections. Once the disease symptoms were found, closer inspections on all varieties were performed. Blast disease was found only on varieties Quest and Opus (Figure 4.26). Within two weeks (from 27 May to 10 June), the disease rating for Opus increased from 5.6 to 7.7, and for Quest increased from 5.3 to 6.6. All other varieties were not affected. Quest and Opus are temperate varieties from NSW. The other two temperate varieties, Kyeema and Doongara, were not affected by the blast disease. It seems like there might be some tolerance to blast disease in most varieties with tropical origin (Table 4.3).
Figure 4.26 Blast disease rating of Quest and Opus at Tortilla Flats during 2014 dry season
5. General discussion

5.1 Rice in the Ord River Irrigation Area

5.1.1 Varieties

Trials at Kununurra during the dry season of 2012 evaluated 5 temperate and 14 tropical rice varieties under raised-bed (aerobic system). Minimum air temperatures less than 15°C during cold sensitive growth stages (tillering, panicle initiation, early pollen microspore and flowering) caused severe cold damage. The results of this study provided some helpful insights regarding selection of varieties for cold tolerance. There is no clear separation of temperate varieties from the tropical varieties for cold stress and grain yield. While several varieties sensitive to cold stress were identified (Pandan Wangi 7, NTR 426, NTR 587, IR 64 and Takanari), selection for cold tolerance was successful only with one variety, Yunlu 29. Factors other than cold stress (for example, phenology/vigour, weed competition, high maximum air temperatures, water stress, etc.) might have influenced the recovery of plants and the final grain yield from each variety. However, Yunlu 29 stands out against all odds and promises to be a suitable variety for aerobic rice (raised-bed) systems in the Ord region. Yunlu 29 has shown considerable cold tolerance and remarkable recovery from cold damage to produce high yields up to 10 t/ha. It appears to be a reliable variety for the aerobic system in the ORIA and to provide high yields even under severe cold events similar to that experienced in the dry season of 2012.

Trials at Kununurra during the dry season of 2012 also evaluated 5 temperate and 12 tropical rice varieties under the flooded system. Results from this study have proved the potential yields that could be realised under this environment. Varieties NTR 587, NTR 426 and Viet 1 have achieved yields greater than 10 t/ha, and these varieties are believed to have moderate resistance to blast disease which caused severe damage to Quest in commercial crops in the Ord region during 2011. The results of this study indicated that further investigations regarding some of the agronomic options such as matching the growth duration of varieties to planting dates to achieve high yields needs to be established during 2013. From an economic view point, the price (farm gate value) offered for rice in Australia in 2012 varied from $255 to $430 per tonne in different states.

5.1.2 Planting date

Trials at Kununurra during the dry season of 2013 investigated the correct planting time which is crucial to achieve high yields and the best grain quality for selected rice varieties in the. To maximise yield, it is essential to ensure that most of the crop’s growth cycle occurs after 21 June, when day length is increasing. Late planting during May–June may help to achieve this, but if the crop matures under harsh, hot weather during October–November, it may reduce the quality of the harvested grain. Aerobic trials in 2013 suffered severe water stress and the results indicated an irrigation interval of 7 days is required for rice in Cununurra Clay soil in the Ord region. For the flooded system, it appears that a planting date of 8 May might enable to achieve very high yields, up to 14.3 t/ha. Among the tested varieties, Yunlu 29 and NTR 587 are recommended for the aerobic and flooded systems, respectively. Quality of the harvested grain was poor and it was believed that quality can be improved by harvesting the crop early at higher moisture levels. These results also provided valuable information for future development of the rice industry on the Ord.

5.1.3 Grain quality

Consistent product quality is an important consideration for both domestic and international markets. Rice has specific quality requirements in terms of physical attributes, cooking and eating characteristics. Prior to harvest, the maturing grain can experience high fluctuations in diurnal temperatures and this is likely to cause cracking of the grains and a high amount of chalk in grains. Adverse weather conditions after physiological maturity and up to the time of harvest will be the most significant factor in reducing the per cent whole grain. Trials at Kununurra during the dry season of
2014 evaluated the grain quality parameters of three rice varieties (NTR 426, NTR 587 and Yunlu 29) as influenced by the tropical environmental conditions that prevailed in 2014 in the ORIA. Important grain quality parameters are percentage whole grain, chalk, protein, and amylose content. This study demonstrated that high millout percentage—greater than 55—could be achieved by harvesting the crop at high grain moisture levels—greater than 19.4%. Protein and amylose contents are important characteristics of the varieties tested, but apparently were not affected by the harvest conditions. However, high amount (greater than 5%) of chalk in harvested grain still remains as a problem and this is due to greater diurnal variation in air temperature during the ripening stages of the crop. This problem could be avoided by planting early—during February–April—so that the crop will mature during mild weather.

5.1.4 Leakage losses

Areas of irrigated agriculture are prone to rising groundwater, waterlogging and salinity under poor irrigation practices. In extreme cases, these negative effects may lead to loss of cropping land or create costs of management which may need to be borne by industry. Previous flooded rice systems in Kununurra are attributed to have contributed to excess groundwater recharge rates. A water balance approach was taken in two separate trials to determine the evaporation, transpiration and deep percolation losses from flooded rice bays on Kununurra Clay soil during the dry seasons of 2013 and 2014 using a set of three lysimeters and lockup bay tests.

The results from the lysimeter trials in 2013 are applicable for variety IR 72 and the growing conditions experienced in 2013. It was estimated that the total water usage might reach 13 ML/ha mark for rice depending on weather conditions. The average deep percolation losses were estimated to be less than 0.97 mm/day or approximately 1 ML/ha for the crop cycle. Similarly, the field trials in 2014 also indicated that the deep percolation losses in Kununurra Clay soil were either negligible or less than 0.64 mm/day. These findings are supported by studies conducted by Marshall (1944) who found that surface water infiltrated no deeper than 1.07 m into Kununurra Clay after surface ponding for 54 hours. Similar results were reported by Muchow and Wood (1981) who found no evidence of upward or downward movement of soil water below a depth of around 1.65 m in Kununurra Clay. Much more recently, Bakker et al. (2006) concluded there was negligible deep drainage below furrow–irrigated sugar cane grown on Kununurra Clay. Therefore, deep percolation under ponded rice culture in Kununurra Clay soils is within accepted leakage rates and given the experimental results are able to be scaled to bay and farm scales, the rates should not unduly affect growers or environmental managers in terms of rising groundwater levels, waterlogging and salinity.

5.2 Rice in the Northern Territory

Physiological development and maturity needs to suit the length of growing season and the time of temperature extremes in proposed production areas in NT. Cultivars with a longer growing season are required for wet season production to ensure grain maturity occurs into the start of the dry season. A shorter growing season is required for cultivars for dry season production so that grain will mature prior to the onset of the wet season. Results so far suggest that Viet 4 and Takanari are promising for dry season production, and that the two NTR lines (NTR 426 and NTR 587) are promising for wet season production. The NTR cultivars are a result of selection of over 1000 lines obtained through IRRI during the 1980s NT rice breeding program.

Floret sterility was observed in some cultivars where flowering occurred during low temperatures in the dry season at Tortilla Flats, and in other varieties in the wet season where flowering occurred during high temperatures and heavy rain periods during February at Katherine. Dry season cold tolerance, wet season heat tolerance and rice blast tolerance are criteria to be considered in cultivar selection in the NT. Potentially suitable cultivars, such as Takanari, Viet 4, NTR lines, and Yunlu29, were identified for a range of rice production systems in the NT.
Dry season lowland rice production produced relatively higher yields and easier management than other systems, suggesting this should be the basis of a northern rice industry. This may be the case for the ORIA which has established irrigation infrastructure, but suitable water availability for dry season rice production is a significant constraint in the NT. Other major obstacles include the procurement of commercial quantities of seed of these cultivars, and favourable market evaluation for their quality characteristics. Further development of specific agronomic practices such as nutrition, sowing technique and water management are also still necessary. Overcoming these obstacles will form the basis of grasping the opportunity that rice production presents to growers in the NT.

Previous trials at Tortilla Flats during the dry season of 2011 produced consistently higher grain yields than the previous wet season (2010/11) crop and the corresponding dry season (2011) upland site at Katherine (Eastick et al. 2012). These initial trends of lowland grain yields greater in the dry season than in the wet season are consistent with previous research conducted in northern Australia (Chapman & Basinski 1985; McDonald 1985) which attributed to increased solar radiation and better harvest indices. Incidence of lodging, and insect, disease and vertebrate pest pressure, were also less in the dry season than in the wet season, water management was easier to regulate, and these factors all contributed to higher yields.

Trials at Katherine during the wet season of 2012/13 identified issues specific to upland production, and also more generic rice production issues. Timing of planting may be one strategy to avoid cold stress occurring at critical times. However, this may be difficult to manipulate with a long season variety within a short dry season, so this may influence variety selection for specific sites. The trial also highlighted the importance of grain fill, and the implications cold temperatures may have on final yield of cold susceptible varieties. Dry season upland rice may not be an economically viable option, even in rotation system for secondary benefit such as green manure crop. Thus, an upland production system would be based over the wet season, when growing season length decreases as head south from Adelaide River region towards Katherine.

When considering yield components, the potential grain yield was defined by panicle number, viable floret number and seed size by 140 days after planting. Weed development in the last 20–50 days affected the ease of harvesting; but similar results considering the vagaries of population were achieved. Supposedly panicle number per plant compensated for differences in plant population despite a low value for $r^2=0.25$. Nitrogen losses due to high rainfall under upland conditions compared with lowland conditions must also be considered. Ability to direct drill seed has advantages over wet seeded lowland systems for tolerance to early bird susceptibility—change in dynamics from ducks and geese to cockatoos and galahs.

Variety Yunlu 29 appears to be the most suitable variety for an upland rice production system in the Katherine region. It has relatively high yields (grain and biomass), a short growing season suitable for the short wet season around Katherine compared to further north around Adelaide River.

It is interesting to note that although Yunlu29 was one of the first to mature (162 DAP) compared to PSBRC 9 (181 DAP). This relationship was less pronounced for the Coastal Plains Research Station trial site during 2011/12 wet season, where both these varieties were harvested at 111 DAS. Obviously, it is not merely days after planting which influences this respective maturity, but differences in heat unit accumulation and cold tolerances of the different cultivars.

**5.3 Economics**

**5.3.1 Gross margins in 2012**

Assessing commercial rice growing as a viable land use in the ORIA will depend on whether the financial returns from rice are comparable to the returns of other annual crops. The best yielding rice varieties from the 2012 research trials at Kununurra indicate that at current rice prices, rice production is competitive with other land uses. Two growing practices were used in the trials: aerobic rice on raised beds and anaerobic rice grown in water filled paddies. While the anaerobic rice yields more
tonnes of grain per hectare, the gross margin per hectare is lower than that for a lower yield on a raised bed system (Table 5.1). The reason being the cost of laser levelling the irrigation bay (estimated at $450 per hectare). If rice is grown for only one year out of a ten year rotation, the switching cost of laser levelling is not covered by the increase in yield from growing the rice crop in an anaerobic system.

Table 5.1 A comparison of yield, revenue, growing costs and gross margins per hectare for rice

<table>
<thead>
<tr>
<th>Production method</th>
<th>Anaerobic</th>
<th>Aerobic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water use mega litres per hectare</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Indicative yield per hectare</td>
<td>11.5 tonnes</td>
<td>9.9 tonnes</td>
</tr>
<tr>
<td>Revenue at: $265/tonne</td>
<td>$3058</td>
<td>$2624</td>
</tr>
<tr>
<td>Revenue at: $255/tonne</td>
<td>$2933</td>
<td>$2525</td>
</tr>
<tr>
<td>Total variable costs</td>
<td>$1687</td>
<td>$1575</td>
</tr>
<tr>
<td>Gross margin at above revenue (note, does not include land lease payment)</td>
<td>$1371</td>
<td>$1149</td>
</tr>
<tr>
<td>Breakeven yield at: $265/tonne</td>
<td>6.2 tonnes</td>
<td>5.9 tonnes</td>
</tr>
<tr>
<td>Breakeven yield at: $255/tonne</td>
<td>6.4 tonnes</td>
<td>6.2 tonnes</td>
</tr>
<tr>
<td>Gross margin at 8 tonnes/hectare</td>
<td>$353-433</td>
<td>$465-545</td>
</tr>
</tbody>
</table>

There are a number of other profit drivers that will affect the relative profitability of rice grown in the ORIA. Major profit drivers are: the price per tonne; the location of the sale point and the cost of freight to get it there; the quality of the product; the suitability of the rice variety to satisfy consumer demand in either domestic or export markets; the level of grain processing; the volume produced in the region. A number of exogenous factors also affect the price received. These include world rice production and grain stocks and the strength of the Australian dollar. For rice to return as a viable crop option in the ORIA, further scientific research is needed to overcome various management issues. The research results also need to be proven at a commercial scale and the profit levels from rice growing must be comparable to the profitability of other crop options.

5.3.2 Gross margins in 2013

The expected gross margins per hectare for the results of the trial plot yields at Kununurra in 2013 were also calculated. The gross margins were prepared only for the anaerobic trials and, based on the plot yields, the equivalent gross margins per hectare were in the range of -$902 to $3725 per hectare, depending on the price per tonne. At a commercially achievable yield of 8 t/ha, the gross margin at $317/t is $298/ha. Based on the trial results, the highest yielding variety, Viet 1, delivered the equivalent of 14.3 t/ha, which at a farm gate price of $317/t, generated revenue of over $4533/ha. This revenue compares very favourably with many of the field crops currently grown in the ORIA. The second highest yield was achieved using NTR 587 and this yielded the equivalent of 12.5 t/ha.

The calculations of the gross margins were done on the scale of experimental trial blocks, with lower planting densities than commercial rice crops grown in the ORIA previously. Assumptions were used to simplify the cost structure of research trials to be equivalent to commercial rice crop management. Examples are; less edge effect as the whole paddy would be planted to rice, higher seed planting rates, best bet planting dates and no discounts for cracked or chalky grain. The results of gross margin analysis are shown in Table 5.2.
Table 5.2  Gross margin sensitivity table

<table>
<thead>
<tr>
<th>Yield (t/ha)</th>
<th>8.0</th>
<th>9.0</th>
<th>10.5</th>
<th>12.5</th>
<th>14.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$167</td>
<td>-$902</td>
<td>-$735</td>
<td>-$484</td>
<td>-$150</td>
<td>$150</td>
</tr>
<tr>
<td>$217</td>
<td>-$502</td>
<td>-$285</td>
<td>$41</td>
<td>$475</td>
<td>$865</td>
</tr>
<tr>
<td>$267</td>
<td>-$102</td>
<td>$165</td>
<td>$566</td>
<td>$1100</td>
<td>$1580</td>
</tr>
<tr>
<td>$317</td>
<td>$298</td>
<td>$615</td>
<td>$1091</td>
<td>$1725</td>
<td>$2295</td>
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<tr>
<td>$367</td>
<td>$698</td>
<td>$1065</td>
<td>$1616</td>
<td>$2350</td>
<td>$3010</td>
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<tr>
<td>$417</td>
<td>$1098</td>
<td>$1515</td>
<td>$2141</td>
<td>$2975</td>
<td>$3725</td>
</tr>
</tbody>
</table>

The yields achieved for 2013 and the high gross margin per hectare would make growing rice an attractive cropping alternative. At a price of $317/t, the breakeven yield is 7.1 t/ha. The expected yield from commercial rice growing was 7.5–8.0 t/ha several years ago with different varieties; this would have generated a gross margin of $120-$600/ha. If yields above 10 tonnes can be replicated in commercial rice crops using suitable varieties, then in the future, rice growing may be a field crop option for growers in tropical areas. Gross margin calculations don’t create a sustainable industry in the ORIA, but the more growers who decide that rice growing is profitable and is part of their crop mixture, the better the chance for a rice industry to return to tropical Western Australia.

5.4 Plant adaptation analysis—a case study

Studies into adaptation of rice varieties to a range of environmental conditions are important to select varieties with yield stability and optimum grain production level. Adaptation is a complex process and very difficult to measure. The local environment, in which the rice plants grow, varies significantly from year to year. Crop management factors such as planting date, weed control, fertiliser application, and water management can also influence the growing environment. These factors can modify the length of the crop cycle, from seed to harvest, or the time taken by each variety to reach crop maturity. Variety by environment interaction, that is, how each variety interacts with each environment, is the main focus in an adaptation analysis. The highest yielding variety in an environment may not be the preferred variety for that location. A variety’s ability to produce consistently high yields, that is, yield stability, at each location is more important. Since varietal performance is influenced by a range of factors, adaptation analysis is required to understand the complex variety by environment interactions. The overall objective of this analysis is to identify locally adapted varieties with good yield stability characteristics.

Rice variety trials were conducted at the Frank Wise Institute of Tropical Agriculture at Kununurra in northern WA from 2009 to 2014. Twenty seven varieties were tested over the six years during the dry seasons which resulted in 23 environments. Varieties, which include 7 temperate and 20 tropical varieties, were sourced from different countries (Table 5.3). Different environments were created by: the year in which the trials were conducted; irrigation method, raised-bed/flushed/flooded; planting date; rate of top dressing; and rate of basal dressing (Table 5.3). Variety by environment matrix for grain yield was unbalanced due to not testing all varieties in all environments. Mean grain yield of 27 varieties tested in 23 environments was analysed using preference ranking organisation method for the enrichment of evaluations (PROMETHEE) and graphical analysis for interactive aid (GAIA) analysis as described by Sivapalan et al. (2007). Visual PROMETHEE 1.4 software was used for this purpose (VPSolutions 2013). Data for aerobic (raised-bed and flushed) system and flooded system were first analysed separately to identify specific adaptation of varieties for each system. Analysis of combined data was performed to identify broad adaptation of varieties for both systems. The PROMETHEE II Complete Ranking based on the net preference flow (Phi) was used to rank the varieties.
Graphical analysis for interactive aid (GAIA) uses Principal Components Analysis and the resulting bi-plots are shown in Figures 5.1 and 5.2. Each variety is represented by a point in the GAIA plane. Varieties with similar performance are closer to each other. The position of individual varieties on the bi-plots for the aerobic and flooded systems is different. This is due to the environmental conditions that prevailed in the aerobic system was rather different to that under the flooded system. Since most axes for the environments are aligned to the right, most favoured varieties are located on the right and least favoured ones on the left. There is no clear separation of temperate varieties from tropical varieties for their performance in both aerobic and flooded systems. In decreasing order, varieties Yunlu 29, Tachiminori, B6144F-MR-6, Quest and Langi were identified as best adapted to the aerobic system. Similarly, varieties NTR 426, Jarrah, ULP R17, Tachiminori and PSBRC 9 were identified as best adapted to the flooded system, in that order. Quest, Langi and Jarrah are temperate varieties from NSW. Among the top performing five varieties, Tachiminori is the only variety common for both systems. Considering all the varieties tested, the rank order shows that selected tropical varieties seem to outperform most of the temperate varieties. It has been observed that night time air temperatures below 15°C can negatively influence growth and yield of rice at this location. However, ponded water in the flooded system can provide some degree of protection against such low temperatures. Therefore, cold sensitive varieties, such as NTR 426 and NTR 587, are ranked lower for the aerobic system and ranked higher for the flooded system. They are positioned on the right for the flooded system but on the left for the aerobic system.

### Table 5.3 Number of varieties used in each trial which created a unique environment

<table>
<thead>
<tr>
<th>Varieties</th>
<th>Origin</th>
<th>Environments*</th>
</tr>
</thead>
<tbody>
<tr>
<td>09-FO-135</td>
<td></td>
<td>10-FO-053</td>
</tr>
<tr>
<td>10-FO-082</td>
<td></td>
<td>10-FO-086</td>
</tr>
<tr>
<td>10-RB-090</td>
<td></td>
<td>10-FO-098</td>
</tr>
<tr>
<td>11-FO-108-050</td>
<td></td>
<td>11-FO-108-100</td>
</tr>
<tr>
<td>11-RB-108-200</td>
<td></td>
<td>12-RB-123</td>
</tr>
<tr>
<td>12-FO-123</td>
<td></td>
<td>13-FO-112</td>
</tr>
<tr>
<td>13-FO-128</td>
<td></td>
<td>13-FO-141</td>
</tr>
<tr>
<td>14-FO-141-525</td>
<td></td>
<td>14-FO-141-310</td>
</tr>
</tbody>
</table>

* first two digits represent the year; FO=flooded; FU=flushed; RB=raised-bed; three digits after the alphabet represent calendar day of planting; last three digits represent three different rate of top dressing in 2011 and two rates of basal dressing in 2014. IRRI=International Rice Research Institute.
Each environment in Figures 5.1 and 5.2 is represented by an axis drawn from the centre of the GAIA plane. The orientation of these axes indicates how closely the environments are related to each other. For example, the three rates of top dressing in 2011 created environments which were similar for both aerobic and flooded systems.
aerobic and flooded systems. However, the environments in 2011 and 2012 were different as their axes are located away from each other. Date of planting failed to identify a pattern among the environments. This may be due to other factors, such as low night temperatures, which dominated each variety's performance. The length of the environment axis is also relevant; the longer an axis the more discriminant the environment. It is the case in 2011 and 2012 when the number of varieties tested varied from 17 to 20 which were higher than in other environments (Table 5.3). Thus the environments in 2011 and 2012 were more discriminant in this investigation. The orientation of an environment axis indicates where the best varieties for this environment are located. Note that varieties Kyeema, Illabong, IR 64 and Viet 4 were tested only in 2012, therefore they are aligned with these environment axes. Other notable cases are where Takanari and Quest which align with environment axes 11-RB-108-100 and 11-RB-108-200, respectively. This may suggest that Quest requires higher rate of top dressing than Takanari in the aerobic system.

The decision axis (thick red axis in Figures 5.1 and 5.2) is a representation of the weighting of the environments. Thus shorter decision axes are less reliable. The orientation of the decision axis indicates which environments are in agreement with the PROMETHEE rankings and which are not. The top ranked varieties Yunlu 29 and Tachiminori are located along the decision axis for the aerobic system, and NTR 426 for the flooded system. These varieties exhibit good yield stability across a range of environmental conditions. A combined analysis of aerobic and flooded systems could identify varieties adapted to both systems (Yunlu 29, Tachiminori, B6144F-MR-6, Langi and PSBRC 9 in that order) at the expense of maximum potential yield achievable in each environment. Therefore, for economic reasons, varieties with specific adaptation to each system must be considered rather than broad adaptation for both systems. Therefore, among the tested varieties, Yunlu 29 for the aerobic system and NTR 426 for the flooded system seem better varieties suited for the ORIA. Grain quality must be tested before undertaking large area production with the selected varieties.

5.5 Other constraints to the project

5.5.1 Hybrid rice evaluation

Hybrid rice in other countries has shown a 20% yield advantage over traditional varieties. An opportunity arose with Pacific Seeds to reap the benefits of hybrid rice in the Ord Valley and tropical NT regions. Therefore the trial at Kununurra during the dry season of 2012 included a hybrid rice (Pac 807) obtained from Pacific Seeds Office in Queensland. The seed arrived late and was planted on 30 May (compared with 2 May planting for all other varieties) under raised-bed system. The seed size of the hybrid line was quite small (17.3 mg/seed) and it had an average germination rate (75.2%) under laboratory conditions. However, it experienced cold temperatures in June, which seriously affected its germination and establishment in the field. Minimum air temperatures remained below 15ºC during 4–16 and 20–27 June and lowest temperatures such as 6.4 and 5.2ºC were experienced during this time (Figure 4.1). From 20 June to 10 July, the minimum air temperatures remained below 11.6ºC and averaged just 9ºC causing further cold damage. Due to its failure to germinate and establish in this trial, it was decided not to continue with hybrid seed evaluations in future trials.

5.5.2 Wet season trials

Rice can be grown in the wet season as demonstrated by the commercial cropping in the ORIA from 1973 to 1983 as well as trials in NT and QLD. After the harvest of a dry season crop, most farming land in the ORIA is fallow during the wet season. If rice is a viable option for the wet season, then growing rice in the wet season can generate a 2nd income to the grower. Out of the 880 mm of annual rainfall, more than 500 mm is available for the wet season crop. This free water can contribute towards half of the rice crop’s water requirement. Longer day length in the ORIA during the summer months has the potential to greatly enhance rice growth and its yield potential compared to a dry season crop. However, cloud cover may be an issue for certain rice varieties. Some of the tropical rice varieties (for example, varieties such as Muncul, Pandan Wangi 10, Pandan Wangi 7, Takanari and Milyang 23)
tested at Frank Wise Institute of Tropical Agriculture during the dry seasons of 2010 and 2011 might be more suited to wet season rather than for dry season.

A trial was initiated incorporating 20 varieties and 2 irrigation systems (aerobic and flooded) for the 2010/11 wet season. Plots were marked, basal fertilizer was applied and seeds were packed and ready to plant in early December. However, the rains started and never stopped long enough to get the land dry enough to start sowing. This situation continued until mid-April next year. Simply, it was too wet to get an opportunity for sowing the wet season crop. This has led to missing out the opportunity to make use of the excellent rainfall events of the 2010/11 wet season. It was decided to start early for the 2011/12 wet season, depending on the seasonal forecast.

For the 2nd attempt, a decision was made to plant in late November in 2011 to take advantage of the predicted wet. Basal fertiliser consisting of DAP (100 kg/ha), Muriate of potash (20 kg/ha), Single Super Phosphate (20 kg/ha), ZnSO4 (15 kg/ha) and Urea (150 kg/ha) was applied on 25 November 2011. Plot size was 120 m long and 6 rows wide for each of 20 varieties (Amaroo, Quest, Jarrah, Doongara, Langi, Lemont, Milyang 23, Muncul, Pandan Wangi 10, Pandan Wangi 7, Tachiminori, Takanari, Vandana, B6144F-MR-6, Fin, IR 72, NTR426, PSBRC 9, ULP R17 and Yunlu 29). Sowing took place on 28 November at the rate of 182 kg/ha. Variety Quest was used for the buffer area. Seed of Quest was obtained from 2011 harvest of commercial crop which had blast disease infections in some sections of the paddock. It was hoped that this seed would serve as a source to introduce the blast disease to the trial area to enable screening varieties for blast tolerance. Viability of this seed was found to be 63%. Herbicide Stomp was sprayed on 29 November. First flushing of the paddock was done on 1 December. Irrigation was continued until the decision was made to abandon the trial on 31 January 2012. The crop failed to establish due to a range of factors.

Optimum temperature range for rice germination is 20-35ºC and for establishment is 25-30ºC. Critical maximum temperature for germination is 45ºC and for establishment is 35ºC. Maximum air temperatures recorded at Frank Wise Institute of Tropical Agriculture automatic weather station from 28 November 2011 to 31 January 2012 indicated that, except for 5 days, the maximum temperatures reached above 35ºC in December 2011. These temperatures were not in favour of successful establishment of the rice crop.

Severe grasshopper damage to surviving seedlings was observed in December 2011 and January 2012. At some locations, the grasshoppers chewed the above ground vegetative parts completely. These plants failed to recover due to the very high air temperatures. Immediately after sowing and between flushes, mice movement in the trial area was observed. This was characterised by empty glumes lying on the ground surface next to the seed rows. Cockatoos were also observed pulling plants from the block.

With the commencement of irrigation, magpie geese and ducks in large numbers moved in and stayed in the paddock throughout the night. The magpie geese and whistler duck problem continued until the crop was abandoned. With limited rainfall events and reduced agricultural activity in the valley, the magpie geese honed in on any blocks with water, resulting in standing room only in the rice block. Attempts were made to move them on but to little avail, they simply returned to the flooded block.

Rainfall in December (116.6 mm) and January (204.8 mm) was lower than long term average which made it necessary to supplementary irrigate the crop. Rain fell in large amounts (50 mm plus) followed by long, dry, hot spells causing crop stress. Constant water supply was hindered by channel work carried out by the Water Corporation. Water access was cut off for periods of 15 days. Hence water stress might also have affected the crop. A decision was made to flood the block early and hold the water due to the sporadic availability of water. The water temperature in the flooded block went very high during the heat of the day causing crop stress. A flow of water could not be maintained.

The 2010/11 wet season was a record breaker with consistent rainfall throughout the season. The opposite was experienced in the 2011/12 wet season. No two wet seasons are the same. The two attempts highlighted the risks that may impact the establishment of a rice crop planted in late
November or early December. It appears that pressures imposed by high air temperatures, insects and birds are much less in late January. Therefore planting a rice crop in late January or early February may lead to a successful crop.

5.5.3 Rice ratooning option

Experience from other countries suggests that certain rice varieties can produce an economical 2nd (ratoon) crop after the harvest of the main crop. Countries such as the USA are already benefiting from ratooning. It is necessary to identify a suitable variety to produce an economical ratoon crop under an aerobic system in tropical environments in Australia. This aspect was planned to test in the current project. However, the problems encountered for a wet season crop (see Section 5.5.2) are also applicable for the ratoon crop after the harvest of a dry season crop. Therefore, decision was made not to proceed along this type of research.

5.5.4 Rice blast disease rating

After a successful 240 ha commercial planting in 2010 in the ORIA, about 650 ha of crop was planted by three growers in 2011. Rice blast disease (*Magnaporthe grisea*) infected the commercial rice crops in the Ord Valley in 2011 with devastating effects on harvestability, grain yield, quality and marketability. A gross margin analysis indicated the blast disease in the ORIA caused total losses of up to $1.2 million in farm business (Sivapalan et al. 2012a). In addition, economic losses were felt by the associated activities in the region. The social impact of the blast disease will prevail in the next few years. Identification of a blast tolerant rice variety is a priority research need for the emerging Ord rice industry. The importance of identifying resistant varieties is also considered as an important spin off to the traditional rice growing areas elsewhere in Australia.

However, the research efforts to identify blast tolerant varieties suitable for WA and NT regions was hindered by no or minimal infections of the trials conducted from 2012 to 2014. Even though, the Ord commercial crops had blast disease infections in 2011, trials at Frank Wise Institute of Tropical Agriculture were not affected by the disease from 2011 to 2014. This is also the case for Katherine and Tortilla Flats sites, except during the 2014 dry season trials at Tortilla Flats where varieties Quest and Opus (both temperate varieties from NSW) had blast disease infections. However, information on blast disease tolerance of some varieties are available from a previous trial conducted at Coastal Plains Research Station in NT.
6. Implications

The yield performance of temperate and tropical rice varieties tested in this study was influenced by the environmental conditions imposed by factors such as growing season, water management, date of planting and basal and top dressing. Aerobic growing system was found to be completely different compared with flooded system in discriminating the varieties. Broad adaptation of varieties for both systems was considered as not preferred for economic reasons. Varieties with specific adaptation to each system have been identified for the ORIA. Varieties originated from tropical regions might be better suited for this region compared with varieties from the temperate regions. Cold air temperatures during the night seem a major issue which impacted on the selection of appropriate varieties with cold tolerance. Grain quality of each variety under different environmental conditions needs to be evaluated before undertaking commercial plantings in the region.

Originated from Yunnan Province in China, variety Yunlu 29 has red coloured grain and is adapted to aerobic conditions. It has good cold tolerance and remarkable recovery after cold temperature events. It has high yielding (10–12 t/ha) ability under favourable conditions. It is also believed that rice from this variety could attract premium prices by targeting speciality markets, locally or internationally.

Originated from IRRI in Philippines, the long grain varieties NTR 426 and NTR 587 are believed to have resistance to blast disease. Both varieties have produced good yields up to 10.7–12.5 t/ha in trials under flooded system. These varieties are very sensitive to cold temperatures and therefore not suited for the aerobic system.

Understanding the amount of leakage that prevails under flooded rice fields is becoming more important in the ORIA. Estimation of evaporation, transpiration and deep percolation losses for a flooded rice crop in Cununurra Clay soil was made using a range of measurement systems. The results showed that deep percolation losses were less than 1 mm/day. The estimated total water usage of flooded rice for variety NTR 587 in 2014 was 9.7 ML/ha. Hence undertaking the cultivation of flooded rice systems in similar soil types of Cununurra Clay soil is considered safe and within manageable limits of groundwater recharge rates in the ORIA.

Tropical regions of Australia are ideally suited for production of high quality speciality rices. The speciality attributes such as aroma, grain appearance, and flavour of some varieties are far superior when they are grown in tropical environments. The demand for special purpose aromatic rice and coloured grain types has dramatically increased over the past two decades, both in Australian and overseas markets. Hence efforts must be devoted in Australian tropical regions to develop and assess rice varieties to fit this high value niche market.
7. Recommendations

Minimum air temperatures less than 15°C had biggest impact on varietal performance. Cold damage during the months of June and July warrants selection of varieties with cold tolerance for this environment, especially for the aerobic rice system.

Ponded water has 4-8°C advantage over the air temperature, thus providing some protection against such cold damage. This has resulted in higher yields under flooded system.

Planting dates, varying from late-February to late-May, were found to play a crucial role for plants to escape the low temperature damage at critical growth stages.

Among the varieties tested, selected tropical varieties yielded higher than the temperate varieties. Yunlu 29 has been identified as the best variety adapted for aerobic rice system in the Ord. NTR 426 was found to outperform all other tested varieties under the flooded system in this environment. Greater focus must be paid on quality of harvested grain.

A complete analysis of data generated in trials conducted from 2009 to 2015 at all sites in WA and NT could help to identify environmental differences between sites and therefore target specific/broad adaptation of varieties with good yield stability.

Future work in northern Australia should consider screening a greater range of fragrant and aromatic rice. Traditionally, fragrant rice varieties attain greater levels of aromatic components in tropical regions. These are high value varieties and represent opportunities for import substitution in Australian markets. There is an opportunity for Australia to tap further into the international rice market by producing these speciality rices in the tropical environments of northern Australia. These are some of the factors that need to be considered to establish a viable rice industry in the ORIA and NT regions.

Rice crop modelling could add significant value and extend the experimental work and field trials, particularly in helping to quantify long-term risks in rice production due to low/high temperatures, climate change, and so on. Once they have been tested and validated, cropping systems models (for example, Agricultural Production Systems Simulator [APSIM]) can give valuable insights into climatic risks over a much longer period (50-100 years) than experiments/field-trials.
8. Appendices

8.1 Publications


Sivapalan, S 2014, *Proper irrigation scheduling is important for successful aerobic rice*, AgMemo: Rangelands Region, June 2014.


Sivapalan, S 2014, *Quality is the focus for this year’s rice trials*, AgMemo: Rangelands Region, August 2014.


**8.2 In the media**

*Exploring rice potential for the north*, Media Statement, DAFWA, 10 August 2012

*Kununurra hosts northern rice research*, ABC Rural Report, 10 August 2012 (interview with Tyne McConnon, ABC Rural Reporter)

*Scientists monitor trial crop for fungus*, The Kimberley Echo, 16 August 2012 (interview with Alicia Bridges, The West Reporter, The West Australian Regional Newspapers)

*Northern rice funding to help find a variety tolerant to fungal disease*, by Matt Brann, Northern territory Country Hour, 21 August 2012

Kununurra Agriculture field day, Northern WA Rural Report, ABC Rural, 19 September 2012 (interview with Tyne McConnon, ABC Rural Reporter)

Creating a vision for rice in northern Australia, by Matt Brann, ABC Rural, Northern Territory Country Hour, 27 September 2012

Four new cultivars for Kimberley rice trials, by Mary-Anne Romano, Science Network WA, 2 October 2012

Chia might get nod ahead of rice in north, Farm Weekly, 5 September 2013, page 11

Field day to cover a variety of rice research, Media Release, DAFWA, 13 September 2013

Ord rice trial yielding ‘excellent results’, Countryman, The West Australian, 16 September 2013

Rice is shaping up to be the next crop for the Ord valley, Western Australia Country Hour, 18 September 2013

More success for Ord rice trials, ABC Rural Radio interview with Tyne McConnon (ABC Rural Reporter), 19 September 2013

Science fights back against rice blast, Media Release, DAFWA, 8 November 2013

End-of-season rice updates help set direction for Ord rice industry, Media Statement, DAFWA, 6 December 2013

Record rice yield for Kununurra, Countryman, The West Australian, 7 December 2013

Commercial rice trials go missing up north, by Matt Brann, ABC Rural, 17 December 2013

Ord rice trials to focus on quality, not quantity, The Kimberley Echo, 10 April 2014, page 3

Demand for Western Australian rice increases as exporters seek niche varieties, ABC Rural online article, 4 September 2014

Trial finds rice trio suitable for the Ord, The Kimberley Echo, 11 September 2014, page 3

Ord rice trials reveal three suitable varieties, Countryman, The West Australian, 13 November 2014

8.3 Field days and review meetings held

Rice Field Day at Frank Wise Institute of Tropical Agriculture on 12 September 2012

Rice Review Meeting at Frank Wise Institute of Tropical Agriculture on 26 March 2013

Rice Field Day at Frank Wise Institute of Tropical Agriculture on 18 September 2013

Rice Review Meeting at Frank Wise Institute of Tropical Agriculture on 27 November 2013

Field Day at Katherine Research Station on 6 April 2013

Rice Field Day at Frank Wise Institute of Tropical Agriculture on 2 September 2014
9. References

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Burt, J 2002, Review of the potential for growing rice at the Ord River Irrigation Area in Kununurra Western Australia, Trade and Development Technical Report, August 2002, Department of Agriculture Western Australia.

Chapman, AL & Basinski, JJ 1985, Coastal Plains Research Station, in JJ Basinski, IM Wood & JB Hacker (eds), The Northern Challenge: A history of CSIRO crop research in the northern Australia, CSIRO Division of Tropical Crops and Pastures, Brisbane, pp. 91-114.


McDonald, DJ 1985, *Review of floodplain cropping (rice) research and industry development in the Northern Territory*, Department of Primary Production, Darwin, 54 pages.


Agronomic Options for Profitable Rice-based Farming System in Northern Australia

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