Strategies for Maximising Sugarcane Yield with Limited Water in the Bundaberg District

A Dissertation submitted by
Craig Baillie, B Eng

For the award of
Master of Engineering
2004
ABSTRACT

Sugarcane farmers in Bundaberg have had limited access to irrigation water over the last ten years. The district has the potential of growing 3.8 million tonnes of sugarcane. However, a series of dry seasons saw this reduce to 2.1 million tonnes in 2002. Compounding the effects of both dry seasons and limited water supplies has been a 30% reduction in the sugar price over this period. The irrigation requirement of sugarcane in the Bundaberg area is 8 ML/ha. The original allocated volume for sugarcane production in this area was 4.5 ML/ha (based on 1970 production areas). However, as the area under production has increased and announced allocations in each year has reduced, this allocation is now equivalent to an application volume of about 2 ML/ha.

A change from the traditional practice of full irrigation is required as water supplies become depleted. As there were no clear guidelines on how growers could respond to diminishing water supplies, this research investigated opportunities to fine tune irrigation practices and the performance of irrigation systems (ie. low cost solutions) that would assist growers to maximise sugarcane yield. A grower survey was initially conducted to identify current practice and opportunities for change. Field investigations focused on the performance of water winch and furrow irrigation systems, which make up 91% of the irrigated area in the district. As most of these application systems have insufficient capacity to meet crop demands opportunities to schedule irrigations were limited to start up after rain.

Improvements in irrigation system performance were found to provide the greatest potential to increase sugarcane yield under conditions of limited water. Investigations identified that irrigation performance could be significantly improved through relatively minor adjustment.

Field trials found that wind speed and direction significantly influenced the performance of travelling gun irrigators. Although growers were generally aware of the effects of wind, meteorological data suggested that the opportunity to operate
water winches in low wind conditions is limited. Changing to a taper nozzle under moderate to high wind conditions will reduce the effect of wind on performance. This practice was found to improve the uniformity (measured by Christiansen’s Uniformity Coefficient, CU) by 16%. The grower survey indicated that there was no preference towards the use of taper nozzles in windy conditions. Additional trial work developed a relationship between the variation in water applied to the field through non-uniformity and sugarcane yield. An 8% reduction in yield was determined for a 10% reduction in CU. This indicated that changing to a taper nozzle could potentially increase sugarcane yield by 15% in high wind conditions. Other settings, which also influenced uniformity, included lane spacing and gun arc angle.

Simple changes to the operation of furrow irrigation systems were also found to dramatically improve irrigation performance. Field measurements in combination with simulation modelling of irrigation events using SIRMOD II identified that current irrigation performance ranged in application efficiency from 45 to 99% (mean of 79%) and a distribution uniformity from 71 to 93% (mean of 82%). Both application efficiency and distribution uniformity were increased to greater than 90% and 84% respectively, except on a cracking clay soil. Improvements in application efficiency and distribution uniformity were achieved by adjusting furrow flow rate (cup size), turning the irrigation off at the right time (ie. just as it reached the end of the field) and banking the end of the field. Growers had a good understanding of the correct cut off time and were attentive to reducing run off through either banking ends or tail water return. However, growers had a poor understanding of the significance of furrow flow rate. Other opportunities to improve irrigation performance on high infiltration soils included alternate furrow irrigation and shallow cultivation practices which maintained compaction in the interspace and reduced infiltration.

Soil moisture and crop growth measurements indicated that sugarcane yield could be maximised by starting the irrigation rotation earlier after rainfall (ie. at a deficit equal to the irrigation amount). These observations were modelled using the crop simulation model APSIM sugar to assess the strategy over a longer time interval and the influence of seasonal variation. Simulation modelling showed that final
Abstract

sugarcane yields were not sensitive to irrigation start-up strategies. Yields for the start-up strategies modelled varied by less than 5 tc/ha. This minor difference occurred as the crop yield was driven by the total amount of water available to the plant. The limited amount of irrigation water available to the plant (2 to 3 ML/ha) had only a minor effect on the water balance and no significant change to effective rainfall between strategies. The greatest difference in yield occurred between irrigation treatments when water was left over at the end of the season (9.2 tc/ha). Starting irrigation earlier after rainfall events (on a 14 day rotation) provided the greatest opportunity to use all of the available irrigation supply. By comparison, delaying the application of the first irrigation after rainfall resulted in some of the irrigation water not being applied in 30% of years.
CERTIFICATION OF DISSERTATION

I certify that the ideas, experimental work, results, analyses and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been submitted for any other award, except where otherwise acknowledged.

______________________________    ____________
Signature of Candidate          Date

ENDORSEMENT

______________________________    ____________
Signature of Supervisor          Date
ACKNOWLEDGEMENTS

I would like to acknowledge those people and organisations who have contributed to this project in one way or another.

Research to determine irrigation strategies for limited water first commenced on Bundaberg Sugar Ltd farms in response to low announced water allocations in 1999. The majority of field work contained in this dissertation was conducted through a secondment to the Bureau of Sugar Experiment Stations (BSES) and the Rural Water Use Efficiency (RWUE) Initiative. The broad aims of both the local RWUE Initiative project and this research work were to assist growers to maximise sugarcane yields with limited water. Field work and activities conducted within the local RWUE Initiative project were directed with this common interest in mind and with the additional rigour required for a research degree. I would like to thank Bundaberg Sugar Ltd for financially supporting this research and the BSES and CANEGROWERS Bundaberg for the opportunity to work on the RWUE Initiative.

I would like to acknowledge the role that others have had in assisting in the collection, analysis and presentation of both the grower survey to benchmark grower practices and field data measuring the performance of travelling guns (water winches). The grower survey was developed in consultation with Danni Stehlik and Kerry Mummery from the Centre for Social Science Research at Central Queensland University (CQU) and presented by the CQU team as part of a benchmarking activity for the RWUE initiative. Glen Gordon provided technical assistance in the collection of the field performance evaluation data for the travelling guns and subsequently presented part of this work for his final year thesis (BENG, Agricultural) at the University of Southern Queensland.

I would also like to thank those growers who participated in the trial work and through discussion helped develop strategies for maximising sugarcane yield with limited water. Additionally, I would like to acknowledge and thank Sandra Dennis for her technical assistance and support and Steven Raine for his energy and direction throughout this process. Most of all I would like to thank my family, particularly Jus, who has helped make this happen.
# TABLE OF CONTENTS

Abstract i  
Certification of Dissertation iv  
Acknowledgements v  
List of Figures ix  
List of Tables xi  
List of Abbreviations xii  

1 Introduction 1  
1.1 Sugarcane Production in the Bundaberg Area 2  
1.2 Irrigation Water Supply 2  
1.2.1 Water Sources 2  
1.2.2 Irrigation Allocations and Water Availability 4  
1.3 Crop Water Requirements 5  
1.4 Irrigation Application Systems 8  
1.5 Project Aims 9  

2 System Performance and Crop Response 11  
2.1 Introduction 11  
2.2 Water Winch Irrigators 12  
2.2.1 Measuring Performance Of Water Winches 14  
2.2.2 Factors Influencing Performance Of Water Winches 14  
2.3 Furrow Irrigation 17  
2.3.1 Measuring Performance Of Furrow Irrigation 19  
2.3.2 Factors Influencing Performance Of Furrow Irrigation 19  
2.4 Crop Response To Irrigation 23  
2.4.1 Irrigation Deficits 23  
2.4.2 Crop Response To Irrigation During The Season 25  
2.4.3 Full vs. Limited Irrigation Supplies 27  
2.5 Developing Strategies For Limited Water 28  
2.5.1 Irrigation System Performance 29  
2.5.2 Maximising Crop Response 29  

3 Benchmarking Irrigation Practices 31  
3.1 Introduction 31
# Table of Contents

3.2 **Methodology** 31  
  3.2.1 Survey Methodology 31  
  3.2.2 Data Analysis 32  

3.3 **Results And Discussion** 33  
  3.3.1 Operation Of Water Winches 33  
  3.3.2 Operation Of Furrow Irrigation 40  
  3.3.3 Irrigation Management 45  

3.4 **Conclusion** 49  

4 **Performance of Travelling Gun Irrigators** 52  
  4.1 Introduction 52  
  4.2 **Methodology** 52  
  4.3 **Results and Discussion** 54  
    4.3.1 Application Patterns 56  
    4.3.2 Wind Speed And Direction 57  
    4.3.3 Lane Spacing 59  
    4.3.4 Nozzle Type 60  
    4.3.5 Gun Arc Angle 60  
    4.3.6 Other Settings 61  
    4.3.7 Atmospheric Losses 62  
  4.4 **Conclusion** 62  

5 **Performance of Surface Irrigation** 64  
  5.1 **Introduction** 64  
  5.2 **Methodology** 64  
    5.2.1 Description Of Field Sites 64  
    5.2.2 Field Measurements 65  
    5.2.3 Determining Field Infiltration Characteristics 67  
    5.2.4 Modelling Irrigation Performance 68  
  5.3 **Results And Discussion** 69  
    5.3.1 Furrow Flow Rate 70  
    5.3.2 Cutoff Time 71  
    5.3.3 Banked Ends 71  
    5.3.4 Alternate Furrow Irrigation 72  
    5.3.5 Cultivation Practices 73  
    5.3.6 Uniformity Between Furrows 74  
  5.4 **Conclusion** 75  

6 **Identifying Crop Responses To Irrigation** 77  
  6.1 **Introduction** 77  
  6.2 **Field Measurements** 77  
    6.2.1 Field Sites 77  
    6.2.2 Stem Elongation Measurements 79  
    6.2.3 Soil Moisture 79  
    6.2.4 Catch Can Measurements 80
<table>
<thead>
<tr>
<th>6.3</th>
<th>Crop Response To Current Practices</th>
<th>82</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3.1</td>
<td>Effect Of Soil Moisture On Crop Stress In Terms Of Stem Elongation</td>
<td>82</td>
</tr>
<tr>
<td>6.3.2</td>
<td>Soil Moisture In Response To Irrigation</td>
<td>84</td>
</tr>
<tr>
<td>6.3.3</td>
<td>Effect On Soil Moisture By Starting Earlier After Rainfall</td>
<td>91</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>6.4</th>
<th>Crop Response To Irrigation Startup Strategies</th>
<th>92</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.4.1</td>
<td>Crop Modelling Process</td>
<td>92</td>
</tr>
<tr>
<td>6.4.2</td>
<td>Crop Modelling Outcomes</td>
<td>95</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>6.5</th>
<th>Crop Response To Irrigation Uniformity</th>
<th>99</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.5.1</td>
<td>Crop Growth Response To Applied Water</td>
<td>99</td>
</tr>
<tr>
<td>6.5.2</td>
<td>Yield Response To Non-Uniformity</td>
<td>101</td>
</tr>
<tr>
<td>6.5.3</td>
<td>Factors Which Influence the Effect Of Uniformity</td>
<td>106</td>
</tr>
<tr>
<td>6.5.4</td>
<td>Impacts Of Management Practices On Yield For Water Winches</td>
<td>107</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>6.6</th>
<th>Conclusion</th>
<th>108</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.6.1</td>
<td>Crop Response To Current Practice</td>
<td>108</td>
</tr>
<tr>
<td>6.6.2</td>
<td>Crop Response To Irrigation Startup Strategies</td>
<td>108</td>
</tr>
<tr>
<td>6.6.3</td>
<td>Crop Response To Irrigation Uniformity</td>
<td>109</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7</th>
<th>General Discussion</th>
<th>110</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>Winch Irrigation</td>
<td>110</td>
</tr>
<tr>
<td>7.2</td>
<td>Furrow Irrigation</td>
<td>111</td>
</tr>
<tr>
<td>7.3</td>
<td>Crop Responses</td>
<td>113</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>8</th>
<th>Conclusion and Recommendations</th>
<th>115</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>9</th>
<th>References</th>
<th>118</th>
</tr>
</thead>
</table>

Appendix A Furrow Irrigation Field Data | 123 |

Appendix B Simulations of Furrow Irrigation Systems (Sirmod II) | 133 |

Appendix C Irrigation Dates At Field Sites | 143 |

Appendix D Soil Moisture Data Recorded At Field Sites 1999 – 2000 | 145 |

Appendix E Soil Moisture Data Recorded At Field Sites 2000 – 2001 | 152 |

Appendix F A Comparison of Soil Moisture and Stem Elongation | 159 |

Appendix G Simulation of Earlier Irrigation Start Up At Field Sites | 164 |

Appendix H Irrigation Start Dates For Modelled Treatments | 168 |
LIST OF FIGURES

Figure 1-1  Fred Haigh Dam ........................................................................................ 3
Figure 1-2 Crop response to irrigation ....................................................................... 6
Figure 1-3 Measuring height to the top visible dewlap ............................................. 7
Figure 2-1  Traveling Gun Irrigator (Water Winch) .................................................. 13
Figure 2-2 Furrow irrigation using layflat ................................................................. 18
Figure 3-1 Maximum operating wind speed for water winches .............................. 34
Figure 3-2 Wind Distribution (Fairymead 1997-1998) ........................................... 35
Figure 3-3 Lane spacing used for water winches ..................................................... 36
Figure 3-4 Gun rotational settings used on water winches ...................................... 37
Figure 3-5 Gun trajectory angles used on water winches ....................................... 37
Figure 3-6 Gun operating pressures used on water winches ................................... 40
Figure 3-7 Furrow length in use .............................................................................. 41
Figure 3-8 Irrigation cutoff times used by growers ............................................... 42
Figure 3-9 Outlet types used on layflat ................................................................. 43
Figure 3-10 Use of banked ends and tail water return ............................................ 44
Figure 3-11 Daily application rates for water winch and furrow irrigation ............. 46
Figure 3-12 Daily operating hours of water winch and furrow irrigation .............. 47
Figure 3-13 Irrigation rotation of water winch and furrow irrigation ..................... 47
Figure 3-14 Days before irrigation is applied after rainfall ..................................... 49
Figure 4-1  Catch can - 90 mm PVC pipe with glued end caps ......................... 53
Figure 4-2 Catch cans arranged in a standing leg test .......................................... 54
Figure 4-3 Spray pattern characteristics ............................................................... 56
Figure 4-4 Sprinkler overlap and uniformity .......................................................... 57
Figure 4-5 Performance of taper and ring nozzles in a parallel wind .................... 58
Figure 4-6 Performance of taper and ring nozzles in a cross wind ....................... 59
List of Figures

Figure 4-7  The effect of changing gun arc angle on sprinkler pattern..................... 61
Figure 5-1  Irrimate furrow advance timers................................................................. 66
Figure 6-1  Catch cans arranged in standing leg test ...................................................... 81
Figure 6-2  Telescopic catch can set above canopy height .......................................... 82
Figure 6-3  Daily Stem Elongation Relative to Soil Water Content (Site 6)................. 83
Figure 6-4  Total soil moisture to 1 m depth; site 4; 1999 - 2000 ............................... 86
Figure 6-5  Separate level soil moisture (mm / 100 mm); site 4; 1999 – 2000.............. 86
Figure 6-6  Total soil moisture to 1 m depth; site 4; 2000 – 2001............................... 87
Figure 6-7  Separate level soil moisture (mm/100mm); site 4; 2000 – 2001.............. 87
Figure 6-8  Total soil moisture to 1 m depth; site 3 1999 – 2000............................... 89
Figure 6-9  Separate level soil moisture (mm / 100 mm); site 3; 1999 – 2000............ 89
Figure 6-10  Total soil moisture to 1 m depth; site 3; 2000 – 2001......................... 90
Figure 6-11  Separate level soil moisture (mm / 100 mm); site 3; 2000 – 2001.......... 90
Figure 6-12  Demonstration of early startup (Site 3: 2000 – 2001)......................... 92
Figure 6-13  Irrigation strategies for an individual irrigation event............................ 94
Figure 6-14  Effect of water application of stalk growth............................................. 100
Figure 6-15  Crop response to water expressed in relative terms .............................. 101
Figure 6-16  Graphical determination of relative water.............................................. 102
Figure 6-17  Graphical determination of total relative yield....................................... 105
Figure 6-18  Reduction in yield due to non uniformity of water winch systems...... 106
Figure 6-19  Reduction in yield due to non uniformity of furrow systems .............. 106
LIST OF TABLES

Table 1-1  District Production and Sugar Price ................................................................. 2
Table 1-2  Surface water and ground water announced allocations.............................. 4
Table 1-3  Irrigation requirements in sugarcane across districts.................................. 6
Table 1-4  Sugarcane crop factors.................................................................................. 8
Table 1-5  Irrigation application systems used in the Bundaberg area ......................... 9
Table 3-1  Percentage of growers* using specific nozzle types and sizes at various wind speeds and direction ................................................................. 39
Table 4-1  Christiansen’s Uniformity Coefficient (CU) for water winch trials............ 55
Table 4-2  Variation of Christiansen’s Uniformity Coefficient (CU) with gun arc angles..................................................................................................................... 61
Table 5-1  Characteristics of surface irrigated field sites................................................. 65
Table 5-2  Measured (Meas.) and Optimised (Opt.) Results ......................................... 69
Table 5-3  Impact of cultivation practices...................................................................... 73
Table 5-4  Uniformity of furrow advance data .............................................................. 74
Table 6-1  Description of Field Sites .......................................................................... 78
Table 6-2  Daily Stem Elongation Rates....................................................................... 84
Table 6-3  APSIM simulated sugarcane yield (3 ML/ha).............................................. 96
Table 6-4  APSIM simulated sugarcane yield (2 ML/ha).............................................. 96
Table 6-5  APSIM simulated effective rain (3 ML/ha).................................................. 97
Table 6-6  APSIM simulated effective rain (2 ML/ha).................................................. 97
### LIST OF ABREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE</td>
<td>Application Efficiency</td>
</tr>
<tr>
<td>CU</td>
<td>Christiansen’s Uniformity Coefficient</td>
</tr>
<tr>
<td>DU</td>
<td>Distribution Uniformity</td>
</tr>
<tr>
<td>ET₀</td>
<td>Reference Evapotranspiration</td>
</tr>
<tr>
<td>fasw</td>
<td>Fraction of Available Soil Water</td>
</tr>
<tr>
<td>PAWC</td>
<td>Plant Available Water Content</td>
</tr>
<tr>
<td>RAW</td>
<td>Readily Available Water</td>
</tr>
<tr>
<td>tc/ha</td>
<td>Tonnes of Cane per Hectare</td>
</tr>
<tr>
<td>tvd</td>
<td>Top Visible Dewlap</td>
</tr>
</tbody>
</table>