The commercial potential of sugar beet (*Beta vulgaris*) for sugar production in the Mareeba-Dimbulah Irrigation Area of North Queensland, Australia.

Brett Ronald Weeden

Master of Applied Science

Central Queensland University

School of Biological and Environmental Sciences
Faculty of Arts, Health and Sciences

June 2002
Abstract

Sugarcane is a tropical plant grown for sugar production under a wide range of mainly warmer climates throughout the world whereas under temperate climates sugar beet is grown for sugar production. In Australia, sugarcane is grown predominantly in the tropical and subtropical regions of the east coast. Since 1996 there has been a rapid expansion of sugarcane production in the Mareeba-Dimbulah Irrigation Area (MDIA), which is part of the Atherton Tableland region, about 50 km inland from Cairns in north Queensland. The expansion has been due to declining sugar yields from sugarcane grown on the coast, several years of devastating storms and cyclones, population growth of Cairns taking up cane land for residential use and the availability of land and water in the MDIA. A major effect of this rapid expansion of sugarcane in the MDIA has been on the availability, supply and cost of irrigation water and the efficiency of water use has become an important issue for growers. This study investigates the potential for sugar beet to be included into the cropping options of both established sugarcane farmers and other producers in the MDIA. As sugar beet has never been grown in the MDIA (and not commercially in Australia since the 1930’s) a number of experiments were conducted to provide yield information under local conditions. Variety trials studied the performance of a number of varieties used in the main sugar beet growing areas of the UK, Europe and the USA. Results showed little difference in sugar yield between varieties which were in the range found under commercial production overseas (10-12 t/ha). Nitrogen, irrigation and population experiments at two sites (Southedge and Walkamin) in 1999 studied the effects of these inputs on sugar beet growth and yield. At Southedge the amount of applied nitrogen was having the greatest effect on root yield with 180 kg/ha N giving the highest sugar yield (13.9 t/ha) while the amount of irrigation and population level were less influential. At 180 kg/ha of N, water use efficiency (WUE) was 11.8 and 2.3 t/ML for root and sugar yield respectively in comparison to an estimated sugarcane
WUE in the MDIA of about 8 and 1.5 l/ML for cane and sugar yield. At Walkamin it was population level that was having the greatest effect with 100,000 plants/ha giving very high root yields (>100 t/ha) however the sucrose concentration was much less compared to Southedge and so sugar yields were not as high as may have been expected but still higher than Southedge (about 16 t/ha). Water use was about 50% more on the heavier soil at Walkamin compared to Southedge with 100,000 plants/ha giving an average WUE of 12.7 and 1.8 l/ML for root and sugar yield respectively. Growth analysis studies at Southedge showed that radiation would not be limiting to dry matter production, with the excess radiation increasing water use. At Walkamin dry matter production was related to plant population and a higher radiation use efficiency at Walkamin compared to Southedge. An economic study using simple gross margin analysis and yield data from the Southedge trial showed that sugar beet could be a profitable crop in the MDIA however at the current low world sugar prices commercial production is unlikely.
## Table of Contents

Abstract

List of Tables

List of Figures

Abbreviations

Acknowledgments

Declaration

Chapter 1 General background

1.1 Introduction

1.2 Sugar beet history in Australia

Chapter 2 Literature review

2.1 Introduction

2.2 Germination, seedling and root growth

2.3 Sucrose accumulation

2.4 Harvesting (maturity)

2.5 Leaf growth and photosynthesis

2.6 Nitrogen

2.6.1 Germination and emergence

2.6.2 Concentration and uptake

2.6.3 Leaf growth and production

2.6.4 Sugar and root yield

2.6.5 Juice quality

2.6.6 Predicting fertiliser requirements

2.6.7 Timing and form of application

2.7 Water use and irrigation

2.7.1 Crop water use

2.7.2 Water use and yield

2.7.3 Water stress

2.7.4 Irrigation and yield

2.7.5 Irrigation and sugar concentration

2.7.6 Irrigation and nutrient uptake

2.7.7 Irrigation methods

2.7.8 Irrigation timing

2.7.9 Other water issues

2.8 Plant spacing and light interception

2.9 Modelling sugar beet growth

2.10 Economics of sugar beet production

Chapter 3 Sugar beet yield and sugar production

3.1 Introduction

3.2 Methodology

3.2.1 Site details

3.2.1.1 Southedge 1999A

---
3.2.1.2 Walkamin 1999
3.2.1.3 Southedge 1998
3.2.1.4 Southedge 1999B
3.2.2 Trial design and management
3.2.2.1 Southedge 1999A
3.2.2.2 Walkamin 1999
3.2.2.3 Southedge 1998
3.2.2.4 Southedge 1999B
3.2.3 Data collection
3.2.3.1 Fresh root yields
3.2.3.2 Sucrose accumulation
3.2.3.3 Sucrose concentration at harvest
3.2.3.3 a) Southedge 1999A
3.2.3.3 b) Walkamin 1999
3.2.3.3 c) Southedge 1998
3.2.3.3 d) Southedge 1999B
3.2.3.4 Sugar yield
3.2.3.5 Soil moisture and water use
3.2.3.6 Statistical analyses

3.3 Results
3.3.1 Southedge 1999A
3.3.1.1 Root, top and total fresh weight yields
3.3.1.1 a) Harvest 1
3.3.1.1 b) Harvest 2
3.3.1.1 c) Harvest 3
3.3.1.2 Sugar concentration - % brix
3.3.1.2 a) Harvest 1
3.3.1.2 b) Harvest 2
3.3.1.2 c) Harvest 3
3.3.1.3 Sugar yield at final harvest
3.3.1.4 Sugar beet water use efficiencies
3.3.2 Walkamin 1999
3.3.2.1 Root, top and total fresh weight yields
3.3.2.1 a) Harvest 1
3.3.2.1 b) Harvest 3
3.3.2.2 Sugar concentration - % brix
3.3.2.2 a) Harvest 1
3.3.2.2 b) Harvest 3
3.3.2.3 Sugar yield at final harvest
3.3.2.4 Sugar beet water use efficiencies
3.3.3 Southedge 1998
3.3.3.1 Root yields, sucrose concentration and sugar yields
3.3.4 Southedge 1999B
3.3.4.1 Root yields, sucrose concentration and sugar yields
3.3.4.2 Sucrose accumulation

3.4 Discussion
3.4.1 Southedge 1999A
   Effects of nitrogen
   Effects of irrigation and water use efficiencies
   Effects of population
3.4.2 Walkamin 1999
Chapter 4  Sugar beet growth and dry matter production  74

4.1  Introduction  74

4.2  Methodology  74
4.2.1  Data collection  74
4.2.1.1  Canopy growth  74
4.2.1.2  Canopy temperature  75
4.2.1.3  Intercepted radiation  75
4.2.1.4  Photosynthesis  75
4.2.1.5  Dry matter and root yields  76
4.2.1.6  Sugar analysis  76
4.2.1.7  Petiole sap nitrate  76
4.2.1.8  Weather data  77

4.3  Results  77
4.3.1  Southedge 1999A  77
4.3.1.1  Canopy growth  77
4.3.1.1 a)  Effect of nitrogen  77
4.3.1.1 b)  Effect of irrigation  79
4.3.1.1 c)  Effect of population  79
4.3.1.2  Canopy temperatures  79
4.3.1.3  Intercepted radiation  80
4.3.1.4  Photosynthesis  81
4.3.1.5  Specific leaf area  85
4.3.1.6  Dry matter yields  85
4.3.1.6 a)  Harvest 1  85
4.3.1.6 b)  Harvest 2  87
4.3.1.6 c)  Harvest 3  87
4.3.1.7  Intercepted radiation and dry matter yields  88
4.3.1.8  Crop growth rate  91
4.3.1.9  Dry matter yield and water use efficiency  92
4.3.1.10  Radiation interception and water use  93
4.3.1.11  Root:shoot and sugar:root dry matter ratios and harvest index  94
4.3.1.12  Petiole sap nitrate levels  95

4.3.2  Walkamin 1999  96
4.3.2.1  Canopy growth  96
4.3.2.1 a)  Effect of nitrogen  96
4.3.2.1 b)  Effect of irrigation  96
4.3.2.1 c)  Effect of population  97
4.3.2.2  Intercepted radiation  98
4.3.2.3  Dry matter yields  99
4.3.2.3 a)  Harvest 1  99
4.3.2.3 b)  Harvest 3  100
4.3.2.4  Intercepted radiation and dry matter yields  101
4.3.2.5 Crop growth rate 103
4.3.2.6 Dry matter yield and water use efficiency 104
4.3.2.7 Radiation interception and water use 105
4.3.2.8 Root:shoot and sugar:root dry matter ratios and harvest index 105
4.3.2.9 Petiole sap nitrate levels 107
4.3.3 Southedge 1998 and 1999B 108
4.3.3.1 Canopy growth 108
4.3.3.2 Canopy temperature 111
4.3.3.3 IRGA analysis 111
4.3.3.4 Specific leaf area 113
4.4 Discussion 113
4.4.1 Southedge 1999A and Walkamin 1999 113
Canopy growth 113
Intercepted radiation 115
IRGA analysis 115
Specific leaf area 116
Dry matter production 116
Radiation interception and water use 122
Dry matter production and water use efficiency 124
Root:shoot and sugar:root dry matter ratios and harvest index 126
Petiole sap nitrate level 128
4.4.2 Southedge 1998 and 1999B 130
Canopy growth 130
IRGA analysis 132

Chapter 5 Economics of sugar beet production 133
5.1 Introduction 133
5.2 Methodology 133
5.2.1 Data collection 133
5.2.2 Data analysis 134
5.2.2.1 Machinery operation costs 135
5.2.2.2 Seed costs 135
5.2.2.3 Fertiliser costs 135
5.2.2.4 Weed and insect control costs 136
5.2.2.5 Irrigation and pumping costs 136
5.2.2.6 Harvest, cartage and levy costs 137
5.2.3 Crop comparisons 137
5.2.4 Sensitivity analysis 137
5.3 Results 138
5.3.1 Gross margin analysis 138
5.3.2 Crop comparisons 139
5.3.3 Sensitivity analysis 139
5.4 Discussion 141
Sugar beet economics 141
Irrigation and sugar production 142
Potential production areas 143

Chapter 6 Conclusions 145

Bibliography 149
### List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 3.1</td>
<td>Summary of research sites and experiments</td>
<td>24</td>
</tr>
<tr>
<td>Table 3.2</td>
<td>Soil properties Southedge 1999A</td>
<td>25</td>
</tr>
<tr>
<td>Table 3.3</td>
<td>Soil properties Walkamin 1999</td>
<td>27</td>
</tr>
<tr>
<td>Table 3.4</td>
<td>Soil properties Southedge 1998</td>
<td>27</td>
</tr>
<tr>
<td>Table 3.5</td>
<td>Irrigation, evaporation and rainfall Southedge 1999A</td>
<td>29</td>
</tr>
<tr>
<td>Table 3.6</td>
<td>Soil nitrogen properties Southedge 1999A</td>
<td>30</td>
</tr>
<tr>
<td>Table 3.7</td>
<td>Irrigation, evaporation and rainfall Walkamin 1999</td>
<td>31</td>
</tr>
<tr>
<td>Table 3.8</td>
<td>Soil nitrogen properties Walkamin 1999</td>
<td>31</td>
</tr>
<tr>
<td>Table 3.9</td>
<td>Varieties used Southedge 1998 and Southedge 1999B</td>
<td>32</td>
</tr>
<tr>
<td>Table 3.10</td>
<td>Water use Southedge 1999A and Walkamin 1999</td>
<td>37</td>
</tr>
<tr>
<td>Table 3.11</td>
<td>Treatment effects on yield Southedge 1999A Harvest 1</td>
<td>38</td>
</tr>
<tr>
<td>Table 3.12</td>
<td>Treatment effects on yield Southedge 1999A Harvest 2</td>
<td>39</td>
</tr>
<tr>
<td>Table 3.13</td>
<td>Treatment effects on yield Southedge 1999A Harvest 3</td>
<td>40</td>
</tr>
<tr>
<td>Table 3.14</td>
<td>Treatment effects on sugar concentration Harvests 1,2 and 3 Southedge 1999A</td>
<td>41</td>
</tr>
<tr>
<td>Table 3.15</td>
<td>Water use efficiencies Southedge 1999A</td>
<td>42</td>
</tr>
<tr>
<td>Table 3.16</td>
<td>Treatment effects on yield Walkamin 1999 Harvest 1</td>
<td>43</td>
</tr>
<tr>
<td>Table 3.17</td>
<td>NXP interactions Walkamin 1999 Harvest 1</td>
<td>44</td>
</tr>
<tr>
<td>Table 3.18</td>
<td>Treatment effects on yield Walkamin 1999 Harvest 3</td>
<td>45</td>
</tr>
<tr>
<td>Table 3.19</td>
<td>NXP and IXP interactions Walkamin 1999 Harvest 3</td>
<td>45</td>
</tr>
<tr>
<td>Table 3.20</td>
<td>Treatment effects on sugar concentration Harvests 1 and 3 Walkamin 1999</td>
<td>47</td>
</tr>
<tr>
<td>Table 3.21</td>
<td>Water use efficiencies Walkamin 1999</td>
<td>47</td>
</tr>
<tr>
<td>Table 3.22</td>
<td>Yield results Southedge 1998</td>
<td>48</td>
</tr>
<tr>
<td>Table 3.23</td>
<td>Yield results Southedge 1999B</td>
<td>49</td>
</tr>
<tr>
<td>Table 3.24</td>
<td>Sugar accumulation Southedge 1999B</td>
<td>49</td>
</tr>
<tr>
<td>Table 3.25</td>
<td>Mean sugar concentrations Southedge 1999B</td>
<td>50</td>
</tr>
<tr>
<td>Table 3.26</td>
<td>Effect of sugar concentrations Harvest 1 to 2 Southedge 1999A</td>
<td>53</td>
</tr>
<tr>
<td>Table 3.27</td>
<td>Effect of nitrogen on growth rate Harvest 2 to 3 Southedge 1999A</td>
<td>54</td>
</tr>
<tr>
<td>Table 3.28</td>
<td>Water use efficiency comparison Southedge 1999A and Walkamin 1999</td>
<td>67</td>
</tr>
<tr>
<td>Table 3.29</td>
<td>Variety performance comparison Malheur and Southedge research stations</td>
<td>72</td>
</tr>
<tr>
<td>Table 4.1</td>
<td>Effect of nitrogen on canopy growth Southedge 1999A</td>
<td>78</td>
</tr>
<tr>
<td>Table 4.2</td>
<td>Effect of irrigation on canopy growth Southedge 1999A</td>
<td>79</td>
</tr>
<tr>
<td>Table 4.3</td>
<td>Treatment effects on intercepted radiation Southedge 1999A</td>
<td>80</td>
</tr>
<tr>
<td>Table 4.4</td>
<td>Treatment effects on photosynthesis, transpiration and stomatal conductance 8/8/1999 Southedge 1999A</td>
<td>81</td>
</tr>
<tr>
<td>Table 4.5</td>
<td>IXP interaction for stomatal conductance 8/8/1999 Southedge 1999A</td>
<td>82</td>
</tr>
<tr>
<td>Table 4.6</td>
<td>Treatment effects on photosynthesis, transpiration and stomatal conductance 9/8/1999 Southedge 1999A</td>
<td>84</td>
</tr>
<tr>
<td>Table 4.7</td>
<td>Treatment effects on dry matter yields Harvest 1 Southedge 1999A</td>
<td>86</td>
</tr>
<tr>
<td>Table 4.8</td>
<td>Treatment effects on dry matter yields Harvest 2 Southedge 1999A</td>
<td>87</td>
</tr>
<tr>
<td>Table 4.9</td>
<td>Treatment effects on dry matter yields Harvest 3 Southedge 1999A</td>
<td>88</td>
</tr>
</tbody>
</table>
Table 4.10  Treatment effects on dry matter production Harvest 1 to 2 and Harvest 2 to 3 Southedge 1999A  89
Table 4.11  Water use efficiencies over each harvest period Southedge 1999A  93
Table 4.12  Root:shoot and sugar:root dry matter ratios at each harvest and harvest index at final harvest Southedge 1999A  95
Table 4.13  Effect of irrigation on canopy growth Walkamin 1999  97
Table 4.14  Treatment effects on intercepted radiation Walkamin 1999  98
Table 4.15  Treatment effects on dry matter yields Harvest 1 Walkamin 1999  100
Table 4.16  NxP interaction Harvest 1 Walkamin 1999  100
Table 4.17  Treatment effects on dry matter yields Harvest 3 Walkamin 1999  101
Table 4.18  Water use efficiencies over each harvest period Walkamin 1999  104
Table 4.19  Root:shoot and sugar:root dry matter ratios at each harvest and harvest index at final harvest Walkamin 1999  106
Table 4.20  NxP interaction Harvest 1 and 3 Walkamin 1999  107
Table 4.21  Percentage canopy cover over time Southedge 1998  109
Table 4.22  Percentage canopy cover days Southedge 1998 and 1999B  110
Table 4.23  Percentage cover days, root and sugar yields Southedge 1998  110
Table 4.24  Percentage cover days, root and sugar yields Southedge 1999B  111
Table 4.25  Varietal differences for photosynthesis, transpiration rate and stomatal conductance 10/8/1999 Southedge 1999B  112
Table 5.1  Sugar beet gross margin analysis  138
Table 5.2  Gross margin estimates for crops in the MDIA  139
Table 5.3  Sugar yield estimates over a range of sugar concentrations and root yields  140
Table 5.4  Gross margin estimates over a range of sugar prices and yields  140
Table 5.5  Sugar based water use efficiency comparison Southedge 1998, 1999A and 1999B  143

List of Figures

Figure 3.1  Monthly temperature, rainfall and evaporation (1999A) and long-term solar radiation data for Southedge research station  25
Figure 3.2  Monthly temperature, rainfall, evaporation and solar radiation data for site Walkamin 1999  26
Figure 3.3  Monthly temperature, rainfall and evaporation for site Southedge 1998  27
Figure 4.1  Effect of nitrogen rate on canopy growth Southedge 1999A  78
Figure 4.2  Relationship between photosynthesis rate and PAR on an overcast day 8/8/1999 Southedge 1999A  83
Figure 4.3  Relationship between stomatal conductance and PAR on an overcast day 8/8/1999 Southedge 1999A  83
Figure 4.4  Relationship between photosynthesis rate and PAR on a sunny day 9/8/1999 Southedge 1999A  84
Figure 4.5  Relationship between stomatal conductance and PAR on a sunny day 9/8/1999 Southedge 1999A  85
Figure 4.6  Relationship between dry matter yield and intercepted radiation at each nitrogen rate Southedge 1999A  90
Figure 4.7  Relationship between total dry matter yield and intercepted radiation over each of three harvest periods Southedge 1999A  90
Figure 4.8  Relationship between cumulative total dry matter yield and cumulative intercepted radiation Southedge 1999A  91
Figure 4.9  Relationship between crop growth rate and intercepted radiation (radiation use efficiency) Southedge 1999A  92
Figure 4.10 Relationship between intercepted radiation and water use over each of three harvest periods Southedge 1999A  94
Figure 4.11 Treatment effects on sap nitrate concentration Southedge 1999A  96
Figure 4.12 Effect of irrigation rate on canopy growth Walkamin 1999  97
Figure 4.13 Relationship between total dry matter yield and intercepted radiation over each of two harvest periods and cumulative total Walkamin 1999  102
Figure 4.14 Relationship between total dry matter yield and intercepted radiation for each population Walkamin 1999  103
Figure 4.15 Relationship between intercepted radiation and water use over each of two harvest periods Walkamin 1999  105
Figure 4.16 Treatment effects on sap nitrate concentration Walkamin 1999  108
Figure 4.17 Average rate of canopy cover growth for nine varieties Southedge 1999B  109
Figure 4.18 Relationship between photosynthesis rate and PAR for each variety Southedge 1999B  112
Figure 4.19 Relationship between stomatal conductance and PAR for each variety Southedge 1999B  113

Figure 5.1  Long term sugar prices 1949-1999  134

**Abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABARE</td>
<td>Australian Bureau of Agricultural Resource Economics</td>
</tr>
<tr>
<td>BRIA</td>
<td>Burdekin River Irrigation Area</td>
</tr>
<tr>
<td>BSES</td>
<td>Bureau of Sugar Experiment Stations</td>
</tr>
<tr>
<td>CCS</td>
<td>Commercial cane sugar</td>
</tr>
<tr>
<td>DAE</td>
<td>Days after emergence</td>
</tr>
<tr>
<td>DAS</td>
<td>Days after sowing</td>
</tr>
<tr>
<td>ET</td>
<td>Evapotranspiration</td>
</tr>
<tr>
<td>FORM</td>
<td>Fuel, oil, repairs and maintenance</td>
</tr>
<tr>
<td>IR</td>
<td>Intercepted radiation</td>
</tr>
<tr>
<td>IRGA</td>
<td>Infrared gas analysis</td>
</tr>
<tr>
<td>LAI</td>
<td>Leaf area index</td>
</tr>
<tr>
<td>MDIA</td>
<td>Mareeba-Dimbulah Irrigation Area</td>
</tr>
<tr>
<td>$N_T$</td>
<td>Total available nitrogen</td>
</tr>
<tr>
<td>PAR</td>
<td>Photosynthetic active radiation</td>
</tr>
<tr>
<td>RUE</td>
<td>Radiation use efficiency</td>
</tr>
<tr>
<td>RWC</td>
<td>Relative water content</td>
</tr>
<tr>
<td>SBWUE</td>
<td>Sugar based water use efficiency</td>
</tr>
<tr>
<td>SLA</td>
<td>Specific leaf area</td>
</tr>
<tr>
<td>SRS</td>
<td>Southedge research station</td>
</tr>
<tr>
<td>TSHM</td>
<td>Tonnes of sugar per hectare per month</td>
</tr>
<tr>
<td>USDA</td>
<td>United States Department of Agriculture</td>
</tr>
<tr>
<td>WRS</td>
<td>Walkamin research station</td>
</tr>
<tr>
<td>WUE</td>
<td>Water use efficiency</td>
</tr>
<tr>
<td>YFEL</td>
<td>Youngest fully emerged leaf</td>
</tr>
</tbody>
</table>
Acknowledgments

I would firstly like to thank the two organisations that funded the project – namely the Rural Industries Research and Development Corporation and NQ Co-Operative.

I thank South Johnstone Sugar Mill for their support, in particular Ms Karen Sala who conducted the sugar analyses.

I would like to thank the Queensland Department of Primary Industries for supporting my studies and the following staff:

Joanne DeFaveri and Scott Foster for their help and advice with the statistical analysis of the data.
Mr Andrew Hinton for his help and advice with the economic analysis.
Mr Laurie Owens for his technical assistance with the trials.
Farm staff at both Southedge and Walkamin research stations.

I thank Dr John Armour for his support and help and advice with the soil analyses.

I would like to thank Mr Terry Morgan for his support in initiating the study and sharing his enthusiasm for the potential of sugar beet.

I particularly wish to thank my supervisor Professor David Midmore for his advice, patience and guidance.

And finally I would like to thank my wife Mandy and children Kara, Matthew and Mark. Without their love and support this study would not have been possible.

Declaration

This thesis reports the original work of the author, except as otherwise stated. It has not been submitted previously for a degree at any University or other institution.

Signed..............................

Brett Ronald Weeden
June 2002