Overcoming yield limitation of canola by improving water use efficiency

Amritbir Singh Riar
B.Sc. Agric. (Hons)
M.Sc. Agri. (Agronomy)

A thesis submitted to The University of Adelaide, South Australia
In the fulfilment of the degree of DOCTOR OF PHILOSOPHY

School of Agriculture, Food and Wine
Faculty of Science

The University of Adelaide

June 2015
# Table of Contents

Abstract .............................................................................................................................. vi
1. General Introduction ................................................................................................. 1
   1.1. References ............................................................................................................ 4
2. Review of Literature .............................................................................................. 6
   2.1. Canola cultivation in Australia ........................................................................... 6
   2.2. Morphology, Growth and Development of canola ........................................... 7
   2.3. Yield trends in canola and mustard in Australia ............................................... 8
   2.4. Phenology and adaptation ................................................................................ 11
   2.5. Yield determination and effect of water and N on different growth stages of canola 13
      2.5.1. Germination .................................................................................................. 13
      2.5.2. Early leaf development .............................................................................. 14
      2.5.3. Dry matter formation (side shoots, stem elongation, inflorescence and flowering) ................................................................. 15
      2.5.4. Flowering .................................................................................................... 16
      2.5.5. Development of fruit, ripening and senescence ......................................... 17
   2.6. Cultivation practices in Australia ....................................................................... 18
   2.7. Nitrogen use efficiency ..................................................................................... 20
   2.8. Water use efficiency ......................................................................................... 23
   2.9. N-water co-limitation theory ............................................................................. 26
   2.10. Site specific agronomic management to improve the seed yield .................... 27
      2.10.1. Time of sowing .......................................................................................... 27
      2.10.2. Cultivars .................................................................................................... 28
      2.10.3. Balancing pre- and post-flowering water use .......................................... 29
      2.10.4. Reducing soil evaporation ....................................................................... 31
      2.10.5. Rate and delayed application of N on targeted growth stages ............... 32
   2.11. Summary ........................................................................................................... 34
   2.12. References ......................................................................................................... 36
3. Response of canola and mustard to nitrogen applications at key phenological growth stages in a Mediterranean environment .......................................................... 51
   3.1. Abstract 53
   3.2. Introduction ....................................................................................................... 54
   3.3. Material and methods ....................................................................................... 56
      3.3.1. Site description ........................................................................................... 56
3.3.2. Experimental design .................................................................................. 56
3.3.3. Crop management ..................................................................................... 60
3.3.4. Measurements and sampling ..................................................................... 61
3.3.5. Statistics .................................................................................................... 62

3.4. Results 62
3.4.1. Seasonal conditions .................................................................................... 62
3.4.2. Crop development ....................................................................................... 62
3.4.3. Dry matter accumulation ........................................................................... 65
3.4.4. Radiation use efficiency (RUE) ................................................................. 68
3.4.5. Total dry matter (TDM), Seed yield and HI ............................................. 69
3.4.6. Sink development (pods m\(^{-2}\), seeds m\(^{-2}\), seeds pod\(^{-1}\) and 1000 seed weight) 76

3.5. Discussion ..................................................................................................... 77
3.5.1. Canola and mustard in relation to seasonal conditions ......................... 77
3.5.2. Responsiveness to Nitrogen ...................................................................... 79

3.6. Conclusions .................................................................................................. 81

3.7. Acknowledgements ....................................................................................... 82

3.8. Supplementary Tables .................................................................................. 83

3.9. References .................................................................................................... 88

4. Nitrogen and water use efficiency of canola and mustard with nitrogen applications at key phenological stages. ............................................................. 93
4.1. Abstract 95

4.2. Introduction .................................................................................................. 96

4.3. Materials and Methods ................................................................................. 97
4.3.1. Site description ........................................................................................... 97
4.3.2. Experimental design and crop management ........................................... 98
4.3.3. Measurements and sampling .................................................................... 101
4.3.4. Statistics .................................................................................................... 103

4.4. Results 104
4.4.1. Water use pattern and efficiency .............................................................. 104
4.4.1.1. Pre-flowering and post –flowering water use ...................................... 104
4.4.1.2. Water Use Efficiency (WUE) .............................................................. 107
4.4.1.3. Water distribution in the soil profile .................................................. 109
4.4.2. Nitrogen uptake and use efficiency ........................................................... 114
4.4.2.1. Nitrogen uptake and nitrogen harvest index ....................................... 114
4.4.2.2. Nitrogen use efficiency ............................................................................ 119

4.5. Discussion .................................................................................................... 122
4.6. Conclusion .......................................................................................................................... 126
4.7. Acknowledgements .......................................................................................................... 127
4.8. References ....................................................................................................................... 128

5. Yield dynamics of canola under different nitrogen and water regimes in South Australian Mediterranean environments ................................................................. 133

5.1. Abstract 135
5.2. Introduction ...................................................................................................................... 136
5.3. Materials and methods ...................................................................................................... 138
  5.3.1. Site description ............................................................................................................. 138
  5.3.2. Experimental design .................................................................................................. 141
  5.3.3. Crop management ...................................................................................................... 142
  5.3.4. Measurements and sampling ....................................................................................... 142
  5.3.5. Statistics ..................................................................................................................... 145
5.4. Results 145
  5.4.1. Dry matter accumulation and Radiation use efficiency (RUE) ......................... 145
  5.4.2. Sink development (pods m\(^{-2}\), seed m\(^{-2}\), seed pod\(^{-1}\) and seed weight) . 149
  5.4.3. Water use and Water Use Efficiency (WUE) .......................................................... 153
  5.4.4. Water distribution in the soil profile ......................................................................... 155
  5.4.5. Nitrogen uptake, N uptake efficiency and Nitrogen harvest index .................. 156
  5.4.6. Nitrogen use efficiency ......................................................................................... 159
5.5. Discussion......................................................................................................................... 161
5.6. Conclusions ..................................................................................................................... 166
5.7. Acknowledgements .......................................................................................................... 167
5.8. References ....................................................................................................................... 168

6. Effect of post-sowing nitrogen management on Co-limitation of nitrogen and water in canola and mustard ........................................................................................................ 175

6.1. Abstract 177
6.2. Introduction ...................................................................................................................... 178
6.3. Materials and Methods ..................................................................................................... 180
  6.3.1. Field experiments and site description ..................................................................... 180
  6.3.2. Cultivars and Nitrogen management ...................................................................... 181
  6.3.3. Crop management .................................................................................................... 183
  6.3.4. Measurements and sampling ..................................................................................... 183
  6.3.5. Variables used in assessments of yield gaps, different stress and co-limitation indices .................................................................................................................. 184
  6.3.6. Assessments of yield gaps, N and water stress levels ............................................ 185
6.4. Results 187
Abstract

Improved adaptation of canola by breeding has pushed its production into low rainfall areas in southern Australia where previously mustard has been considered a more suitable oilseed. Canola has a high nitrogen (N) requirement and how best to manage N in an environment where rainfall is variable is a challenging problem. Limited research has been undertaken in Australia to look at ways to improve water use efficiency (WUE) and to understand influences of interactions between N, water and seasonal variation on canola seed yield and nitrogen use efficiency (NUE$_{GY}$).

Field experiments were conducted at a medium rainfall site (Roseworthy) in South Australia between 2011 and 2013. These three years experienced contrasting amounts and patterns of rainfall. Different N management strategies in canola and mustard were tested to match the demand and supply for N in each year and in one experiment supplementary irrigation was also used. Two mustard and four canola cultivars, including two triazine tolerant (TT) and two non-TT cultivars, were evaluated under different N application strategies comprising three N rates (0, 100 and 200 kg N ha$^{-1}$) and different timings of application. A non-limiting control was used in which 200 kg N ha$^{-1}$ was applied in up to five split applications throughout the growing season. Treatments were selected to alter the crop canopy and to assess the balance between N and water use.

Mustard and canola perform similarly in the high rainfall year but canola out-yielded mustard in the season with below-average rainfall. Seed yields of canola and mustard were closely associated with total dry matter production and harvest index (HI)
varied little between treatments. Applying N at the rosette stage was the key for achieving high seed yield of canola and mustard as it achieved 85% and 94% of the seed yield obtained with the non-limiting N treatment. Nitrogen rate and timing did not influence total water use of canola and mustard but influenced its partitioning between pre- and post-flowering periods. Nitrogen rate increased water extraction depth at flowering but at maturity all treatments extracted water from a similar depth of soil. Irrigation improved total shoot dry matter by 41% and yield by 49% with a little change in HI. The additional water from irrigation was used almost twice as efficiently as the seasonal water use. Irrigation improved NUE$_{GY}$ but higher N rates decreased NUE$_{GY}$.

Optimising the sink capacity by improving pre-flowering biomass has an important influence on seed yield of canola and mustard. By delaying and targeting a specific growth stage for N application there was only slight improvement in HI and slight reduction in oil content. Low NUE$_{GY}$ in these environments was mainly related to limitation of low agronomic efficiency and low nitrogen harvest index N uptake and low N uptake efficiency rather than physiological N efficiency.

The study also provides empirical evidence that yields of canola and mustard are co-limited by water and N under the post-sowing N management strategies Analysis of water and N co-limitation found that N was the bigger limiting factor than water. The rate of N rather its timing was found to be important to yield and WUE. This study also indicates that better use of subsoil moisture may be an avenue for improvements in yield and WUE of canola in this environment. Future studies should focus on the interaction of pre and post-flowering water use and targeted N application on rosette stage in devising improved management tools.
DECLARATION

This work contains no material which has been accepted for the award of any other
degree or diploma in any university or other tertiary institution to Amritbir Singh Riar
and, to the best of my knowledge and belief, contains no material previously published
or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis when deposited in the University Library,
being made available for loan and photocopying, subject to the provisions of the
Copyright Act 1968.

I also give permission for the digital version of my thesis to be made available on the
web, via the University’s digital research repository, the Library catalogue, the
Australasian
Digital Theses Program (ADTP) and also through web search engines, unless
permission has been granted by the University to restrict access for a period of time.

Amritbir Singh Riar

Date: 23/06/2015
Acknowledgement

One of the joys of successful completion of an important task is when one spares a moment and says thank you to the ones who helped.

First and foremost I want to thank my advisors; Glenn McDonald and Gurjeet Gill (The University of Adelaide) for providing continued contribution and support throughout this study. It has been an honour to work with them. An input of technical expertise, experimentation guidance, academic advice, editorial direction and comments on manuscripts are some of the numerous roles they performed. All of which are greatly appreciated.

I would like to acknowledge the financial support from the Australian Centre for International Agriculture Research (ACIAR) in the form of John Allwright Fellowship. I also would like to acknowledge the financial, academic and technical support of the University of Adelaide and its staff.

I am grateful to the assistance I received from researchers, agronomist, technicians and farmers within Australia and overseas, but they are too many to mention by name.

Words cannot express how grateful I am to my family and friends for their continuous support and encouragement. Your prayers have sustained me thus far.