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Effect of post-sowing nitrogen management on co-limitation of nitrogen and water in canola and mustard

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ABSTRACT

In rainfed Mediterranean environments crop yields are limited by nitrogen (N) and water. The concept of water and N co-limitation has been used to describe how these competing resources are allocated during growth, it has been proposed that growth is optimum when water and N are equally limiting. All the published work so far on water and N co-limitation has been done in cereals using single applications of fixed amounts of N. However, delayed and split applications of N at key phenological growth stages can improve N use efficiency and alter the severity of N and water stress during the growth of the crop. The aim of the work reported here was to assess water and N co-limitation in the indeterminate crops canola (*Brassica napus*) and mustard (*B. juncea*) under different post-sowing N treatments. Four field experiments were conducted over three years with different cultivars of canola and mustard, under different water regimes, and grown with three N rates (0, 100 and 200 kg N ha^{-1} as granular urea) applied at different phenological growth stages. The results suggested that yield gaps (Y_g; the difference between actual and attainable yield) increased as total stress from water and N (T_{WN}) and the maximum of the two stresses (M_{WN}) increased and declined as the degree of water-N co-limitation increased, whether based on total stress (CT_{WN}) or maximum stress (CM_{WN}). However, seasonal and genotypic variation in the Y_g reduction and improvement in water use efficiency (WUE) with the degree of co-limitation were observed for CT_{WN}. Application of N improved the CT_{WN} without having the effect of split N application timing. No relationship was found between N use efficiency for seed yield (NUE_{SY}) of canola and mustard and co-limitation indices, which may be due to low N uptake efficiency during the pre-flowering period and low physiological efficiency during the post – flowering period. This study provides the first empirical evidence that yield of canola and mustard is co-limited by water and N under post-sowing N application with seasonal and genotypic variation in response to CT_{WN}. Future studies need to focus on the interaction of pre and post-flowering water and N stresses and their effect on CT_{WN} in devising crop management tools for this environment.

1. Introduction

Canola (*Brassica napus*) has become the most widely-grown broadleaf crop in Australia and is now the third main crop after wheat (*Triticum* spp.) and barley (*Hordeum vulgare* L.) (ABARE, 2014). The current area of canola production is 2.1 Mha, but in recent years it has been as high as 3.3 Mha (Australian Oilseeds Federation, 2016). In southern-Australia, rainfed production of canola has increased dramatically in the last decade due to the role of canola as a valuable break crop for cereal diseases (Angus et al., 1991; Seymour et al., 2012) as well as a providing alternative weed management strategies. Mustard (*Brassica juncea*) is a quick-developing crop, which has been often suggested as an alternative to canola in low rainfall areas (Hocking and Stapper, 2001a,b), but its production is still much lower than canola. The introduction of improved cultivars of canola and mustard with high early vigour, herbicide tolerance and the increased use of nitrogen (N) fertiliser have improved seed yields of these crops (Karamanos et al., 2005; Stanton et al., 2010; Stuchberry, 2009). However, there is still a large gap between the actual and attainable yields (Y_a) of canola and mustard (Lisson et al., 2007; Kebede et al., 2010). As N and water are the key factors limiting dryland crop yield in Mediterranean environments (Cossani et al., 2010), it will be difficult to achieve the full potential of genetic improvement without improv-

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ing the N and water use efficiencies of these crops (Sinclair and Rufty, 2012).

Water is a limiting resource in rain-fed systems and its availability depends on the total rainfall during the fallow and growing season which varies seasonally. Total N uptake is a function of plant available water (Campbell et al., 2004) and water deficits can limit N responses by reducing N uptake and utilisation (Benjamin et al., 1997). Water availability has a large influence on crop demand for and response to N. Effective water use is vital to minimise the gap between actual and maximum attainable water-use efficiency (WUE) under rain-fed systems (Sadras and Angus, 2006) but poor N nutrition can limit soil water extraction and WUE (Sadras et al., 2012). Many studies have shown interactive effects of water availability on N response of crops and *vice-versa* (Sadras, 2004; Norton and Wachsmann, 2006; Sinclair and Rufty, 2012).

Bloom et al. (1985) proposed that plants control the allocation of resources so that growth is equally limited by all resources. Consequently, growth of a plant will be optimum when all resources are equally limiting. In other words, the growth and yield of a crop stressed from scarcity of N and/or water will be positively related to the degree of co-limitation of these resources. Co-limitation has been identified in different systems; from cell to biomes (Venterink et al., 2001; Flynn, 2002; Maberly et al., 2002). The degree of co-limitation changes over time with availability and interactions of different resources (Sinclair and Park, 1993; Berman and DeJong, 1997; Maberly et al., 2002; Sadras, 2004). Based on the Bloom's et al. (1985) economic analog for resource limitations, Sadras (2004) hypothesised a negative relationship between the degree of water and N co-limitation (C_{WN}) and the yield gap (Y_g = measured yield − attainable yield). Based on a computer simulation study, Sadras (2004) found that Y_g was low when water and N equally limited the growth of wheat. These findings were further supported by the field studies in wheat and barley (Cossani et al., 2010).

The work so far on water and N co-limitation in cereals has been based on single applications of fixed amounts of N (Sadras, 2004; Sadras, 2005; Cossani et al., 2010). However strategic post-sowing N is often used in response to in-season rainfall and is an important tool for risk management for improved N use efficiency (NUE) and WUE in rainfed environments (Sadras, 2004; Potter et al., 2009). Delayed and split applications of N that improve yield and NUE may also alter the degree of co-limitation, but there is no empirical data that has documented the effect of differences in N strategies in water and N co-limitation. Canola and mustard are indeterminate crops with extended periods of flowering and pod set and where the critical stages of growth may differ from cereals. Therefore the dynamics of water and N uptake of canola and mustard may differ fundamentally from those of cereals. Furthermore, water and N co-limitation have not been examined in canola and mustard. The aim of the work was to examine whether N strategy alters the magnitude of the degree of co-limitation in canola and mustard. The experiments tested the hypothesis that an increase in seed yield, NUE and WUE in canola and mustard occur as the degree of water and N co-limitation increases.

2. Materials and methods

2.1. Field experiments design

Field experiments were conducted at two sites in South Australia; a medium rainfall site at Roseworthy (latitude 34.53°S; longitude 138.72°E) between 2011 and 2013, and at a high rainfall site near Tarlee (latitude −34.15°S; longitude 138.73°E) in 2013. The long-term annual average rainfall for Roseworthy is 440 mm with the growing season average rainfall (defined in South Australia as rainfall from April to October (French and Schultz, 1984)) of 329 mm and the long term annual rainfall of Tarlee is 527 mm with growing season rainfall of 374 mm (Table 1). The soils at the sites in 2011 and 2012 were classified as Calcisols (FAO-Unesco, 1998; Driessen et al., 2000, equivalent to calcarosol in the Australian soil classification (Isbell, 2002)). In 2013 the experiment at Roseworthy was conducted on a Luvisol (chromosol) and that at Tarlee on a Vertisol (vertosol). All soils are alkaline, moderately saline in the subsoil and low in mineral N (Table 2).

In 2011 and 2012, the experiments were split plot designs with cultivars as the main plot treatments and N management strategies randomly allocated to the subplots. Treatments were replicated three times for each of the experiment. Two mustard and four canola cultivars (including two triazine tolerant (TT) and two non-TT cultivars) were evaluated under different N application strategies. The canola and mustard varieties, selected from the same maturity group (mid-season) but with differences in early vigour, were chosen to represent varieties commonly grown in the region. The cultivars were AV Garnet (open pollinated (OP), conventional), FighterTT (OP, TT), Hyola555TT (hybrid, TT), Hyola575CL (hybrid, Clearfield (CL)), Oasis (OP, CL mustard) and Varuna (OP, conventional mustard). Nitrogen treatments were designed to generate a range in biomass and canopy size and were targeted at specific growth stages. Three N rates (0, 100 and 200 kg N ha^{-1}) were applied and split among the various growth stages. When 100 kg N ha^{-1} was applied, the fertiliser was split among three equal applications at rosette (GS30), 30% of flowering (GS63) and 10% pod maturity (GS71) whereas 200 kg N ha^{-1} was applied in five equal split applications (rosette (GS30), green-bud (GS51), start of flowering (GS61), start of pod filling (GS67) and 10% pod maturity (GS71)) to maintain a steady supply of N throughout the season and to serve as a non-N limiting control. Crop growth stages were recorded by using the BBCH canola scale (Lancashire et al., 1991).

In 2013, the experiments compared the growth and yield of a single variety (Hyola 575CL) under different N treatments. At Tarlee, the design was a 2 × 2 factorial combination of rate and timing of N plus a zero N control with six replicates. Nitrogen was applied at rates of 100 kg N ha^{-1} or 200 kg N ha^{-1} which were applied either as a single application just after seedling emergence or equally split among the rosette stage (GS30), green bud appearance (GS51) and first flower (GS61) stages.

At Roseworthy, the interaction between water and N was examined by using two water regimes (irrigated and rainfed) in a split plot design with irrigation treatment as the whole plot and N treatments randomised within the subplots. The same N treatments as those used at Tarlee were applied and the treatments were replicated 3 times. The irrigation treatment involved a single irrigation using a drip irrigation system. Water was applied at the rosette stage (GS31) to wet the soil profile to the drained upper limit (DUL) to 100 cm depth, which was equivalent to 60 mm of irrigation. In

Table 1
Rainfall received and soil water at (0–100 cm) in the experiments conducted between 2011 and 2013 for Roseworthy and Tarlee. Sowing soil water is shown as mean ± s.e.m.

	Site and year			
	Roseworthy			Tarlee
	2011	2012	2013	2013
	(mm)			
Rainfall				
Total	394	292	358	542
April-October	232	220	284	464
Autumn	119	91	90	114
Winter	103	119	159	217
Spring	94	45	45	142
Sowing soil water	220 ± 11	70 ± 5	198 ± 24	124 ± 10