Effect of phosphorus fertiliser at sowing on canola (*Brassica napus* L.) yield responses under waterlogged conditions

Dilnee Suraweera[1], Malcolm McCaskill[1], Penny Riffkin[1], Debra Partington[1], Jamie Smith[1], Irma Grimmer[1], and Tony Dickson[1]

[1] Agriculture Victoria Research, 915 Mt Napier Rd, Hamilton Victoria 3300, Australia
dilnee.suraweera@ecodev.vic.gov.au

Abstract
Yield potential of canola in the high rainfall zone in the south-west Victoria is higher than most other parts of Australia due to higher rainfall and longer growing season. However, in some years it is constrained by waterlogging during winter and early spring. Adequate phosphorus (P) fertiliser at sowing is critical in achieving high canola yields. Data were collected in 2017 growing season from canola field plots affected by waterlogging in an experiment conducted with a range of soil P fertility levels at the Long-term Phosphate Experiment (LTPE) site in Hamilton, Victoria. The aim of this study was to examine the canola yield responses to additional P fertilizer at sowing under different waterlogging regimes. A scale was developed to assess the severity of waterlogging at the start of flowering (GS 4.1) and full flowering (GS 4.9) stages. At grain maturity, plants were harvested separately based on the scale. Grain yield, grain number, non-grain biomass, 1000-grain weight and harvest index were determined. In 2017, the growing season rainfall was greater than the long-term average particularly over August-September resulting in significant waterlogging over this period which coincides with the canola bud visible and flowering stages. Response relationship showed that canola grain yield significantly increased (R^2= 0.84, p<0.001), in response to P fertilizer application at sowing. This response to P was greatest for non-waterlogged plants and was progressively lower as the magnitude of waterlogging increased. Waterlogged plots reduced canola grain yield by 38-62% compared to non-waterlogged plots under the range of applied P fertilizer rates. There was a significant interaction between P fertilization and waterlogging in most of the parameters measured. Therefore, enhanced P fertilization at sowing with non-limiting levels of other nutrients has potential to increase canola grain yield under waterlogged conditions. But the response of canola grain yield to P fertilizer at sowing is reduced with increasing waterlogging severities. These findings will be useful to understand the P fertilizer requirements for canola growing in waterlogging-prone soils.

Key Words
waterlogging, phosphorus, canola, high rainfall zone, flowering stage, grain yield

Introduction
Commercial canola (*Brassica napus* L.) yields in the high rainfall zone (HRZ) of south-west Victoria (1.5 t/ha) are well below their water-limited potential (3.6 t/ha) (http://www.yieldgapaustralia.com.au). Nutrient limitations and transient waterlogging are the major causes for yield gaps in the HRZ cropping systems (Zhang et al., 2014). Canola is very sensitive to waterlogging and canola yield loss has been reported with waterlogging durations as short as 3 days (Hartman, 2014). Canola production in most parts of the HRZ of south-west Victoria is affected by waterlogging during winter and early spring and this often lowers yields (Bluett and Wightman, 1999). The effects of waterlogging on canola crops are usually seen as reduced growth and chlorosis of older leaves (Bakker, 2017) due to poor root development and the consequential slow uptake of nutrients from the anaerobic soil (Hartman, 2014).
The effect of waterlogging on canola yield depends on the frequency and duration of the waterlogging event(s) and timing with respect to the growth stage of the crop (Hartman, 2014). Published literature indicates that waterlogging has the greatest detrimental effect on canola crop yields when it occurs at seedling or in the floral development stages whereas waterlogging that occurs at the pod development stage has no significant impact on final grain yield (Zhou and Lin, 1995). All these results were observed in controlled environmental studies conducted either in pots or specially designed experimental tanks with varying duration of waterlogging. However, little is known on the effects of waterlogging on canola yield under field conditions. A study conducted in north-east Victoria showed 19% and 31% increase in canola yields by surface and subsurface drainage compared with undrained (waterlogged) conditions (Johnston, 1999). The vulnerability of canola to waterlogging early in the growing season, limits crop options available to growers to break the cereal disease cycle in crop rotations in many parts of southern Australia. Therefore, understanding the impact of waterlogging on canola crop and the potential use of fertilizer management

strategies to minimize the detrimental impacts of waterlogging on canola yield are required for profitable canola production in waterlogging-prone soils. Most of the canola nutrition experiments conducted across Australia have been focused on well-drained soils, and there is little information available on the interaction between nutrition and waterlogging. Therefore, this study aimed to understand the effects of application of P fertilizers on canola yield in waterlogging-prone soils.

Methods

Data were collected in the 2017 growing season from canola field plots affected by waterlogging in an experiment conducted with a range of soil P fertility levels at the Long-term Phosphate Experiment (LTPE) site on the Agriculture Victoria research farm in Hamilton, Victoria. (142°4’15” E, 37°49’27”S). The soil at the experimental site was Ferric- Eutrophic Brown Chromosol that is prone to waterlogging. Six separate small-plot experiments were conducted in 6 of the large plots that had a wide range of background soil P fertility levels (10, 13, 24, 34, 63, and 121 mg Colwell P/kg). Phosphate buffer index values for the 6 large plots were calculated according to Burkitt *et al*. (2002) and ranged from 173 to 245. Each small-plot experiment had 8 P treatments (0, 3, 6, 12, 25, 50, 100 kg P/ha) applied at sowing in 4 replicates. Canola (*Brassica napus* L.) cv. 45Y91 was sown at 4 kg/ha on 12 m x 1.6 m flat beds on April 30 with 15 cm row spacings. Prior to sowing, fertiliser was added using a seed drill using a blend of mono-ammonium phosphate (MAP) as the P source balanced for N by urea (46 kg N/ha). Total P applied for each plot was calculated by adding the equivalent P rates of the starting Colwell P and additional P rate applied at sowing. Sulphate of ammonia (14.5 kg N/ha) was applied at the 5-leaf stage and urea was applied at the bud visible (75 kg N/ha) and first flowering (75 kg N/ha) stages to meet the 100% of estimated Nitrogen (N) requirements. The site had previously been a pasture based on phalaris (*Phalaris aquatica* cv Australian) and perennial ryegrass (*Lolium perenne* cv Victorian).

Score	Description
1	No any signs of waterlogging (erect healthy plants).
2	purple-red to yellow older leaves and stem bases (<20%), slight plant lodging (<20%), no wilted shoot tops
3	30-50% purple-red to yellow leaves and stem bases, 30-50% plant lodging, a few (<20%) wilted shoot tops
4	50-80% purple-red leaves and stem bases, 50-80% plant lodging, stunted plants, 30-50% wilted shoot tops
5	> 80% purple-red leaves and stem bases, plants completely laying on the ground, plant death, >50% wilted shoot tops

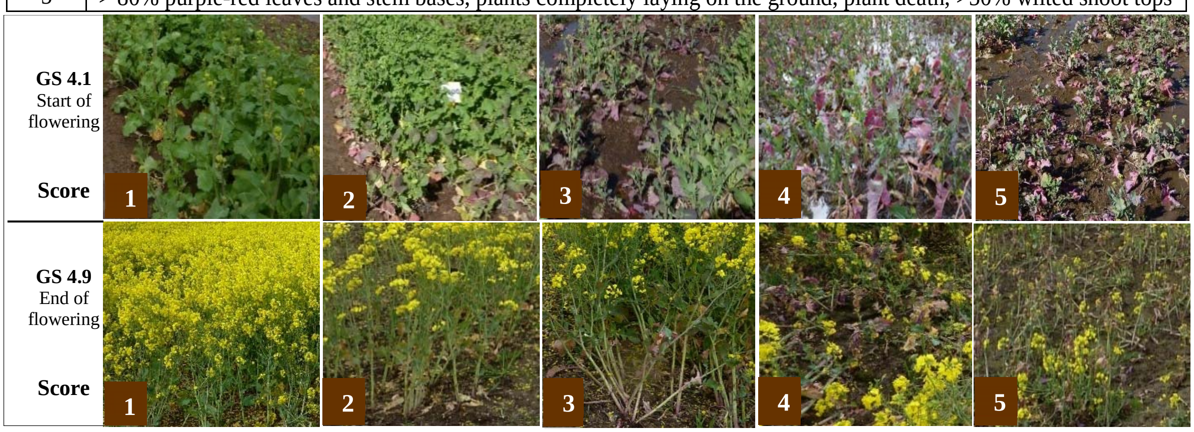

Figure 1. Scale for waterlogging severity

A scale was developed to assess the severity of waterlogging (Figure 1). All the plots were visually rated at the start of flowering (GS 4.1, September 18, during waterlogging) and full flowering (GS 4.9, October 10, after waterlogging) stages for the severity of their waterlogging symptoms based on a scale where, ‘1’ represents no effects of waterlogging and ‘5’ represents severely affected by waterlogging (Figure 1). Where a section of a plot had a high waterlogging score, it was marked with paint for subsequent grain harvest. Dates of first flower (GS 4.1) and physiological maturity (seeds colour was between 40 and 60% brown/black) were recorded. At final harvest, plants within two quadrats (1 m x 6 inner rows) per plot from waterlogged and non-waterlogged areas were hand-harvested. Waterlogged plots reached maturity a week later than non-waterlogged plots. Samples were oven dried at 40°C and threshed to separate grains to determine grain yield, grain number, non-grain biomass, 1000-grain weight and harvest index (ratio of grain yield to above ground biomass).

Data were analysed by GenStat 18th edition (VSN International Ltd., 2016) using the FITCURVE procedure with the waterlogging score as a fixed effect to examine the relationships between grain yield and yield components in response to P fertilizer application under different waterlogging regimes. Because of the relatively small number of measurements for waterlogging scores greater than 1, the 6 levels of starting P and 7 rates of starting P were combined into a single value of “P supply” by finding an equivalent P application rate for Colwell P values above the lowest value of 14 mg/kg. This was done by minimising squared deviations of grain yield for plots with a waterlogging score of 1. Using this method, a starting Colwell P of 53 mg/kg to which no P was applied had a yield equivalent to an application rate of 57.9 kg/ha for a starting Colwell P of 14 mg/kg. The Fisher's protected least significant difference test, ($P=0.05$), was used to compare the differences between P fertilizer treatments and waterlogging scores.

Results

In 2017 growing season, rainfall fluctuations were typical of seasonal conditions in this region and are shown in Table. 1. The annual rainfall was 706 mm and the growing season rainfall was 577 mm which were close to the long-term average. By contrast, rainfall during winter and early spring particularly over August-September was higher than the long-term average and there was surface water in micro-topographic hollows across much of the site from 27 July to 18 September (visual observation). This waterlogging period was coincided with the canola bud visible and flowering period.

Table 1. Annual, growing season and monthly rainfall data for study site in Hamilton Victoria.

Year	Annual rainfall (mm)	Apr-Nov rainfall (mm)	Jun-Aug rainfall (mm)	Monthly rainfalls (mm) June	July	Aug	Sep
2017	706	577	183	17	65	102	72
Long-term average	705	553	240	71	83	86	78

April-November rainfall defined as growing season rainfall, June-Aug rainfall represents winter rainfall

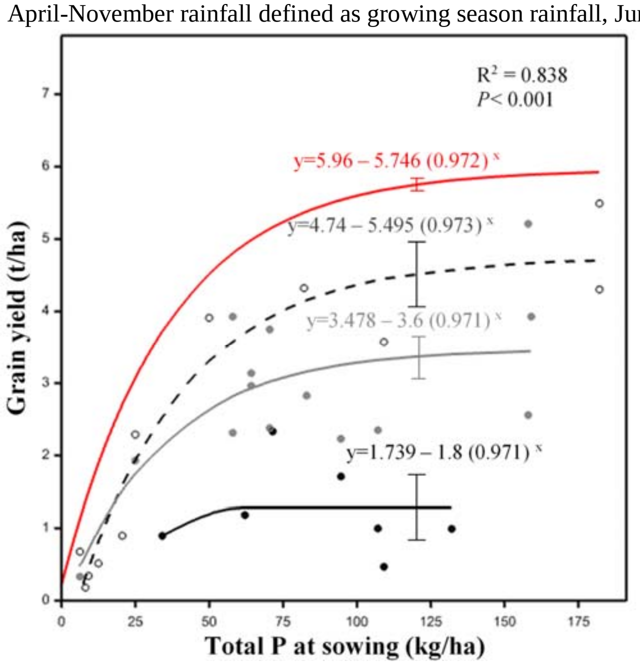

Figure 2. Relationship between total P at sowing and grain yield in canola under different waterlogging severities. In the graph, —, score-1; - - and ○, score-2; — and ●, score-3; — and ●, score-4. Regression equations for the best fit curves are shown at the top of the error bar of each curve. Error bars represent standard errors of differences (s.e.d) of means at 120 kg P ha^{-1}. Significance levels represent the total P at sowing x grain yield x waterlogging score interaction. Data points for waterlogging score-1 are not shown in the figure. Total P at sowing was calculated by adding the equivalent P rates of the starting Colwell P and additional P rate applied at sowing.

Canola crop phenology was affected by waterlogging and delayed the days to first flower and physiological maturity by 5-7 days under severe waterlogging (score 2 and 3) compared with non-waterlogged plots (score 1). The waterlogging occurred at early flower development stage (GS 3.7-4.5) and reduced the above-ground biomass at flowering (GS 4.1) by 15- 30% (data not shown). Waterlogged canola plots (score 2-4), showed lower grain yield (38-62%), non-grain biomass (19-37%), grain number (36-57%), 1000-grain weight (7-14%), harvest index (13-34%) compared to non-waterlogged plots under the range of applied P fertilizer rates. This reduction was lower at high P application rates compared to low P application rates. There was a significant interaction between P fertilization and waterlogging in grain yield (Fig. 2). The reduction in canola grain yield and yield components under waterlogging increased with increasing waterlogging severities (score 1 to 4). Response relationships showed that canola grain yield (R^2= 0.84, p<0.001), non-grain biomass (R^2= 0.74, p<0.001), grain number (R^2= 0.77, p<0.001) and harvest index (R^2=

0.67, *p*<0.001) significantly increased in response to P fertilizer application at sowing. This response to P was greatest for non-waterlogged plants (score 1) and was progressively lower as the magnitude of waterlogging increased. At waterlogging scores of 4, there was no significant effect of P supply on grain yield. Therefore, increasing P application rates increased canola grain yield and yield components in non-waterlogged crops but the detrimental effects of severe waterlogging on canola grain yield was not addressed by increasing P application. There was no strong relationship (R^2= 0.43) observed for 1000-grain weight in response to P fertilizer application at sowing and waterlogging (data not shown).

Discussion

The growth of canola plants and the biomass at flowering were reduced when waterlogging occurred at early flower development stages, and its adverse effects remained afterwards. The leaf senescence in canola plants caused by waterlogging leads to decreases in plant photosynthesis and the retardation of plant growth, and ultimately reduced grain yield and yield components. Canola is extremely responsive to P under non-waterlogged condition and high P applied plots significantly increased grain yields in non-waterlogged crops compared to the low P plots. This is consistent with the findings of McCaskill et al. (2017). Early P application is critical in achieving high canola yields and failure to meet this early P demand can result in reduced potential yield, regardless of improved P access later in the season. Therefore, adequate P supply at sowing is essential to obtain high returns from non-waterlogged canola crops. However, high P application cannot overcome the damage to canola plants under severe waterlogging which may be due to a reduction in nutrient uptake from damaged roots. Hartman (2014) reported that the lack of aerenchyma and high rates of radial oxygen loss from the root base contribute to the waterlogging intolerance of canola. Poor soil aeration and reduced root activity under waterlogging restricts P uptake in crops. Gutierrez Boem *et al*. (1996) reported that the waterlogging favours iron oxide formation and the iron oxide locks onto available P, making it less available to plants under waterlogging and ultimately restrict P uptake. Despite visible surface water for a 7-week period of the growing season, canola, supplied with sufficient P and N and not located in micro-topographic depressions, could achieve grain yields of 6 t/ha. This contrasts with areas of the surrounding plots that did not receive in-crop N, where yields were between 0.9 and 1.8 t/ha (McCaskill *et al*., 2017). Nevertheless, there were areas where neither supply of P nor N could alleviate the effects of waterlogging on yield. In such areas the crop could not grow out of waterlogging effects that were recorded at bud visible and flowering period, and no financial returns could be expected from additional nutrition.

Conclusions

Application of additional P fertiliser at sowing has a potential to increase canola yields in waterlogged soils, but the response of canola grain yield to P fertilizer at sowing is reduced with increasing waterlogging severities. Therefore, additional P supply at sowing could not alleviate the effects of severe waterlogging on canola yield. Overall, canola growers can obtain high returns from non-waterlogged crops by applying additional P fertiliser, but no financial returns could be expected from severely waterlogged canola crops.

Acknowledgements

We acknowledge Fiona Robertson for helpful comments on the manuscript and John Byron for technical assistance. This research was funded through the Grains Research and Development Corporation (DAV00141 and DAV00151) and the Victorian State Government through the Department of Jobs, Precincts and Regions.

References

Bluett CA and Wightman BD (1999). Growing Canola on raised beds in south-west Victoria. Proceedings of 10th International Rapeseed Congress. Canberra, Australia. Australian Institute of Agricultural Science.

Burkitt LL, Moody PW, Gourley CJP, Hannah MC (2002). A simple phosphorus buffering index for Australian soils. Australian Journal of Soil Research 40, 497-513.

Gutierrez-Boem FH, Lavado RS and Porcelli CA (1996). Note on the effects of winter and spring waterlogging on growth, chemical composition and yield of rapeseed. Field Crops Research 47(2-3):175-179.

Hartman M (2014). Waterlogging and canola. Issue 3. Canola Council of Canada. Pp 1-19.

Johnston T (1999). Subsoil Drainage for Increased Productivity on Duplex Soils. Grains Research and Development Corporation Final Report (DAV214/331SR). Agriculture Victoria, Rutherglen. 1-19.

McCaskill M, Stott K, Christy B, Riffkin P, Norton R and Partington D (2017) Phosphorus response and fertiliser decision support. In 'Trial Results Victoria Edition 2017'. Southern Farming Systems. 102-105.

Yield Gap Australia (2019). http://yieldgapaustralia.com.au. CSIRO, Accessed 4 March 2019.

Zhang H, Turner NC and Poole ML (2004). Yield of wheat and canola in the high rainfall zone of south-western Australia in years with and without a transient perched water table. Australian Journal of Agricultural Research: 55(4).461 – 470

Zhou W and Lin X (1995). Effects of waterlogging at different growth stages on physiological characteristics and seed yield of winter rape (Brassica *napus L.).* Field Crops Research 44. 103-1 l0.