Waterlogging effects on soils and wheat crops in the high rainfall zone of Victoria

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Abstract
Waterlogging is a significant constraint on crop production in the high rainfall zone of southern Australia. To better understand how waterlogging affects soil conditions and crop growth, we conducted field experiments to compare the effects of differing degrees of waterlogging on soils and wheat crops at three sites in SW Victoria. The apparent reduction in grain yield due to waterlogging ranged from nil to 38%, with a decline in total N uptake from nil to 40%. The effect of waterlogging on the crop was influenced by several factors including the depth of waterlogging, the duration of waterlogging, the aeration conditions (redox potential) in the soil and the timing of waterlogging. The importance of the various factors varied among sites and further work is required to evaluate their influence in different situations.

Background

Waterlogging during winter is common across many parts of the high rainfall zone (HRZ) of southern Australia but its impact on crop production is not well understood. Field experiments suggest that cereal yield losses due to waterlogging could vary between nil and more than 80% (Gardner and Flood 1993; MacEwan et al. 1992; McDonald and Gardner 1987; Setter 2000). Options for managing waterlogging are currently limited. Drainage (surface or subsurface) has been shown to be effective in some situations but ineffective in others, and has not been widely adopted by growers (DEDJTR 2015). Similarly, raised beds can significantly reduce yield losses from waterlogging in wet years in some but not all situations (Acuña et al. 2011; Bakker et al. 2007; Riffkin and Evans 2003). The objective of this study was to measure the effects of a range of waterlogging conditions on soils and crops under field conditions in the HRZ of SE Australia.

Methods

Field experiments were conducted in the HRZ of south-western Victoria to investigate the effects of differing degrees of waterlogging on soil conditions and growth of the crop. The focus was on wheat (*Triticum aestivum*) on texture-contrast soils (Chromosols and Sodosols, Isbell 2002). These soils are naturally prone to waterlogging after rainfall as water accumulates in the loamy topsoil because of slow drainage through the heavy clay subsoil, leading to the development of a perched water table (Cox and McFarlane 1995).

In 2017, experimental sites were established at Hamilton, Glenthompson and Tatyoon. The Hamilton sites were on the Agriculture Victoria research farm on raised beds and the Glenthompson and Tatyoon sites on commercial farms on the flat. All sites were sown to wheat in May (cv. Trojan at Hamilton and Tatyoon, cv. Beaufort at Glenthompson) shortly before the experimental areas were set up. At each site (paddock), three locations (approximately 20 x 20 m) were selected that differed in their expected susceptibility to waterlogging. These locations, termed Dry, Medium and Wet, were positioned on the upper, middle and lower parts of the paddock, respectively. The central part of each location (approximately 8 x 12 m) was reserved for experimental measurements and sampling. Irrigation was applied during winter to the Wet location at Hamilton (~100 mm) and Tatyoon (~85 mm). Total annual rainfall was 706 mm at Hamilton, 595 mm at Glenthompson, and 520 mm at Tatyoon. The soils were of similar texture at all sites and locations, with the heavy clay B horizon occurring at an average depth of 30 cm.

At each location, duplicate instruments were installed to measure soil moisture content (neutron moisture meter and EnviroPro® probes), the height of the water table (piezometer tubes containing Odyssey® water level sensors) and crop root growth (CI-600 in-situ root imager). Soil aeration status (redox potential) was measured at the Wet locations (Paleo Terra redox probes). The crop was sampled from quadrat cuts (4 per location) at key growth stages (booting (GS 45), anthesis (GS 65) and maturity (GS 92)) for dry matter and N analysis. Data were analysed by REML variance components analysis with error calculated from pseudo-replicates within locations.

Results

Crop growth and N uptake

Grain yield at Hamilton and Glenthompson was reduced in the Wet locations compared to the Medium and Dry locations, which were similar. Grain yield at Tatyoon did not differ significantly among the Dry, Medium and Wet locations (Figure 1). The yield reduction at Glenthompson (2.1 t/ha, 38%) was due to reduced number of ears. The yield reduction at Hamilton (1.7 t/ha, 20%) was due to reduced grains per ear. Total plant N uptake at maturity was also lower at the Wet location than the Medium and Dry locations at Hamilton (14% reduction) and Glenthompson (40% reduction), but not at Tatyoon (Figure 1). Grain protein concentration was lower in the Wet location at Glenthompson only (data not shown). These trends were also evident in total aboveground crop biomass and total N uptake at the booting and anthesis stages. Root length at maturity in the top 48 cm of soil was lower at the Wet than at the Dry and Medium locations (by 15%, 47% and 13% at Hamilton, Glenthompson and Tatyoon, respectively).

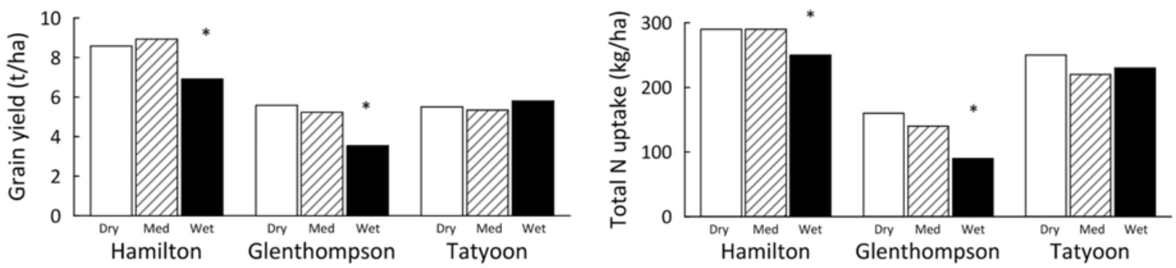

Figure 1. Wheat grain yield and total crop N uptake at maturity. Asterisks indicate that Wet location is significantly different to Medium and Dry.

Soil conditions

Soil moisture content was at or near saturation between June and the beginning of October throughout the soil profile (0-100 cm depth) at the Dry, Medium and Wet locations at Hamilton, Glenthompson and Tatyoon. All soils began to dry rapidly during October but, due to a large rainfall event in November, they remained close to saturation below the 40 cm depth for the rest of the season (data not shown).

A perched water table was present between July and October, sometimes reaching the soil surface, at the Dry, Medium and Wet locations at Hamilton and Glenthompson and the Wet location at Tatyoon. A water table also developed at the Medium and Dry locations at Tatyoon but was much lower and of shorter duration. The period of high water table was mostly between the stem elongation and anthesis stages at Hamilton and Tatyoon, and between tillering and booting at Glenthompson. An example of the water table data is shown in Figure 3 (a) for the Hamilton Wet location.

The depth of the water table and its duration over the season, both important factors for assessing the severity of waterlogging, were combined in an index called the Sum of Excess Water in the top 30 cm (SEW30) (Cox and McFarlane 1995). This is the total amount of waterlogging that occurs each day between the soil surface and 30 cm depth over a given period. The SEW30 over the season (Figure 2) increased in the order Dry<Medium<Wet locations at Hamilton and Glenthompson but not at Tatyoon.

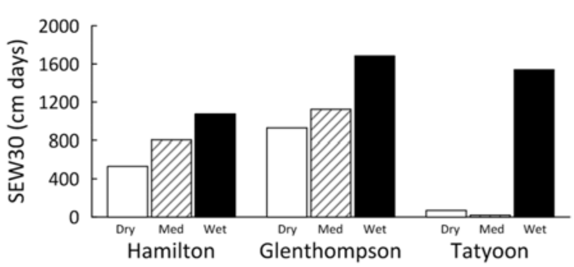

Figure 2. Sum of Excess Water index (SEW30) at the experimental sites, indicating the accumulated depth and duration of waterlogging in the top 30 cm of soil over the 2017 season.

Redox potential, which represents the aeration status of the soil, reads >700 mV in fully aerated (aerobic) conditions; 350-700 mV in partially aerobic conditions; and <350 when oxygen is completely absent the soil (anaerobic). Nitrogen loss due to denitrification is most likely to occur around 250-350 mV. At Hamilton, redox potential was in the partially aerobic zone when measurements began in July. With the formation of the water table, redox declined, rapidly in the upper soil depths and slowly at the deeper (57 cm) depth, into the anaerobic zone, where it stayed until late September. Redox began to rise again in October as the water table receded, and was generally in the partially aerobic and aerobic zones after October, except for a short drop in aeration status after one heavy rainfall event in November (Figure 3 (b)).

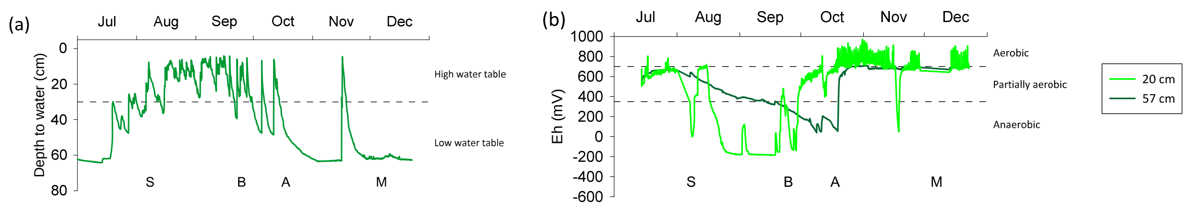

Figure 3. Depth of the water table (a) and soil redox potential (b) at the Hamilton Wet location during the 2017 season. Markings represent stem elongation, S; booting, B; anthesis, A; maturity, M.

At Glenthompson, the water table was already present and redox potential was mostly in the partially aerobic zone in July. Again, redox potential (data not shown) generally declined until the end of September, though it did not become as strongly anaerobic as at Hamilton. As the water table receded, redox potential rose rapidly and by the end of October was generally in the aerobic zone, except for some declines in the surface 5 cm due to rainfall occurring late in the growing season.

At Tatyoon, the redox potential (data not shown) was also in the partially aerobic zone in July but, unlike the other sites, it did not decline appreciably with the development of the water table. In fact, redox potential rose into the fully aerobic zone in early October, notwithstanding the presence of a high water table.

Discussion

The SEW30 index showed a large range in the depth and duration of waterlogging at Hamilton, Glenthompson and Tatyoon, but the soil and crop responses to waterlogging differed at each site. The greatest impact of waterlogging was at the Glenthompson site, with an apparent yield loss of 38%. The Glenthompson Wet location had the longest duration of very high water tables, and the soil aeration status was very poor until the booting stage. These conditions are likely to have strongly impacted the growth and functioning of the crop roots and shoots, including by reducing the uptake of nutrients, particularly N. The waterlogging at Glenthompson began approximately one month earlier than at the other sites and waterlogging damage (reduced plant height and tillering) was clearly visible from the tillering stage. Thus, with early damage and prolonged waterlogging, the crop had little opportunity to recover until the booting stage.

At Hamilton, there was an apparent yield loss of 20% due to waterlogging despite the presence of raised beds. The period of high water tables resulted in very hostile soil aeration conditions which are likely to have impaired crop growth and N uptake. Given that the soil aeration conditions at Hamilton were less favourable for crop growth than at Glenthompson, it may seem surprising that there was less yield loss at Hamilton than at Glenthompson. However, crop damage may have been limited at Hamilton because the waterlogging began relatively late, in early August, when the crop was more advanced (stem elongation stage), with well developed roots and tillers, which may have helped it survive and recover from the hostile soil conditions.

At Tatyoon, the amount of waterlogging in the top 30cm of soil was intermediate between Glenthompson and Hamilton, yet there was no apparent effect of waterlogging on yield. Soil conditions were considerably less hostile at Tatyoon - the soil remained partially aerobic during the entire waterlogging period. This comparatively mild decline in redox under waterlogging at Tatyoon may be related to its lower soil organic carbon content (1.3% C in the 0-20 cm depth, compared to 2.0% and 2.2% C at Glenthompson and Hamilton, respectively). The low carbon content would be associated with a lower demand for oxygen by microbes (Tiedje et al. 1984). In addition to the less extreme soil redox conditions, the late onset of waterlogging at Tatyoon (early August), when the crop was relatively advanced (stem elongation), is likely to have enabled better survival and recovery of the crop and minimised yield loss.

Differences in N availability may also have influenced the crop responses to waterlogging. Some loss of N though denitrification is likely to have occurred, particularly at Hamilton and Glenthompson. The timing and amount of N fertiliser application also differed among the sites. The potential role of N in how crops respond to waterlogging warrants further investigation.

It is possible that at Hamilton and Glenthompson, the apparent effects of waterlogging on crop yield were underestimated, as the Dry and Medium locations to which the Wet sites were compared were also waterlogged for part of the season. It was evident that these texture contrast soils can become significantly waterlogged without water being visible at the surface, so waterlogging may be a hidden constraint to production in some situations.

Conclusion

This study found that apparent yield losses of wheat to waterlogging ranged from nil to 38% (with a decline in total N uptake from nil to 40%). The results suggest that the consequences of waterlogging for crop production are likely to depend on factors such as the depth of waterlogging (the height of the water table), the duration of waterlogging, the aeration (redox) conditions that develop in the soil under waterlogging, the timing of the waterlogging and other factors not identified here. Further study is required to establish the importance of the various factors and how they interact in different situations.

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