Agronomic Responses of Cotton to Low Soil oxygen during Waterlogging

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Abstract

The effect of waterlogging on growth, development and yield of cotton was quantified in a furrow irrigated field experiment conducted on a cracking clay. The experiment was a four replicated split plot design with two main plot treatments of normal irrigation (8 hrs running water) for the control (-WL) and 52-72 hrs running water for the waterlogging (+WL) plots. The sub plot treatments were factorial of two varieties and two ridge heights. Soil O_2 decreased rapidly in the waterlogged treatment, which became anoxic within 48 hours of inundation. At 24 hrs after waterlogging, photosynthesis decreased by 30% relative to non-waterlogged plants, while reduction in the leaf greenness occurred slower and biomass production did not decrease until after the 3rd waterlogging event. Yield was not different between varieties, but waterlogging significantly lowered yield in the low ridge but not in the high ridge plots.

Key words

Cotton, waterlogging, low soil oxygen, physiology, photosynthesis, growth, irrigation.

Introduction

In Australia, cotton is generally grown using furrow irrigation on cracking grey clays (Vertosols) with slow drainage, and is therefore usually subjected to some degree of waterlogging. This problem is made worse by poor land forming such as field length, slope and leveling or by rainfall after irrigation. The visual symptoms of waterlogging damage are leaf chlorosis, reduced growth and shedding of squares and bolls. Ten to 40% yield reductions are common, resulting in millions of dollars annual loss to farmers (5, 8).

The term ‘waterlogged’ or ‘flooded’ is normally used to indicate the unfavorable aeration status of the soil with excessive water levels, leaving little or no room for gasses, especially O_2 (2, 10). This adversely affects plants by curtailing plant growth and development, decreasing absorption of nutrients and water, changing the oxidation state of mineral nutrients resulting in decreased availability or increased toxicity, and by the formation of toxic compounds (4, 6, 10, 12, 14). The major and immediate effect of waterlogged soils on plant growth is a deficiency of O_2 required for root respiration and growth (2, 11, 12). This happens because gases diffuse 10,000 times more slowly in water than in air (1). Hence, soil O_2 supply from the atmosphere is reduced while other toxic gases, such as carbon dioxide, ethylene or methane accumulate to high levels (2, 10, 12, 16).

At present, cotton computer models such as OZCOT contain very simple physiological information about the plant's response to waterlogging (7). Although Hodgson and Constable did significant research on this topic during 1975-1990 (3, 8, 9), more information is still needed to be able to quantify growth reduction due to waterlogging as well as the need to test the response of new cotton varieties. The basic questions when farmers see free water lying in their cotton fields are a) will I get waterlogging? and b) will my cotton suffer yield loss?

Materials And Methods

To answer these questions, a split-plot field experiment with 4 replications was conducted at ACRI, Narrabri. NuCotton 37 and Sicala V2*i* were planted on low (5cm) and normal (15 cm) ridges. The main plot treatments were normal irrigation with 8 hrs running water (control, -WL), or inundation for 52 to 72 hrs at each irrigation in the waterlogged (+WL) treatment. Irrigation was scheduled as per commercial practice and waterlogging was imposed on the relevant plots at each irrigation, giving five waterlogging events between 16 December, 1999 and 1 March, 2000. On the day before and 1, 2, 3, 5, 7, 14, and 21 days after each waterlogging event, sequential measurements were made of soil O_2 at 15 cm depth using O_2 platinum microelectrodes (Unisense?, Denmark); photosynthesis using portable photosynthesis system (Licor? 6400); and leaf greenness using SPAD-502 chlorophyll meter (Minolta?). Plants from 1 m row of each plot were sampled for biomass measurement on the day before and 7, 14 and 21 days after irrigation. Yield and total bolls per metre were measured by hand harvesting at the end of the season.

Results And Discussion

Varietal differences were nonsignificant. Therefore all the discussion is based only upon the waterlogging and ridge height treatments.

When will waterlogging occur?

Fig. 1A shows the change over time in the O_2 concentration at a depth of 15cm depth from the surface. Normal irrigation never caused a decline to zero and it recovered quickly, while O_2 in the +WL treatment declined to zero after 48 hrs and by time of the next irrigation had only returned to half of the original level. This 48 hrs time lag might be explained by the fact that even when all the soil pores have filled with water, there are still small but significant quantities of O_2 in the soil that can be used by plant roots or soil micro-organisms for metabolism (17, 18). If this O_2 is used up prior to the excess water being removed, then root respiration will be jeopardized. In spite of the high clay content of the soil, O_2 content at the surface increased rapidly after irrigation ceased; thus ensuring good drainage of surface water from the field can be expected to have a significant impact in reducing the risk of waterlogging. These results suggest that in this cracking clay soil with 1:1500 slope, waterlogging is not likely to occur unless the soil surface is continuously under water, either from irrigation or rainfall, for at least 48 hrs. The quicker the. excess water is drained, the less chance there is of waterlogging occurring.

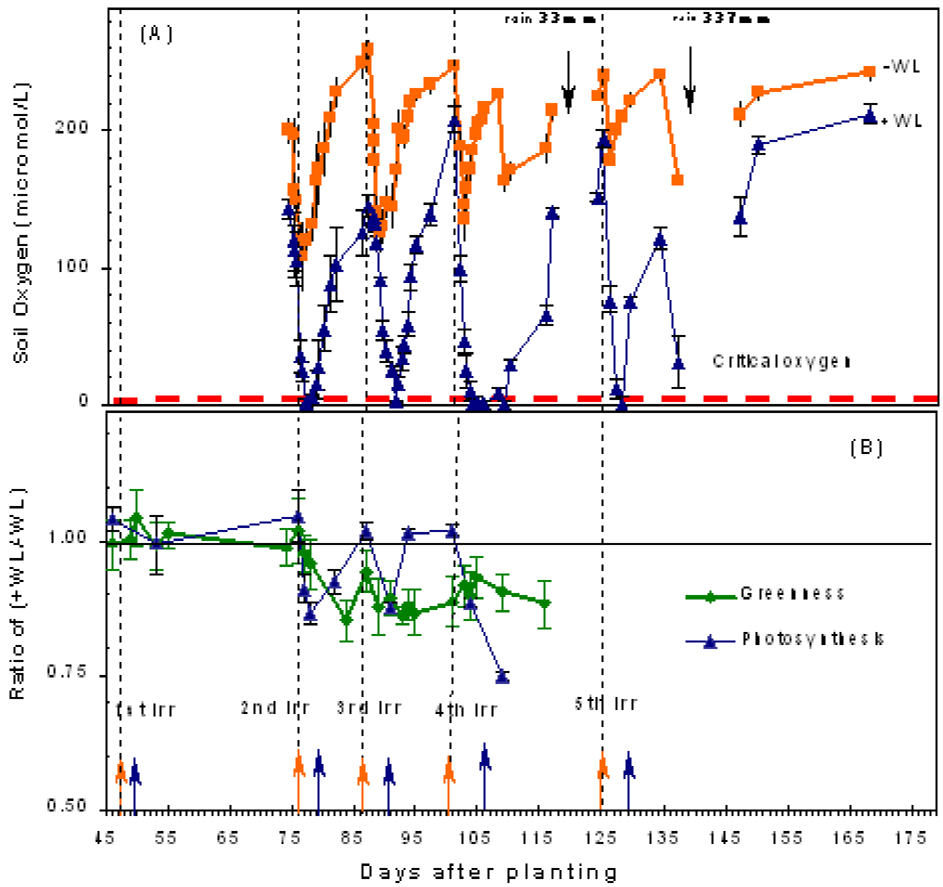

Figure 1. Soil O_2 concentration at 15 cm depth (A), and ratio between +WL and -WL of photosynthesis and leaf greenness (B) from the 1st irrigation to the end of season. The vertical lines mark the beginning of each irrigation, ending at uparrows, the grey represents -WL and the black represents +WL.

Fig1B shows changes in the ratio between +WL and -WL treatments of leaf greenness and photosynthesis over time. Photosynthesis seemed to be more responsive to soil O_2 status than the greenness of the leaf. Photosynthesis dropped more sharply and reached a minimum within 48 hrs of inundation and rapidly increased as the soil O_2 increased, while the greenness ratio took a few days longer and did not recover to the control levels. This suggested photosynthetic reduction might be a better physiological indicator for waterlogging than the classic visual symptom of leaf chlorosis. We found no biologically significant difference in stomatal conductance, supporting the previous suggestion that photosynthetic reduction in waterlogged cotton might be due to non-stomatal factors (15). Our hypothesis for this quick photosynthetic reduction is the negative feedback on photosynthesis due to the accumulation of assimilate in the leaf, as the consequence of less translocation to the root as root growth stops immediately under waterlogging (11, 12). This could be tested by monitoring root growth and the level of non-structural carbohydrate in various plant parts.

When will waterlogging effect cotton growth?

Hodgson (9) and Meyer (13) found that the effect of waterlogging on growth and yield depends on the cumulative time that the root system is exposed to an O_2 level less than 0.1%, and/or air-filled porosity less than 0.1 $m^3\ m^{-3}$ ($D_{f0.1}$; equivalent to 5.17 µmolO_2/L, in our case), whether this occurs in a single event or a number of events. Hodgson (8) demonstrated that the yield of cotton started to decline after 2 cumulative days below this critical oxygenation. We don't have data to test relationship between $D_{f0.1}$

and yield, however, our results in biomass (Fig. 2A) are consistent with this trend. As derived from Fig 1A, the number of days with O_2 lower than the critical level are 1.5, 1, 5.5 and 0.5 days for the 2nd, 3rd 4th and

5th irrigation respectively. Difference in total biomass between +WL and –WL treatments did not occur until after the 3rd irrigation, when the growth rate of –WL plots increased markedly but that of the +WL plots did not. At this time, $D_{f0.1}$ was 2.5 days, consistent with the results of Hodgson. The major component of biomass reduction was initially leaf dry weight and then less bolls in the later growth stage.

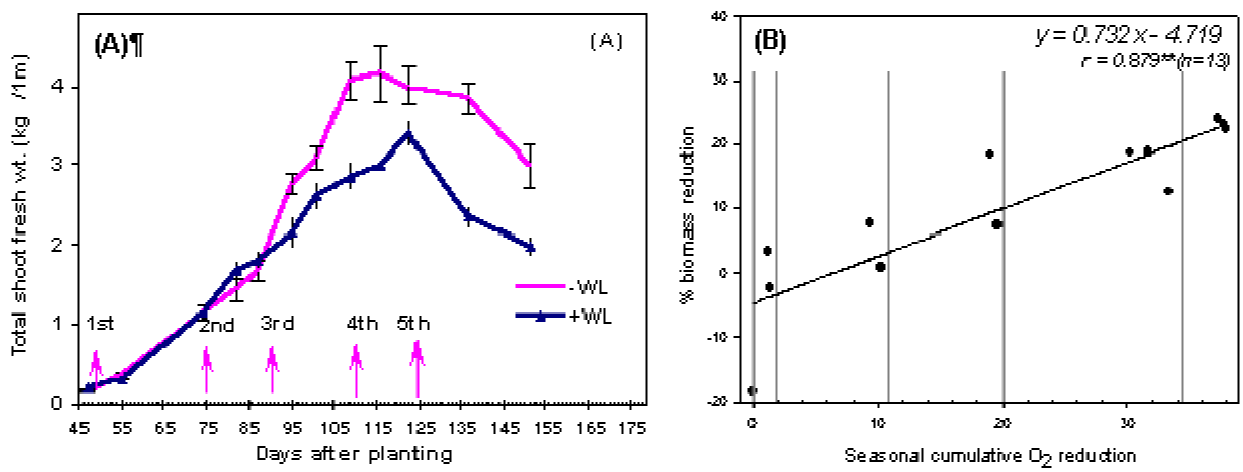

Figure 2. Total top fresh weight over the season (A) and correlation between reduction of soil O_2 and biomass compared to control non-waterlogged plots (B). Vertical lines mark irrigation date.

There was no correlation between $D_{f0.1}$ and % biomass reduction due to waterlogging. This might due to the fact that the relationship at each respective time does not reflect the continuously cumulative effect of O_2 reduction on growth. On the other hand, the sum of O_2 reduction between +WL and –WL up to each growth stage was significantly correlated to % biomass reduction as shown in Fig. 2B. Except for the first irrigation in which waterlogging was not achieved, biomass was reduced markedly after each waterlogging event according to the large increase in O_2 reduction. As the soil dried and the O_2 differences between the waterlogged and control plot became less, biomass of +WL plants started to recover, but then fell back again after the next waterlogging event, and remained below the level of the control plants. The linearity of this correlation supports the previous statement that changes in growth & yield are strongly depended on the seasonal cumulative O_2 reduction, whether this occur as a series of short term (8) or one long term waterlogging (13). However, the two types of event need to be compared in a replicated field experiment, as well as assessing the effect of waterlogging at different growth stages.

Effect of waterlogging on cotton yield

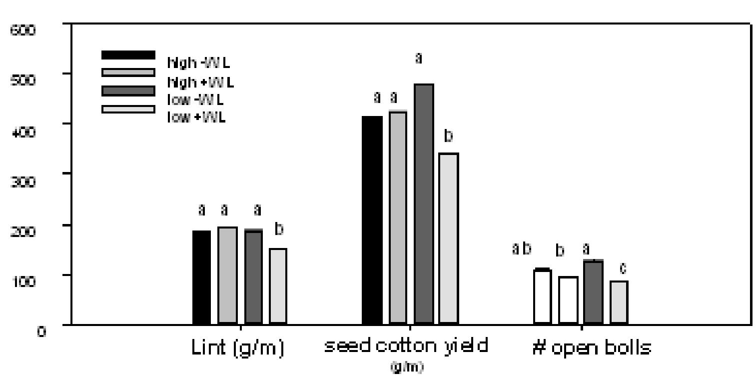

Figure 3. Seed cotton, lint yield and No. total bolls/m, (letters shows significant difference at 5% probability).

The effect of waterlogging and ridge height on yield and total boll number is shown in Fig 3. Yield and total bolls were lowest in the low ridge +WL, but there was no significant difference among the high ridge +WL, the high ridge –WL and the low ridge -WL plots. This result suggested that low ridges were not different from the high ridges under non-waterlogged conditions, but caused a higher susceptibility to waterlogging; with yield and total number of bolls being significant lower in the low ridge+WL plots.

Hypothesis for the mechanisms of cotton response to waterlogging

Cotton is known to be one of the plants most susceptible to waterlogging due to its low levels of alcoholdehydrogenase (ADH) and pyruvate decarboxylase (PDC), the two main enzymes in anaerobic respiration (5). The primary aim of this project was to provide information for models on the mechanisms involved in the response of cotton to waterlogging. Changes in crop growth rate, photosynthesis, and nutrient uptake especially N & Fe (7) will be quantitatively related to the observed differences in soil O_2 and water content, which will lead to better prediction of crop losses due to waterlogging. Transgenic cotton lines with enhanced expression of ADH and PDC will be tested for the contribution effect of anaerobic respiration, and the involvement of ethylene will be tested using an inhibitor of ethylene production AVG (aminoethoxyvinylglycine). A better understanding of cotton's response to waterlogging will help in developing improved agronomic management and in breeding to reduce its impact on yield.

Conclusion

These results illustrate that under waterlogged conditions, the growth and yield of cotton are markedly affected by low soil O_2 status. Photosynthesis seems to be the first plant physiological process that responded to decreasing soil O_2 concentration; prior to the visual symptom of leaf chlorosis. In terms of management, it demonstrates the importance of ensuring adequate bed height and the ability to remove excess water from the field as soon as possible. Attempts to improve cotton tolerance to waterlogging are the subject of further research.

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