A Study on Yield, Growth and Physiological Response of Soybean to High Night Temperature

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1. Introduction

Soybean [*Glycine max* (L.) Merr.] is one of the most important crops worldwide. Soybean production at relatively high temperatures may cause a decrease in seed yield and quality, resulting in economic losses due to climate change. It has been determined that night temperatures (NTs) may increase to a greater extent than daytime temperatures, but studies on the effect of high night temperature (HNT) stress on soybean production are still limited or do not adequately consider changing climate. This study was conducted in order to understand the impact of HNT on the performance of soybean. First, the soybean yield attributes were evaluated for a commercial cultivar, 'Fukuyutaka'. Then, physiological responses of this cultivar were examined under HNT during early and/or late reproductive stages. Finally, the performance of a high temperature (HT) tolerant cultivar, 'DS25-1', was compared with that of 'Fukuyutaka', under HNT conditions.

2. The influence of high night temperature on yield attributes in 'Fukuyutaka'

To evaluate soybean performance in response to HNT, a soybean cultivar, 'Fukuyutaka', was grown for 2 years under different night temperatures during reproductive stage in a mini field in a temperature gradient chamber (TGC). The average night temperature ranged from 21.7 ℃ to 23.9 ℃ and from 20.3 ℃ to 22.8 ℃ in 2017 and 2018, respectively. In the TGC, the yield tended to decline by 4.6% per ℃ increase in temperature when the results from the 2 years were combined. The responses of the yield components tended to offset, and the harvest index (HI) did not respond to varying NTs. Thus, the decrease in yield observed under HNT conditions resulted from a change in biomass. The reduction in biomass was attributable more to branch growth than to growth of the main stem, and more to leaf growth than to the growth of other organs. Leaf area and leaf weight displayed responses to NT nonlinearly drawing convex curves, suggesting that HNT over some level inhibits leaf growth. The light saturated photosynthetic rate (A_{sat}) was not significantly affected by HNT in the TGC. The estimated maintenance respiration (R_m) increased with HNT, but it seemed to explain only partially the biomass response to HNTs.

3. The effect of high night temperature on physiological activity, leaf senescence, and growth in 'Fukuyutaka'

The physiological processes that cause the negative response of soybean to HNT were investigated for 'Fukuyutaka', under a controlled environment using phytotron and TGC to analyze plant nitrogen (N) dynamics, leaf photosynthesis, and other relevant physiological activity as well as plant growth. High (28 ℃, HNT) and low (22 ℃, LNT) night temperatures were established in the phytotron over 2 years, during the first and/or second half of reproductive stage in 2019, and whole reproductive stage in 2020. Plant biomass at R6.5 declined under HNT during the whole reproductive stage as compared to that under LNT. In the phytotron, a lower HI was also found in the treatment of HNT during second half of the reproductive stage. In reference to N dynamics, N fixation (N_{fix}, TGC study) and N accumulation (phytotron study) declined by HNT. Leaf area (LA), N weight per LA (LNC) and the ratio of leaf N weight to total N weight tended be lower under HNT than under LNT, particularly when plants were exposed to HNT during first half of the reproductive stage. This suggests that N translocation from leaf to seed occurred earlier with exposure to HNTs, thereby resulting in earlier leaf senescence. HNT caused a low A_{sat} during late reproductive stages, which were associated with low stomatal conductance and A per intercellular space CO_2 concentration (A/Ci). Low A/Ci was presumably due to low LNC or accelerated senescence according to changes in the chlorophyll meter value. In addition, at 28 days after the initiation of HNT treatment and afterward, a lower increase of photosynthetic rate (A) in the morning was found by HNT, being associated with low leaf water potential at predawn (LWP_{pd}) and low A/Ci. These results suggest that plant growth and biomass of soybean are affected by HNTs, particularly in the early reproductive stage, through physiological activity, including A_{sat} and how fast the A increases in the morning, and accelerated senescence.

4. The effect of high night temperature on yield and yield components of two soybean cultivars

In order to explore opportunity of genetic improvement for adaptation to HNT, an exotic soybean cultivar was characterized in terms of performance under HNTs. A new US cultivar, ‘DS25-1’, has been considered HT tolerant, particularly in the seed quality traits. But the performance has not been tested under controlled environments. ‘DS25-1’ was grown along with ‘Fukuyutaka’ in the TGC. Average NT ranged from 21.8 ℃ to 24.7 ℃ in 2017 and 23.9 ℃ and 28.9 ℃ in 2020. The temperature gradient was created only in 2017. The yields of both cultivars tended to decline by HNTs less evidently in ‘DS25-1’. In both years, the yield decrease in ‘Fukuyutaka’ was due to lower biomass production, while a lower pod-set was observed in ‘DS25-1’. In both cultivars, the HI did not change significantly although there were slight reduction trends in some yield components. The A_{sat} of ‘DS25-1’ also remained stable as compared to ‘Fukuyutaka’ under HNTs. As for seed quality, the seed size and seed appearance quality were well retained in ‘DS25-1’ under HNT. It was confirmed that ‘DS25-1’ better maintains seed quality and biomass production under increased NT.

5. General discussion and conclusions

In this study three experiments were conducted, 1: a crop level experiment with moderate HNT in two years using the TGC, 2: a plant level experiment with extreme HNT in two years using the phytotron and 3: a cultivar comparison under moderate/extreme HNT using the TGC. The yield was reduced under HNT in major cases and the yield loss was mainly due to decrease of biomass rather than due to decrease of HI. Differently from previous studies, the effect of HNT on HI was not evident even though some of the yield components were sensitive to extremely HNTs of the early reproductive stage. It seemed that due to compensation between the yield components HI was relatively stable under HNT. It was found that biomass was reduced under HNT through several physiological activities, including higher R_m, low N_{fix}, low A_{sat}, and slow rise of A in the early morning, leading to reduced carbohydrate availability. The decline of N_{fix} was important because it resulted in not only low LA but also low LNC, thus lowering biomass production. LWP_{pd} tended to be low, which may have caused slow increase of A in the morning. The senescence also seemed responding HNT, which may be related to physiological activities.

In conclusion, the yield of soybean was negatively affected by HNTs in the warm region. This was mainly due to biomass reduction caused by low physiological activities. A HT tolerant cultivar, ‘DS25-1’, is considered a potential genetic source for the improvement of soybean for adaptation to the HNT environment in warm regions of Asia.