Should We Be Worried About Higher Temperatures In Crop Production?

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With global warming and climate change, high temperature stress has become a major factor affecting crop growth and yield. However, there is uncertainty about how serious this will be on the growth and yield of crops. Temperature is a primary controller of the rate of plant growth, developmental events, and fruit maturation, but extreme temperatures can adversely affect growth and therefore yield. Cotton in its native state grows as a perennial shrub in a semi-desert habitat, and as such requires warm temperatures. It is generally thought that because cotton is a warm season crop it should thrive in hot conditions. However, even though cotton originates from hot climates, it does not necessarily yield best at excessively high temperatures, and a negative correlation has been reported between yield and high temperature during boll development.

The Temperature Range for Cotton

The ideal temperature range for cotton is reported to be 68-86oF, but the average daily maximum temperature in the US Cotton Belt during boll development is almost always well above this.

Once temperatures reach about 95°F, plant growth rate and photosynthesis begin to decrease.

Elevated temperatures can affect all stages of cotton development, but the crop seems to be particularly sensitive to adverse temperatures during reproductive development.

The effects of high temperature on germination, seedling growth and vegetative growth and crop development have been well documented, but the effects on flowering and fertilization are less clear.

Environmental stress during floral development is a considered a major reason for the disparity between actual and potential yields. Recent research has shed light on why and how high temperature affects yield development.

Events Occurring in the Flower

The day of anthesis is a critical event in the reproductive development of cotton. The flower opens as a white flower at dawn with pollination reported to occur between 0700 and 1100 h and germination within 30 minutes following pollination. The pollen tube extends through the transmitting tissue of the style and fertilization of the ovule occurs between 12 and 24 h later. Because a number of reproductive processes must occur in a highly concerted fashion for fertilization to occur, sexual reproduction is only as tolerant to heat stress as the most thermosensitive process. As a consequence, the yield of plant species with reproductive structures of agricultural importance is exceptionally sensitive to high temperature stress during flowering.

Heat stress can limit fertilization by inhibiting both male and female gametophyte development, and subsequent pollen germination, and pollen tube growth and fertilization of the ovules. Much of the sensitivity of reproductive organs to heat stress has been attributed to the sensitivity of the (female) microgametophyte to temperature extremes. In contrast with female reproductive tissues, mature (male) pollen grains exhibit no acclimative response to heat stress. Due to the inability of mature pollen grains to effectively respond to adverse environmental conditions, numerous studies have focused on pollen tube elongation responses to high temperature.

Pollen germination and pollen tube growth

Both pollen germination and tube growth are strongly influenced by high temperature. The sensitivity of pollen tube growth to high temperature is thought to be a major cause of low yields for crops with valuable reproductive structures. The optimal temperature across a range of cotton cultivars for pollen tube growth is cited as 82-90°F, with a strong correlation between maximum pollen tube growth and boll retention. Pollen germination has a much broader temperature range of 82-99°F, suggesting pollen germination may not be as sensitive to high temperature as pollen tube growth. Successful pollen tube growth and subsequent fertilization of the ovule is a prerequisite for seed formation in cotton, because seeds with their associated fibers are the basic components of yield.

Carbohydrates and Antioxidants

The leaf supplies the necessary carbohydrates for growth. In cotton, subtending leaves are the primary sources of carbohydrate supplied to subtended bolls. Heat stress affects both leaf growth and photosynthesis, and therefore the carbohydrate and energy supply in the pistil of the flower. We have shown that the energy demands of growing pollen tubes cannot be met under heat stress due to decreased source leaf activity. In general reproductive development and yield are more sensitive to high temperature stress than photosynthesis in a number of plant species.

Tolerance to High Temperature

Recent studies have suggested that the thermostability of major source leaves may correlate with reproductive thermostability by insuring sufficient photosynthate allocation to developing reproductive units under high temperature. Numerous studies have illustrated the need for antioxidant enzymes in acquired photosynthetic thermotolerance. Maintaining a sufficient antioxidant enzyme pool prior to heat stress is an innate mechanism in cotton for coping with rapid leaf temperature increases that commonly occur under field conditions. In heat-stressed pistils, a calcium-augmented antioxidant response interferes with enzyme production needed for normal pollen tube growth. Our results show that reproductive thermotolerance in cotton is closely associated with elevated pre-stress antioxidant enzyme activity in the pistil which may protect against rapid temperature fluctuations that commonly occur under natural field conditions. Furthermore, genotypic differences in ATP and calcium content of the cotton pistil are strong determinants of genotypic thermotolerance in cotton.

Influence of Water Stress

High temperatures can have both direct inhibitory effects on growth and yield, and indirect effects due to high evaporative demand causing more intense water stress. Plant water deficit stress often coincides with high temperatures, but with irrigation and adequate precipitation this is not always a problem. It is difficult to separate the exacerbating effects of water deficit on temperature stress.

Conclusions

The cotton crops experience periods of high temperatures during flowering and boll development in excess of the optimal range for growth, and this places a stress on reproductive development resulting in lowered yields. The sensitivity of pollen tube growth to high temperature, and not pollen germination or subtending leaf photosynthesis, is concluded to be a major cause of low yields. In addition, it appears that innate reproductive thermotolerance in cotton is closely associated with elevated pre-stress antioxidant enzyme activity in the pistil. Δ

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