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Recent perspective on understanding of Parawilt of cotton and its management

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Introduction

Cotton is globally important fiber crop. It is one of more than 4000 species of Malvaceae family. *Gossypium hirsutum* (upland) and *G. barbadense* are the two major species under cultivation. Of lesser commercial importance *G. herbaceum* and *G. arboretum* are native to India and eastern Asia respectively. Bt cotton is one of the first genetically modified (GM) crop with wide distribution in developing countries. In India and China, in particular, the area under Bt cotton has increased sharply over the last decade. All these variants of cotton are affected by Fusarium wilt is of particular concern to cotton growers as the pathogen frequently causes severe economic losses. Another wilt of less importance called Parawilt or new wilt, a physiological disorder cause 5-8% crop loss during specific atmospheric conditions. The details of these atmospheric conditions will be discussed in later part of the chapter. Parawilt is an important constraint identified in Bt cotton hybrids. Parawilt of cotton involves sudden drooping of leaves when irrigation /rainfall applied after a long dry spell (Sarlach *et al*., 2008). It was first reported in 1978 from Adilabad district of Andhra Pradesh on rainfed cotton, but now it is prevalent to varying regimes in many other cotton growing regions.

A huge amount of work has been done to study the cause of the disease. Isolation, pathogen distribution and transmission studies proved that the fungi, bacteria and nematodes were not associated in the occurrence of disease. As observed previously that the Fusarium wilt occurs in groups of plants in the entire field but the parawilt occurs in random distribution (Mayee *et al*., 1990). It took long to prove cause of the parawilt because of uncertainty of its occurrence and its inability to stimulate under artificial conditions. Environmental conditions like high temperature, bright sunlight followed by heavy rain was found to favour parawilt occurrence. Several abiotic agents have been proved as probable cause of the parawilt. On an average parawilt incidence occurs in the range of 3.0 to 9.0% over different period of time. Weather parameters like maximum temperature and sunshine hours were found to be positively correlated while rainfall was negatively correlated with parawilt incidence (Jambhulkar *et al.*, 2014). Parawilt appears soon after rainfall recedes and bright sunshine appears.

Now a days parawilt is being observed in Bt cotton fields of Andhra Pradesh, Telangana, Maharashtra, Karnataka, Madhya Pradesh , Gujarat and Uttar Pradesh. Detailed studies of parawilt in farmers' fields were carried out in different cotton-growing areas and the subsequent successful simulation of this disorder in experimental fields and the detailed research work carried out at Central Institute for Cotton Research (CICR), Nagpur, have adequately established that it is a physiological disorder (Hebbar and Khadi 2006). The study pointed out that there is disturbance in soil-plant-atmospheric continuum due to adverse environmental factors like flooding and soil saturation. High air temperature and bright sun soon after continuous overcast weather accelerate this sudden wilting and its occurrence is much more severe if there is hybrid Bt cotton in the field.

Symptoms

Parawilt developes either slow or quick to cause premature death of top leaves, entire plant dry and collapse. The drooping of leaves appears soon after a continuous and heavy rain recedes and bright sun shine appears. If bright sunshine persists for a few hours, entire plant succumbs to parawilt typically from flowering and boll formation stage of crop. These are the most vulnerable stages of crop. Premature abscission of leaves and fruiting parts may occur. Leaves lose turgidity due to enhanced transpiration (Fig. 1.). After few days entire plant sheds its leaves. The incidence is particularly high in plants with large canopy and heavy boll load. Squares and young bolls are shed and immature bolls are forcefully opened. Wilted plants show development of anthocyanin pigment. Most of the wilted plants gradually recover and produce new flushes, however their contribution to yield is negligible. Under cloudy weather, leaves often turns yellow and die with little or no wilting (Fig. 2). Epinasty appears more on top leaves compared to lower leaves. The parawilt occurs sporadically in the field. All the plants in a row may not wilt. Similarly in a hill, out of two plants, one plant may wilt and the other plant may remain normal. Flowering and squaring are the most vulnerable stages of cotton crop for parawilt incidence (Fig. 3 a,b). Recovery of the parawilt affected plant depends on at what stage parawilt occurs. If the parawilt occurs at early squaring or flowering stage, recovery may occur to certain extent (Hebbar and Mayee 2011).

Fig. 1. Symptoms of Parawilt affected plant

Fig. 2. Parawilt affected plant during cloudy weather

Fig. 3. Most vulnerable stage of crop to parawilt (a) Square formation and (b) Flowering

Severity and yield losses

The incidence of parawilt is more frequently observed in Bt cotton crop. The most probable reason assigned to it that it is a hybrid crop with high vigour. Occurrence of Parawilt is not region specific. In north India, where most of the crops are irrigated, the wilting occurs due to excessive irrigation and late season rains. In central and south India, major region is under rainfed condition. The wilting occurs due to heavy rains in August-October. Sarlach and Kaur (2013) reported 1.5-8.5% incidence in Punjab while Jambhulkar *et al*. (2014) reported 3.4 9.5% incidence of parawilt in southern Rajasthan. The incidence is very less and scattered. Thus there is no report of huge economic loss. But the occurrence of parawilt is still a matter of great concern.

Cause of parawilt

The exact cause of parawilt is still unknown. There is a correlation with the environment for the occurrence of parawilt. Also it occurs usually in a period in which soil environment is unfavourable to root growth. Many Plant Physiologist and Plant Pathologist after years of study established that parawilt is caused by several factors, which leads to poor root development and its function. There are three main factors which are implicated with the cause of this disorder complex i.e. agronomic, weather condition and plant factors. All these factors interact to cause seasonal occurrence of Parawilt. Parawilt occurs in ill drained soils where the soil remains saturated at least for a few hours after rainfall. High air temperature and bright sun shine accelerates sudden wilting. Its occurrence may also depend on the vigour of the plants, apparently being much more severe, if the hybrid cotton is being grown as it grows rapidly. Parawilt is more common and severe on clayey soils because they drain more slowly than sandy soils, but injury sometimes may occurs even on sandy soils, if poorly drained. This suggests that the main pre-requisites are essential for occurrence of parawilt are 1. Soil saturation / water-logging; 2. Grand growth stage of crop; and 3. Bright sunshine and hot air temperature (Hebbar and Mayee, 2011).

Effect of soil saturation and water logging

In waterlogged soils, air in the soil replaced by water and plant roots become deprived of oxygen. Clay soils can become depleted of oxygen after just a short span of 2 days of standing water, especially where soil have high nitrogen levels. Respiration in plant roots hamper when roots become deprived of oxygen, which provides energy and the building blocks for shoot and root growth. Cotton can handle saturated soils for a short period of time; however, plant growth will remain slow and there will be delay in each developmental stage of the crop. Earlier research finding has revealed that under short-term flooding (7 days) leaf growth is decreased by over 25% and photosynthesis by over 15%, while root growth was not hindered little. However, under continued saturated conditions, root growth will also be significantly impacted and may have long-term detrimental impacts on total root growth, root distribution, and yield potential. In saturated soils the air pores are filled with water thus the oxygen present in the pores are replaced by water. It creates anaerobic conditions for root (Fig. 4).

Typically, cotton roots grow 0.5-2 inches per day and its roots system extending 3+ feet deep by the first flower growth stage. Major root growth occurs the first 60 days after germination (Morgan 2015). In waterlogged soils, root growth slowed, and roots tends to proliferate near the soil surface where more oxygen is present. Reduced growth and shallow depth of the roots make plants more susceptible to drought stress and parawilt.

An absence of oxygen usually hampers the root growth and death principally because of (i) demand for ATP exceeds the supply and (ii) self-poisoning by products of anaerobic metabolism. In case of (i) anaerobic roots generate ATP mainly by glycolysis through the ethanolic fermentative pathway. This pathway yields only two ATPs from each glucose molecule, which is only about 6% of the ATP generated by mitochondria-based aerobic respiration. The small yield of ATP in anaerobic cells is insufficient for survival beyond a few hours and decreases the membrane integrity and viability of root cells (Rawyler, 2002). In case of (ii) the most notable toxin being excess protons that acidify the cytoplasm and vacuole; others toxins include acetaldehyde, reactive oxygen species and gases such as ethylene and carbon di-oxide (Felle, 2005).

Fig. 4. Cotton field under saturated soil condition

Physiological processes and their contribution to waterlogging damage

Flooding, excess irrigation and subsequent soil waterlogging usually accentuate rapid decline in photosynthetic rate, ranging from 10 to 90 % in different species (Kozlowski and Pallardy, 1984). Various reasons for hypoxia-induced photosynthetic impairment are reported in the literature. Waterlogging sensitivity of cotton has been strongly associated with photosynthetic inhibition (Najeeb *et al.*, 2015a) and cause a significant drop in the rate of photosynthesis under sustained waterlogging treatments for 72 h, while rates recovered to normal as the soil O_2 status improved (Milroy and Bange, 2013). They showed that the rate of photosynthesis exhibited a degree of acclimation, becoming less responsive to soil O_2 status during the later growth stages (Fig 5). Nutrient deficiency in cotton leaves has been considered as the main reason for the fall in leaf photosynthetic rates. However, there was a lack of improvement in photosynthesis of waterlogged cotton under foliar and soil fertilizer (N, P and K) application (Ashraf *et al.*, 2011; Zhou and Oosterhuis, 2012) suggested that long-distance signaling from roots might explain impaired leaf function; possibilities include hydraulics (e.g. stomatal closure) and hormones (e.g. changes in expression of critical photosynthetic genes, chlorophyll degradation).

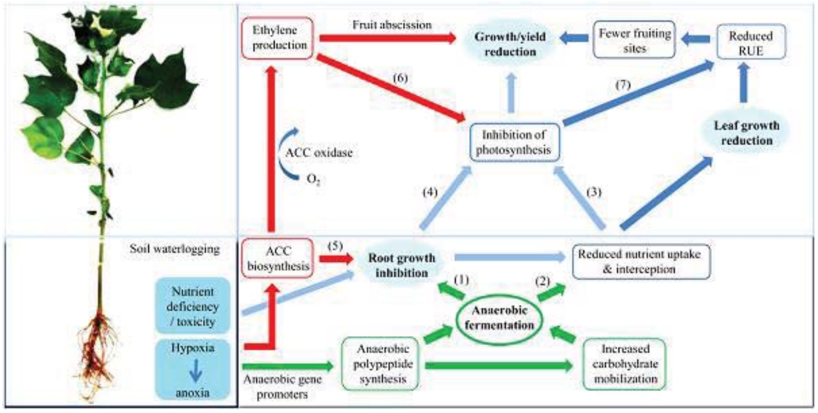

Fig. 5. Changes in cotton growth and yield in response to soil waterlogging. (Najeeb *et al.*, 2015b, AoB PLANTS, Volume 7)

Flows are represented in four categories: green (biochemical pathway); red (hormonal/signalling pathway); light blue (physiological pathways); dark blue (morphological changes). (1) Lower ATP synthesis under O_2 deficiency inhibits root growth (Armstrong and Drew 2002). (2) Reduced plasma membrane H^+-ATPase activity impairs nutrient uptake and interception (3) Limited nutrient transport to leaf tissues damage chlorophyll and photosynthesis (4) Inhibited root growth acts as a negative feedback to photosynthesis by reducing the root carbohydrate demand (5) Higher ACC concentration in root tissues could inhibit root growth (Leblanc *et al.* 2008). (6) Ethylene can influence ABA-induced stomatal dynamic and photosynthesis (7) Inhibited leaf photosynthesis in turn influence biomass accumulation, leaf size, canopy development and overall radiation-use efficiency

Waterlogging cause internal damage to photosystem II (PSII) associated with photoinhibition, independent of stomatal closure. These non-stomatal / metabolic factors include intercellular biochemical reactions, gas diffusion, reduction in CO_2 assimilation rates and quantum yield of PSII.

Global gene expression in cotton leaves due to waterlogging stress

Cotton is sensitive to waterlogging stress, which usually results in stunted growth and yield loss due to parawilt. Low oxygen causes drastic changes in transcription, translation, and metabolite levels. Analysis of Arabidopsis lines over- or under-expressing sucrose synthase 1 (SUS1) and sucrose synthase 4 (SUS4) or the ethanolic fermentation genes alcohol dehydrogenase (ADH) has indicated that these genes are essential for tolerance to low oxygen (Zhang *et al*., 2017).

The induction of hormones under waterlogging stress is involved in signaling cascades, including increases in ethylene, abscisic acid (ABA) and gibberellic acid (GA), and a reduction in cytokinin (CK) and auxin (IAA). ABA is an important signal which can be induced by some abiotic stress in regulating stomatal conductance and photosynthesis and transpiration. An increase in ABA concentration was noted in leaves of flooded alfalfa Castonguay *et al*., 1993; Bai *et al*., 2011 also found an increased ABA content in Malus leaves under hypoxia stress, indicating that ABA is a key signal in mediating responses to waterlogging.

To study molecular mechanisms underlying the responses to waterlogging in cotton. Zhang *et al*., 2017 grown cotton in a rain-shelter and subjected to 0 (control)-, 10-, 15- and 20-d waterlogging at flowering stage. The fourth-leaves on the main-stem from the top were sampled and immediately frozen in liquid nitrogen for physiological measurement. Global gene transcription in the leaves of 15-d waterlogged plants was analyzed by RNA-Sequencing. Seven hundred and ninety four genes were up-regulated and 1018 genes were down-regulated in waterlogged cotton leaves compared with non-waterlogged control. The differentially expressed genes were mainly related to photosynthesis, nitrogen metabolism, starch and sucrose metabolism, glycolysis and plant hormone signal transduction. KEGG (Kyoto Encyclopedia of Genes and Genomes) analysis indicated that most genes related to flavonoid biosynthesis, oxidative phosphorylation, amino acid metabolism and biosynthesis as well as circadian rhythm pathways were differently expressed (Fig. 6). Waterlogging increased the expression of anaerobic fermentation related genes, such as alcohol dehydrogenase (ADH), but decreased the leaf chlorophyll concentration and photosynthesis by down-regulating the expression of photosynthesis related genes. Many genes related to plant hormones and transcription factors were differently expressed under waterlogging stress. Most of the ethylene related genes and ethylene-responsive factor-type transcription factors were up-regulated under water-logging stress, suggesting that ethylene may play key roles in the survival of cotton under waterlogging stress.

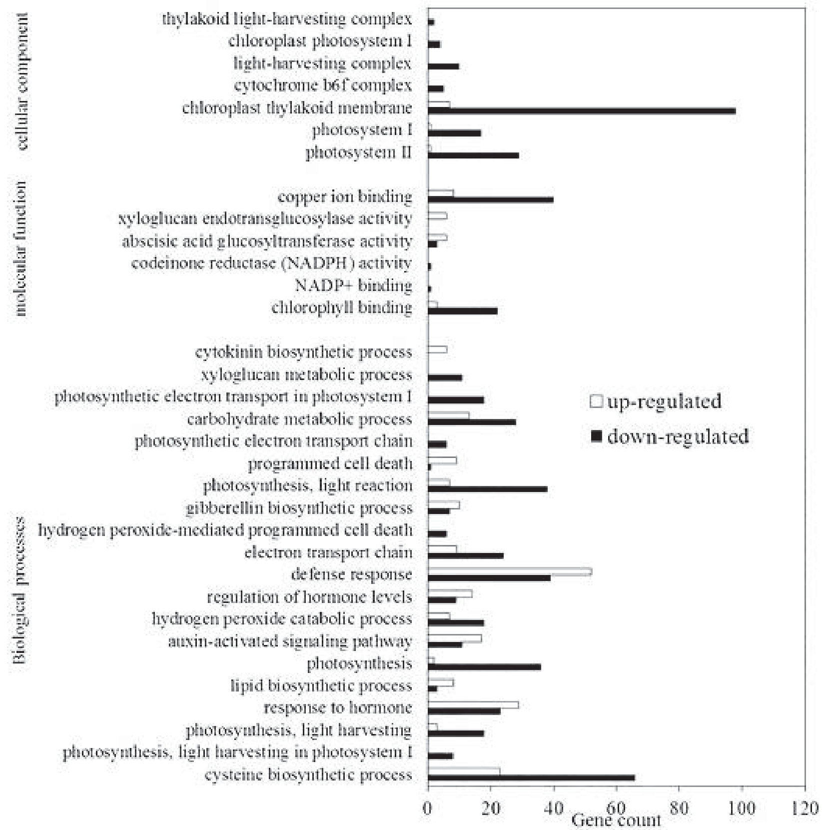

Fig. 6. GO analysis of differentially expressed genes obtained from Solexa sequencing. The abscissa of the bar plot represents the gene count within each GO category. All processes listed had enrichment p values < 0.05. (Zhang *et al*., 2017; PLoS ONE 12(9): e0185075.)

Metabolic responses of water logging

Rapid depletion of oxygen in rhizosphere unbalances soil chemistry and disturbs energy and hormone metabolism, triggering the downstream physiological and biochemical events. Adaptive metabolic responses to these events are natural targets for improved waterlogging tolerance of cotton which can be broadly divided into four groups:

1. Induction of anaerobic polypeptides (ANPs), enabling carbohydrate mobilization and subsequent fermentation.
2. Regulation of intracellular pH and thereby, membrane charge, via changes in transporter activity.

3. Alteration in expression pattern of genes controlling O_2 sensing.

Waterlogging

Gene expression responses in hypoxia involve ethylene biosynthesis, nitrogen metabolism and cell wall degeneration. Up-regulation of common genes has been reported in O_2 deficits in plant taxa covering a spectrum of flood tolerance. These consistent changes suggest that evolutionary 'solutions' to surviving this most challenging of environmental stresses must have their origins in ancient progenitors, often prokaryotic (Müller *et al*., 2001).

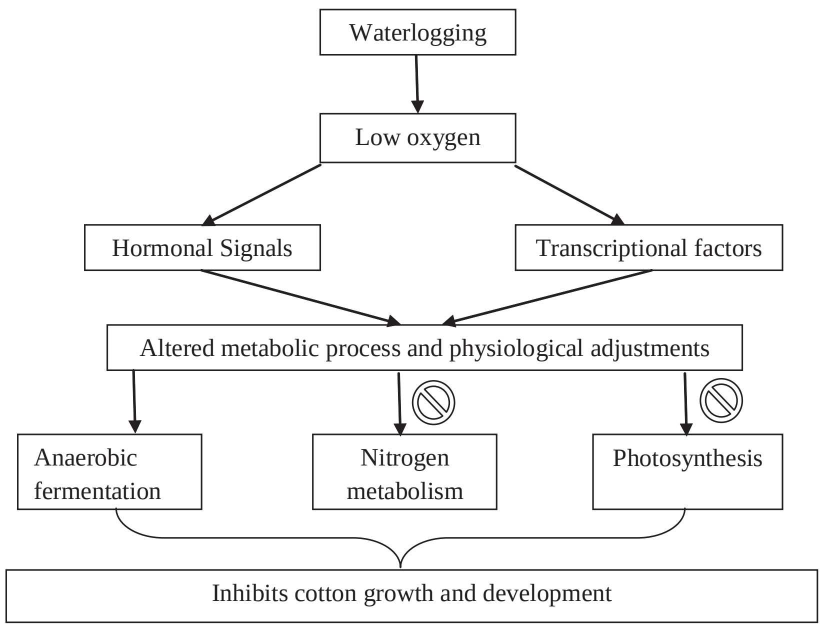

Fig.7. Simplified overview of effect of water logging on plant metabolism

The response of waterlogging stress results in biological change such as reduced photosynthesis and decreased contents of chlorophyll, Nitric oxide, total soluble sugar and protein. Such biological changes in waterlogged cotton were attributed to the decreased expression of photosynthesis related genes, and increased expression of glycolytic pathway and fermentation genes (Zheng *et al*., 2009). Furthermore, the changes in the expression pattern of these genes might be regulated by synthesis and perception of plant hormones like ethylene and GA, and some transcription factors (Fig. 7).

Association between stages of plant growth and occurrence of parawilt

Cotton is a crop with poor tolerance to waterlogging. The number of days of inundation and depth of waterlogging, as well as the growth stage during waterlogging, can affect the growth and development of the cotton and its physiological metabolism, yield and quality. Squaring and flowering stages are most sensitive stages to waterlogging which significantly inhibits the morphological development of cotton, and leaf area growth is subject to the greatest inhibitory effect of waterlogging stress. An experiment was conducted at four growth stages of cotton (seedling, squaring, flowering, and boll opening), and the waterlogging duration at each stage was set to five levels (2, 4, 6, 8, and 10 d) and the waterlogging depth was 5cm. It was observed that waterlogging treatments at the different growth stages reduced the morphological and yield parameters of the cotton plants as well as the physiological parameters of the cotton leaves, and the extent of the reduction in these parameters increased with the extension of the waterlogging duration. It was also observed that waterlogging at different growth stages on the cotton decreased in the order of the flowering, squaring, seedling, and boll-opening stages, and the highest yield reduction rates for the four stages were 38.8%, 27.9%, 18.3% and 7.6% respectively (Wang *et al.*, 2017). Study also inferred that at the seedling stage waterlogging for no more than 6 d allowed the morphological and yield parameters to recover in the boll-opening stage upon timely drainage, and these parameters showed no significant decreases compared with the control level. The critical duration of waterlogging at the squaring stage was 4 d. However, at the flowering stage, even 2 d of waterlogging could lead to the stagnation of morphological development and prevent the recovery of the cotton yield to the control level. Therefore, when waterlogging disasters occur in cotton fields, the implementation of appropriate surface and subsurface drainage schemes for the different growth stages is needed as soon as possible to mitigate the damage (Wang *et al.*, 2017). The cotton plant has high metabolic rate at flowering and boll formation stage. With optimum light, temperature and soil moisture, plants exhibit high transpiration (*T*r), stomatal conductance (*g*s) and photosynthesis (*P*N). There is a strong association between photosynthesis and stomatal conductance and hence, these plants would lose water through transpiration at a faster rate. If water uptake from the soil is not commensurate with the water loss through the leaves, then the plants will wilt. The nutrient uptake through the roots is an active process requiring ATP for respiration and hence, plants with higher root respiration consume the limited O_2 available in waterlogged soil at a fast rate. This lack of O_2 in the root zone causes root injury. Thus, the rapidly growing plants are more vulnerable to flooding injury (Hebbar and Mayee, 2011).

Effect of O_2 deprivation hampers plant metabolism

Soil O_2 deficiency accelerates the biosynthesis of ethylene precursor 1-aminocyclopropane-1-carboxylic acid (ACC) in cotton roots (Christianson *et al*., 2010), which is converted into ethylene upon arrival to the above ground aerated parts. In cotton, elevated ethylene levels induce square and boll abscission. Development of genetic and management techniques that can block ethylene induction or perception are thus of great interest to the cotton industry. Chemical agents [e.g. amino-ethoxy-vinylglycine (AVG), amino-ethoxy-acetic acid (AOA), 1-methyl-cyclopropene (1-MCP) and cobalt and silver ions] regulate ethylene accumulation by blocking its biosynthetic pathway (Najeeb *et al*., 2015a). AVG block ethylene accumulation in leaves and subsequently improved leaf growth, N acquisition and photosynthetic parameters. In addition, AVG increase fruit production of both cotton cultivars under waterlogged and non-waterlogged conditions. Higher ethylene production in cotton is associated with fruit abscission, implying that AVG-induced ethylene inhibition could potentially limit yield losses in waterlogged cotton.

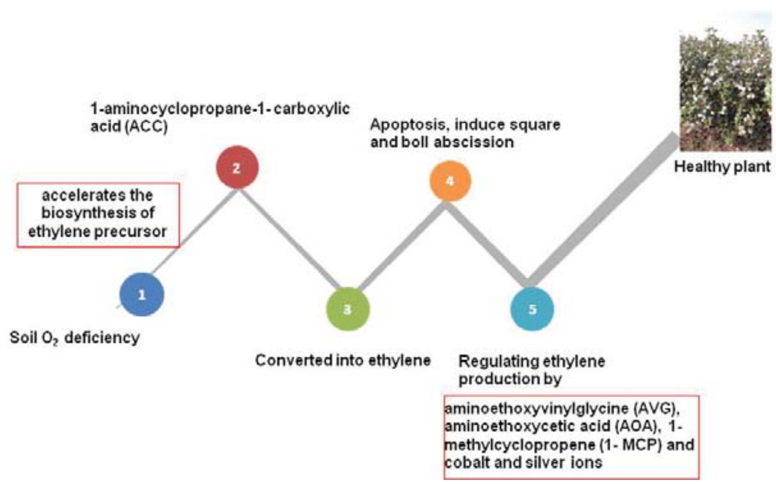

Fig. 8. Amino-ethoxy-vinyl-glycine (AVG), amino-ethoxy-acetic acid, Methyl-cyclopropane cobalt and silver ions ameliorates waterlogging induced damage in cotton by inhibiting ethylene synthesis

Studies suggest that long-term soil waterlogging restricted the N acquisition and promote ethylene accumulation in cotton leaves. Lower concentrations of N in leaves impaired photosynthesis, and thereby inhibit shoot growth, node and fruit development. Waterlogging also accelerate leaf and fruit abscission by inducing higher ethylene production in cotton tissues, while AVG play pivotal role in increasing leaf and fruit retention by blocking ethylene biosynthesis (Fig 8). However, this limited role of AVG on shoot growth and nutrient uptake of water logged cotton suggests that blocking ethylene biosynthesis alone is not adequate to mitigate waterlogging tolerance in cotton (Najeeb *et al*., 2015b). Therefore, an integrated approach of soil and fertilizer management along with AVG application could be more effective in ameliorating waterlogging-induced damage in cotton.

Other ethylene inhibitor includes silver nitrate $AgNO_3$ and Cobalt chloride $CoCl_2$. $AgNO_3$ acts by reducing the receptor capacity of plant to bind ethylene, by inducing somatic embryogenesis and by promoting efficient shoot and root formation, by improving callus formation and promoting root formation. While cobalt chloride acts by inhibiting the activities of ACC oxidase and reduces ethylene production, by increasing growth of seedlings that alleciates the senescence, by increasing fresh and dry weight of leaves and roots, promotes plant height and number of leaves per plant.

Impact of bright sunshine soon after prolonged overcast/cloudy weather

Continuous rains saturate the soil and a bright sunshine soon after a prolonged overcast cloudy weather leads to sudden wilting of vigorously growing cotton plants. The high intensity of sunlight accentuates photosynthesis in cotton crop. Cloudy weather slowes down the photosysnthesisrate and crop growing in shade or cloudy overcast weather will not get sufficient light for plant growth, thus there will be less stomatal conductance, transpiration and photosynthesis. Conversely sudden wilt occurs under bright sunlight in which plant will have high stomatal conductance, transpiration and photosynthesis. It leads to higher O_2 requirement for respiration but under saturated soil condition there is absence of O_2 in air pores in soil which leads to anaerobic respiration thus generate only 2 ATP which will cause shock to the plants thus succumb to the rapid injury.

There is relationship between weather variables and incidence of parawilt in Bt cotton crop. It has been previously shown that although correlations exists between incidence of parawilt and weather variables, the nature of conditions influencing these correlations depends on the environmental characteristics of the specific region (Rotem, 1994). Jambhulkar *et al*. (2014) studied influence of weather parameters on incidence of parawilt. They observed that parawilt incidence showed strong positive correlation with maximum temperature and sunshine hour while rainfall has negative correlation. They reported that temperature and sunshine hours equally contributes for the incidence of parawilt at every 1^{o}C and 1 hr increase in maximum temperature and sunshine hours respectively. The simple regression model equation developed individually for each variable showed coefficient of determination (R^2) of 34.9% for temperature, 49.0% for rainfall and 58.5% for sunshine hours but when the pooled data was analysed to develop multiple regression model the prediction of parawilt can be done with more accuracy of 60.3% . This suggests that these variables viz. maximum temperature, rainfall and sunshine hours collectively decide the incidence of parawilt in Bt cotton.

Management

Management of parawilt is possible only when there will be better regulation at above-ground level so as to keep the soil–plant–atmosphere continuum intact under higher incidence of extreme rainfall events as projected by the scenarios of climate change. The major issues need to be taken care of while managing incidence of parawilt are: 1. Irrigation management. Excess irrigation at any stage of crop must be avoided because over irrigating in the early life of a crop forces the roots to grow on the surface and can support the plants till flowering. At flowering, the demand of more moisture and the tendency to apply more irrigation water results in soil anaerobiosis which in plants with shallow roots, leads to sudden wilt. Over irrigating, under hot and bright sun, particularly at flowering and early boll set, should be avoided. Accurate management of irrigation is essential to minimize the disorder. 2. Proper drainage: Cotton crop mostly grown in black cotton soil which has high amount of clay. Such soils have a tendency to absorb and retain more water. Cotton crops grown in well-drained soils are less at risk of developing parawilt than those grown in poorly drained soils.

As discussed in previous paragraph that there are some ethylene inhibitors like aminoethoxyvinylglycine (AVG), aminoethoxycetic acid (AOA), 1-methylcyclopropene (1-MCP) and cobalt and silver ions does inhibit ethylene production.

Accumulation of ethylene induces growth abnormalities of *in vitro* generated plants including inhibition of growth, leaf epinasty, leaf senescence and diminution of foliar area (Hazarika, 2006; Steinitz *et al*., 2010). Ethylene was reported to be important for shoot morphogenesis in rice callus (Adkins *et al.*, 1990) and embryogenesis from anther cultures of *Hordeum vulgare* (Cho and Kasha, 1989). In contrast, ethylene accumulation was found to inhibit *in vitro* regeneration of several plant species (Gong and Pua, 2004). In fact, addition of ethylene inhibitors such as silver nitrate (AgNO3), cobalt chloride (CoCl2), amino-oxy-acetic acid (AOA) and aminoethoxyvinylglycine (AVG) to culture media have been demonstrated to improve regeneration and growth performance of both dicot and monocot plant tissue cultures (Sandra and Maira, 2013; Tamimi, 2015).

A recommendation was made to farmers to use spray of cobalt chloride (10 ppm) on parawilt affected plants. Cobalt (Co), a transition element, is an essential component of several enzymes and co-enzymes. It has been shown to affect growth and metabolism of plants, in different degrees, depending on the concentration and status of cobalt in rhizosphere and soil. It also promotes the growth of seedlings and alleviates the senescence of aged tissues as it inhibits the activities of ACC oxidase and reduced ethylene (ETH) production. Toxic effect of cobalt on morphology include leaf fall, inhibition of greening, discolored veins, premature leaf closure, and reduced shoot weight. Being a component of vitamin B_{12} and cobamide coenzyme, Co2+ helps in the fixation of molecular nitrogen in root nodules of leguminous plants. The beneficial effects of cobalt include retardation of senescence of leaf, increase in drought resistance in seeds, regulation of alkaloid accumulation in medicinal plants and inhibition of ethylene biosynthesis. Co is an inhibitor of 1-aminocyclopropane 1-carboxylic acid (ACC) oxidase and does inhibit ETH production (Locke *et al.*, 2000). At low concentration Co significantly increased shoot and root length and did not influence shoot and root dry weight, whereas higher Co concentrations resulted in a considerable decrease of shoot and root length as well as shoot and root dry weight (Abdul Jaleel *et al.*, 2009). Co at high levels may inhibit root and shoot growth directly by inhibition of cell division or cell elongation or a combination of both, resulting in the limited exploration of the culture medium volume for uptake and translocation of nutrients and water and induced mineral deficiency (Hemantaranjan *et al.*, 2000). As the stress continued, lipid peroxidation and chlorophyll damage in the leaves of potato seedlings became aggravated. Furthermore, treatment with cobalt alleviated the lipid peroxidation, the reduction in chlorophyll content, and cell membrane damage. These results showed that cobalt alleviated leaf damage as the osmotic stress was aggravated.

Conclusion

Conclusively waterlogging stress accompanied with other weather parameters resulted in a number of biological changes in cotton crop such as reduced photosynthesis and decreased contents of chlorophyll, total soluble sugar and protein etc. make plant succumb to a wilting condition. A plant can sustain few days of water logging but when waterlogging disasters occur in cotton fields, the implementation of appropriate surface and subsurface drainage schemes for the different growth stages is needed as soon as possible to mitigate the damage. Study showed that there are many ethylene related genes upregulated and down regulated suggesting that ethylene may play a key roles in the survival of cotton under waterlogging stress. Ethylene inhibitors like AgNO3, $CoCl_2$, AVG and AOA may be used as important tools for protecting cotton crop from negative effects of ethylene in fields.

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