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Determining the prominent factors contributing to the occurrence of sudden wilt in upland cotton (*Gossypium hirsutum* L.)

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ABSTRACT: The occurrence of sudden wilt problem in cotton in north India is increasing since the last one decade. Hence, to understand the factors responsible for sudden wilt, field data were collected from July to November during 2017-2018 and 2018-2019 from Rajasthan, Haryana, and Punjab. Among all, 29.7 per cent of cotton fields showed typical sudden wilting from September onwards during 2018-2019. In these fields, no deep ploughing, cotton-wheat-cotton cropping system more than the past 5 years, and early irrigation (before 30 DAS) was practiced. The soil EC and pH in these fields ranged between 2.5 to 4.5 dS/m and 7.6 to 7.9, respectively. The root depth in these fields was ranged between 100-200 mm with higher root density in the first 100 mm layer 21-50 per cent fields and 200-300 mm root depth in 50-67.5 per cent fields. These practices and soil health situations appeared to be the prominent factors contributing to the poor root development and occurrence of sudden wilt at the great grand growth stage of the cotton crop (125-160 DAS). Comparatively, sudden wilt was found to be more prominent in early maturing and high yielding *Bt* hybrids (BG-II) compared to *Gossypium hirsutum* varieties. This situation also enhanced the vulnerability of cotton crops to biotic problems such as root rot, nematodes, fungal foliar spots (71.4 %) and termites/root rot (28.6 %). Hence, to manage the sudden wilt problem and to achieve the potential yield, a large and deep root system must be developed as quickly as possible and shoot growth should be controlled before the plants enter the reproductive growth stage.

Key words: Causative factors; *Gossypium hirsutum*; Cotton; sudden wilt occurrence

Apart from the soil-borne fungal, cotton leaf curl virus diseases (CLCuD) a physiological disorder sudden wilt known as parawilt is a rising threat to cotton production both in north and central India. The sudden wilt was first reported in 1978 in an intra/hirsutum hybrid JKHY-1 from Adilabad district of Andhra Pradesh in India, which later called as mysterious wilt, new wilt, sudden wilt, parawilt, *etc.* Past studies have established that in sudden wilt the soil–plant–atmosphere continuum is broken due to adverse environmental factors like soil saturation/waterlogging, which results in poor root-growth, and slowing of oxygen influx is the principal cause of injury to roots and the shoots. During waterlogging situations, the rate of water intake by roots is declined by 60 per cent within one hour of flooding, as the primary roots and root hairs are damaged soon after flooding, the roots cannot survive more than 30 min of O_2 deficiency. Later in 1995 'xylem emboli' were observed in wilted plants, which generally occurs under extreme water-deficit stress or freezing conditions. The important preconditions for sudden wilt occurrence in cotton plants are its great grand growth stage together with bright sunshine, which enhances stomatal conductance, transpiration and photosynthesis. The high transpiration loss of water in a fully grown plant requires more uptake of water and nutrient, however, damaged or poor root system function under waterlogging results in the collapse of the soil–plant–atmosphere continuum. Thus, the inconsistency between the uptake of water through roots and loss of water through leaves transpiration results in sudden wilt in cotton. Its occurrence of sudden wilt may also depend on the growth condition of the plants, as it is much more severe at the rapid growth stages of cotton plants (Hebbar and Mayee, 2011).

Such types of problems have also been reported in the north Indian cotton-growing zone where the field situations are different from central India and generally, waterlogging/soil saturation conditions do not arise, besides heavy rainfall or heavy flood irrigation. The soils of the central and south zone are mostly black basalt and red soil with less to medium organic carbon, a large amount of clay, and humus. While in north zone, soils are alluvial with silt, clay, sand, gravel, and less organic carbon level. This indicates that the situations reported on the occurrence of sudden wilt in previous studies could be different under the north zone environmental conditions. There may be some other factors, which are responsible for the appearance problem in cotton in north India, which is creating the disparity between the uptake of water through the roots and transpiration loss of water through the leaves. Moreover, there may be some issues related to soil health and cultural practices (soil-plant root interactions) which may ameliorate such a situation to occur sudden wilt under field conditions in the north cotton growing zone. Till now, the conditions which are enhancing such a situation to occur sudden wilt particularly at its great grand growth stage during August –September (120-160 DAS) are still not much clear. Hence, this study was conducted to determine the area under sudden wilt problem, understanding the field situations and cultural practices which are ameliorating sudden wilt in north Indian cotton-growing areas.

MATERIALS AND METHODS

Survey and data collection: To collect the data on parawilt/sudden wilt incidence in Rajasthan (Hanumangarh, Sriganganagar), Haryana (Sirsa, Fatehabad, Hisar) and Punjab (Mansa, Abohar, Bathinda). The field survey was conducted in 50 farmer's fields in each district (2-3 villages) from July to November 2017 and 2018. The incidence of sudden wilt and root rot was observed from randomly selected 100 plants across a diagonal in each of the fields. Fields were kept under observation throughout the growing season. The disease incidence was assessed based on plants affected in the sampled area. The root length and root volume of randomly selected plants were measured.

The data on the cropping history, problem/disease history, soil type, soil organic carbon level, soil pH, EC, cropping sequences, field preparation practices, irrigation timing and frequency, soil health management practices, cultural practices, and the crop management practices in the randomly selected fields and their results were also collected. The data were pooled and probability analysis was done to correlate the problem and the basic or preliminary cause was depicted in the percentage.

RESULTS AND DISCUSSION

The root rot incidence during 2017-2018 was ranged between 0 to 75 per cent in Haryana and 0 to 15 per cent in Rajasthan and 0 to 5 per cent in Punjab. However, wilting type problems were observed in those cotton fields which were observed also with root rot and nematode infection (28.3 %), root rot (15.8 %), root rot and termites (7.2 %), and fungal foliar spots (26.5 %) (Fig. 1).

Among all, 57.7 per cent of farmers' fields followed the cotton-wheat-cotton cropping system in the past 5 years or more. In 46.2 per cent of fields, farmers did not apply FYM/manure, 38.5 per cent practiced deep ploughing, and laser leveling was adopted for the last five years or more in 84.4 per cent fields. The cotton root system in 50 per cent fields was observed with poor growth (100-200 mm soil layer) and in 50 per cent fields, it was with medium growth (300-400 mm soil layer). In addition to the poor growth (100-200 mm soil

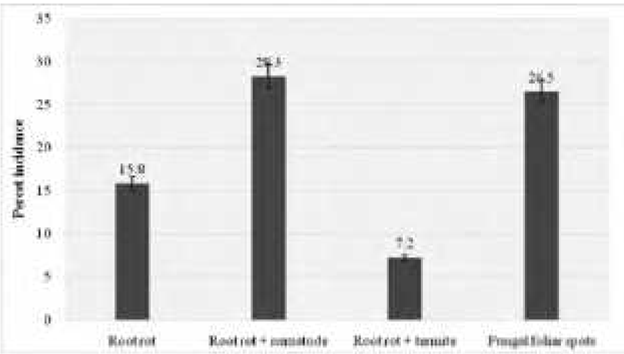

Fig. 1. Percentage of incidence of different problems resembling sudden wilt (2017-2018) Error bars represent the standard error of the mean total mortality.

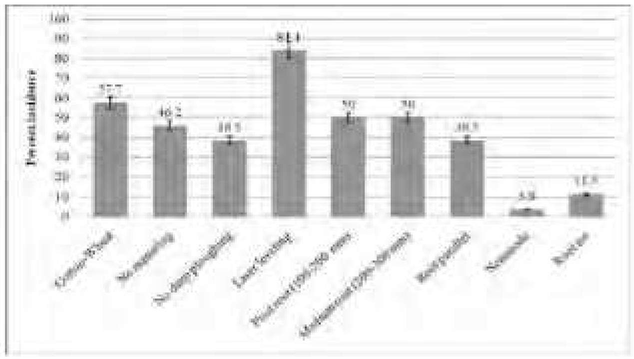

Fig. 2. Percentage of incidence of different problems resembling sudden wilt (2017-2018) Error bars represent the standard error of the mean total mortality.

layer), the parallel roots were also observed between 100-150 mm soil depth in 38.5 per cent cotton fields (Fig.2).

During 2018-2019, survey data from farmer's fields indicated that 94.6 per cent of farmers have not done deep ploughing since last 5 years or more, 70 per cent of farmers were following cotton-wheat-cotton cropping system, 48.6 per cent of farmers have applied the first irrigation before 30 days against the recommendation (45-50 days after sowing). Among these, 35.1 per cent of farmers have followed all three practices- *i.e.* cotton-wheat-cotton cropping system, no deep ploughing and early irrigation in the last five years or more. 20.7 per cent of farmer's fields had the soil hardpan conditions, 11 per cent have followed the cotton-mustard-cotton cropping system. About 5.4 per cent of fields were with high soil moisture as the cotton fields were nearer to paddy growing areas/fields. Such fields also had the biotic problems like root rot and nematode infection (32.4 %), root rot (10.8 %), root rot and termite (8.1 %) and fungal foliar spots (24.3 %) during the later stage. Among all, 29.7 per cent cotton field was observed with the typical sudden wilting problem during September onwards. Also, the sudden wilting situation was more prominent in early maturing and high yielding *Bt* hybrids (BG-II) during the first fortnight of September. Out of all, only 10.8-11.0 per cent farmers field crops were healthy and in such fields, farmers have adopted crop rotations with cluster bean in place of cotton, crop residue incorporation, deep ploughing, timely irrigation (45-60 DAS), appropriate nutrient management etc. which ultimately resulted in better crop with a deep-rooted system (>300 mm) (Fig. 3).

The 29.7 per cent cotton fields observed with sudden wilting type problems, were observed to be with no deep ploughing, cotton-wheat-cotton cropping system for the past 5 years or more, and early irrigation (before 30 DAS). The soil EC and pH in these fields were ranged between 2.5 to 4.5 dS/m and 7.6 to 7.9, respectively. In these cotton fields, the root system was observed to be with poor growth (less than 200 mm). These practices and soil health situations appeared to be the main reasons for parawilt/sudden wilt followed by the enhanced vulnerability of cotton crop to biotic problems such as root rot, nematodes, fungal foliar spots (71.4 %), and termites/root rot (28.6 %) (Fig. 4). The researchers in the past have found 'xylem emboli' in wilted plants, which generally occurs under extreme water-deficit stress or freezing conditions. As, during August – September cotton plants remain at its great grand growth stage together with bright sunshine (after the

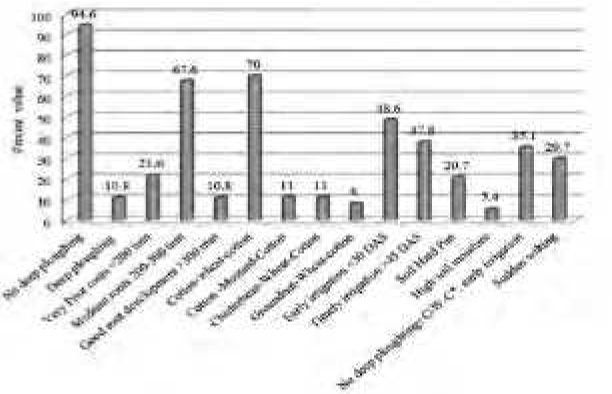

Fig. 3. Percentage of different cultural practices being followed by and the problems being faced by cotton farmers (2018-2019) (*C-W-C= Cotton-wheat-cotton)

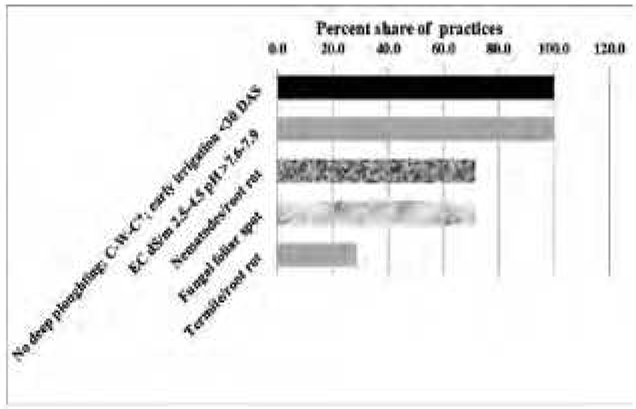

Fig. 4. Predominant factors found to be responsible for sudden wilting in cotton fields (*C-W-C= Cotton-wheat-cotton)

rainy season ends) (Hebbar and Mayee, 2011). This situation when the plant requires more water and nutrition at its boll development stage and at the same time dry season forces enhanced stomatal conductance, transpiration, and photosynthesis. Thus, the discrepancy between the uptake of water through roots and loss of water through leaves transpiration causes sudden wilt in cotton.

As, it is well understood that, the root growth in cotton (total root length) increases as the plant develops until fruiting begins. The total root length reaches a peak at peak plant height and reproductive growth commences *i.e.* onset of flowering (Mai *et al.*, 2012). Although the nutrient and water requirements of cotton plants will be lower during advanced growth stages, it is still necessary to maintain relatively high root activity for normal boll opening and to achieve a high yield. The root length then begins to decline as plant height stays the same and older roots die. From 120 DAS to 160 DAS, the root length decreases in the 0–100 mm soil layer and decreased significantly in the 200–400 mm layer. The root length in 0–100 mm layer declines under flood irrigation from 125 to 160 DAS, but in 400–600 mm soil depth roots continue to grow, and thus the root system can compensate for the decline in root density in shallow soil layers (Mai *et al.*, 2012). Our results are not in contrast with the results of other researchers. The fields which showed typical sudden wilt problems were observed with shallow rooting (less than 100-200 mm deep) and lateral roots on top (less than 100 mm deep).

Cotton roots are more sensitive to increased soil strength than other crops. The depth of penetration of main and lateral roots may vary according to the variety, soil type, soil water content, and other soil and plant-related factors and conditions. In the present study, the root depth in the affected fields was ranged between 100-200 mm with higher root density in the first 100 mm layer in 21-50 per cent fields and 200-300 mm root depth in 50-67.5 per cent fields. This may be due to the continuous adoption of the cotton-wheat-cotton cropping system, low organic carbon, and no deep ploughing which increases soil compactness. Moreover, the late sowing crops (after 15 May) face the raised soil temperature which may harm proper root development. The optimum soil temperature for cotton root growth is somewhere between 28 °C and 35 °C. The overall rate of cotton root elongation is reduced, more branching will occur and enzymatic activity and metabolism are reduced at high temperature. The early and frequent irrigation (before 45 DAS) enhance more number of fine lateral root system during the early growth phase and ultimately reduced the main tap root system and this is more in shallow soils. The roots of cotton are also sensitive to nitrogen stress and high nitrogen fertilizer reduces root length (in 0-400 mm layer), root surface area, volume, and diameter and stimulated the growth of the above-ground parts (Min *et al.*, 2014; Xu *et al.*, 2015). Consequently, the poor root development with decreased root depth during the early stage may not be able to maintain the balance between uptake and the requirement of water and nutrients of the plant for its reproductive activities and leads to sudden wilting at their grand growth phase. During our study, we also observed that the farmers who followed continuous cotton-wheat-cotton cropping system, no deep ploughing, non-incorporation of crop residue, or manure application followed by early irrigation in the fields were found to be the main cause for poor root development. We also observed that these activities are found to be responsible for poor soil health (soil hardiness, poor aeration, low organic carbon, etc.). The early irrigation (~30 DAS), and hard soil pan (near 100-150 mm soil depth) were found to force the roots to remain shallow and induce parallel growth.

The decline in cotton root length during advanced growth stages under shallow cultivated soils might also partly reflect the local accumulation of salt (bore well water). Soil salinity is a dominated factor affecting cotton above-ground dry mass, root development, and K uptake. We have also observed that problematic fields had naturally high salt content (EC 2.5 to 4.5 dS/m, pH 7.6 to 7.9) in the 0-100 mm layer which may also contribute to the reduction of water and nutrient uptake by the plants. The salt content of the tillage layer (0–300 mm) decreases because it is maintained in a moist state, but soil salt migrates and accumulates below the tillage layer. Seed dry weight is reduced by 22, 52 and 84 per cent when the soil salinity level increased from a control level of 2.4 dS/m to 7.7 dS/m, 12.5 dS/m and to 17.1 dS/m, respectively (Chen *et al.*, 2010). Both cellular and metabolic processes involved in osmotic stress due to salinity are similar to those due to drought. More squares and bolls develop at the later plant growth stage, greater quantities of nutrients and carbohydrates will be transported to the reproductive organs, whereas carbohydrate supply to the roots will be reduced. Together with increased root degradation by rhizosphere insects and parasites, the decline in root biomass would more rapid because of greater fine-root formation under early irrigation and or drip irrigation. The increased root degradation may also be one of the reasons for increased virulence of the week plants for root rot, termite, and fungal foliar spots.

The use of cobalt chloride @10 µg/mL in Punjab (Sarlach and Kaur, 2013) which is known to inhibit the biosynthesis of ethylene. But, once the plants are affected by parawilt, cobalt chloride treatment is not showing much recovery in many fields. Also, ethylene production in the parawilt affected cotton plant did not have sufficient experimental proof to confirm that it could be the primary causative agent of parawilt in waterlogged areas (Hebbar and Mayee, 2011). However, the present study indicates that the crucial factors especially soil health management and cultural practices being adopted for the development of root systems coinciding with shoot growth, which can be the precursors (belowground interaction) of these later physiological conditions and biochemical changes. Moreover, long-term use of frequent irrigation or early irrigation can cause negative impacts on the development of root systems and reduction in taproot length and density of root growth in the shallow soil layer. In the present study, it was recorded, that development of the root system is affected by cropping system, soil compaction, soil aeration, soil salinity, quality, time and

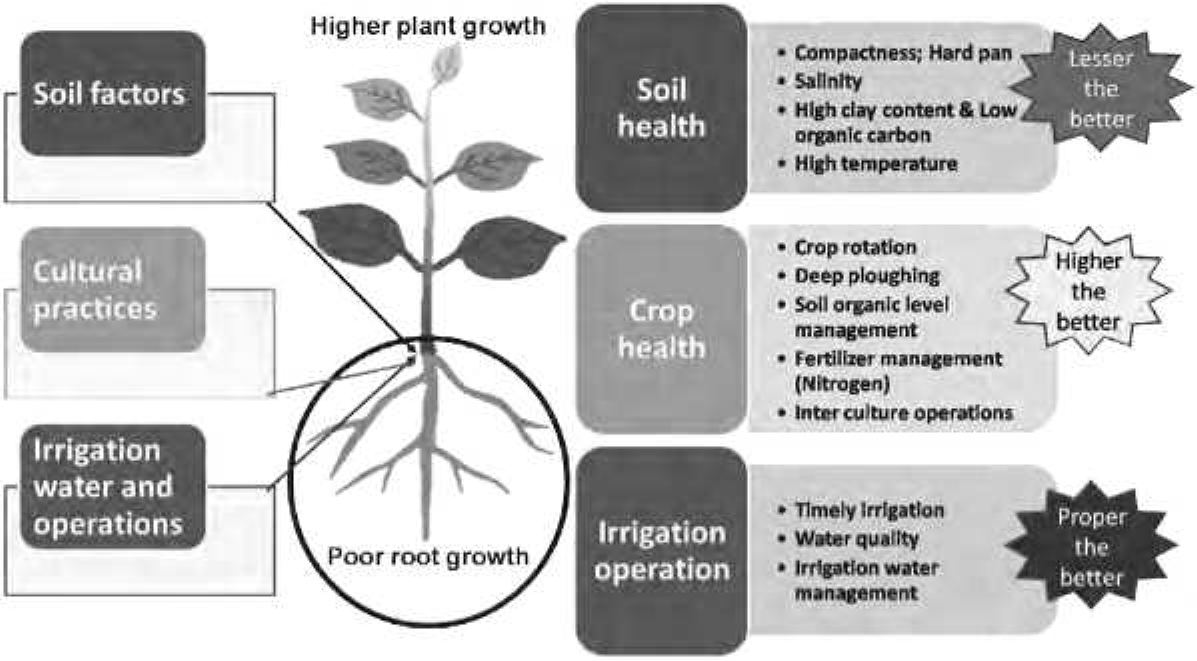

Fig. 5. Prominent factors contributing imbalance between below and above ground growth (sudden wilt) and vice versa

frequency of irrigation water, cultural practices, fertilizer application, etc. Lack of these practices result in poor root development (100-300 mm) and sudden wilt like problems and or increased other biotic problems. Late sowing (After mid-May) coupled with early and frequent irrigation also results in poor root development (100-300 mm) with higher density in 50-100 mm may cause an imbalance between the uptake and loss of water and nutrients at 125-140 DAS. Moreover, the heavy application of nitrogen fertilizers during the early growth stage reduces root growth and enhances shoot growth. The early and frequent irrigation with saline water with poor soil aeration enhances the soil compaction which results in poor root growth, reduces taproot length, and increases root density in upper soil layers (parallel roots). Sudden wilt tolerant cotton cultivars have been reported to have a positive association with root volume and depth, as it would get O_2 from larger areas (Hebbar and Mayee, 2011). Hence, well developed deep root system prevents reliance on the absorption of nutrients and water from shallow soil layers, and at advanced growth stages, even under stressful conditions such as drought/saturation stress, low temperature and it will enable the plant to utilize nutrients and water in deep soil layers.

CONCLUSION

In conclusion, it is essential to stimulate root development in deeper soil layers (400-600 mm) to maintain the vitality of the root system during advanced growth stages, and so that the nutrient and water needs of the shoots can be met. Well developed deep root system not only prevents reliance on the absorption of nutrients and water from shallow soil layers but at advanced growth stages and even under stressful conditions. The excessive shoot growth with excess application of N fertilizers are responsible for declining root systems; hence, carbohydrate allocation during early growth and development should be regulated to promote root growth. Moreover, poor soil health, continuous cotton-wheat-cotton cropping system, low organic carbon, poor water quality, early irrigation, excessive N fertilizer application, and inadequate cultural practices, etc. are some of the factors responsible for poor root development. To achieve the development of a healthy root system, the cultivation of cotton should focus on the following two aspects (Fig. 5). First, a large and deep root system should be developed as quickly as possible, and shoot growth should be controlled before the plants enter the reproductive growth stage. Secondly, site- and cultivar specific management strategies need to be taken into consideration to optimize balanced plant growth, better crop health, and productivity. Furthermore, management strategies should be flexible to allow for changing environmental conditions.

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