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Defoliants Harvest-aid Chemicals: Cost Effective Technology to Facilitate Synchronized Maturity for Mechanical Harvesting in Cotton: A Review

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ABSTRACT

In the recent years, increasing labour cost and shortage of labour being the major constraints to follow manual harvesting in cotton in staggered manner. Further, it is very expensive and farmers would like to increasingly opt for mechanical harvesting. In this context, it is suggested that research should focus to reduce cost of cultivation substantially by promoting the use of synchronized maturity in cotton and use of defoliants to encourage mechanical harvesting. In agriculture, defoliants are used to eliminate the leaves of a crop plant so that they do not interfere with the harvesting by machinery. Early harvesting with good boll opening can also be achieved by use of defoliants. The use of defoliants also reduces the trash content in picked cotton which will also help in improving the quality of cotton. There is a need to identify suitable defoliant with suitable dose and time of application so as to facilitate mechanical harvesting in rainfed cotton. Some of the successful defoliants for uniform boll bursting and higher yield of cotton such as rthrel, rthepon, mepiquat chloride (MC), sodium salt and DU (Dropp Ultra) are the hormonal defoliants and TDZ thidiazuron, butifos, merphos, tribufos and tribufate are the herbicidal defoliants. The best combination of thidiazuron + diuron (DCMU), pyraflufen ethyl, thidiazuron + diuroncellular isozyme, Ethephon + AMADS, ethephon + cyclanilide ethephon + tribufos Mepiquat chloride (MC) + cyclanilide may be recommended to facilitate mechanical harvesting in cotton.

Key words: Cotton, Defoliants, Mechanical harvesting.

Defoliation is shedding of leaves that usually occur when the leaves become physiologically mature. Leaf shedding (abscission) results from activity of special cells in the abscission layer at the base of the leaf petiole where it joins the stem. Several factors like frost, disease, drought and mineral deficiency cause defoliation. It also can be artificially induced by the use of certain chemicals called “defoliants”. Desiccation is drying of plant tissues due to disruption of cell membranes and rapid loss of moisture, often resulting in “stuck leaves”. Defoliants or desiccators are widely used in crop production. There are many categories of defoliants. Hormonal defoliants enhance ethylene production and / or inhibit auxin transport in the plant (Gwathmey and Craig, 2007). The foliage does not dry or abscise when mature. This is the major limiting factor in mechanical harvesting. Hence, plants must be defoliated to facilitate mechanical harvesting. Moreover, it aids in the addition of organic matter to the soil through leaf fall before harvesting (Singh and Singh, 2011).

Crop senescence and defoliation are encouraged most heavily by a substantial harvestable produce load. This helps to complete the maturation of the harvestable produce, but it also makes the leaves easier to remove with a defoliant. In order to conduct an effective defoliation, it is important to consider the biological development of cotton in a field, plant density, irrigation norm, nutritional factors to provide efficiency of defoliation (Fatullateshaev and Khaitov, 2015). Defoliation at proper timing involves balancing the value of potential yield increases and losses with possible alterations in fibre quality and possible discounts (Sarlach *et al.,* 2010).

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With the advent of mechanical harvesters, cotton defoliation techniques were studied and practised. Several chemicals are employed as defoliants including some of the herbicides. Defoliation not only facilitates early harvest by machines but also has certain advantages. Just prior to harvest, defoliation is done to permit aeration and sunlight which are important for normal boll opening. Besides, while harvesting kapas the admixture levels of dust and trash and

staining can be reduced. In short the quality of cotton will be better.

Chemical defoliants are successful under certain situations. They are more effective on cotton grown under certain situations. They are more effective on cotton grown under irrigation and when the fruits are well developed. Mature leaves react favourably and desired level of defoliation is possible, when day and night temperatures are higher. Calcium cyanimide was initially used in the form of dust but it is expensive and difficult to handle and hence and hence not recommended. Others chemicals such as monosodium cynamiode, pentochlorophenol (PCP), potassium cyanate, sodium chlorate, 2,4-D (at lower concentrations) and others have been found to be useful. These care expensive and requires cautious handing. Atpresent, the use of contact herbicide and common salt may be recommended to the farmer. Both are less expensive as to handle and desired effects are possible. Since mechanical harvest is not in vogue in india at present and as our varieties are mostly not suited for mechanical harvesting, these defoliants have limited use (Nerkar *et al.,* 2017).

Importance of defoliants on crop production

Defoliants are any substance or mixture of substances intended for causing the leaves or foliage to drop from a plant, with or without causing abscission. Plant defoliation does not hasten maturity; for maximum yield and crop quality potential, defoliants should not be applied until physiological maturity. Defoliants function in several primary ways, both resulting in more rapid development of abscission layers. The abscission layer is the zone where leaf petioles meet stems. Once adequately formed, leaves drop from the abscission layer. Several defoliants do not target green tissue destruction, but promote the formation of the abscission layer directly, resulting in leaf drop. The activity of a defoliant is favored by warm temperatures, particularly greater than 50°F (Fishel, 2015). Early defoliation can be critical in maximizing yield. Delaying defoliation increases the risks of yield loss due to damaging early frost and late season rainy weather, both of which are possible in the cotton growing areas (Bange and Milory, 2001).

Plant growth regulators are products largely employed in agriculture to influence specific aspects of plant growth and development and harvest aids are used to induce a faster defoliation, desiccation, fruit maturation and regrowth suppression (Logan and Gwathmey, 2002). Defoliation describes a management practice which aids formation of abscission layer in the leaf petioles and results in the desiccation or shedding of foliage earlier than would have naturally (Bange *et al*., 2008).

Hormonal defoliants are a type of harvest aid chemicals that mimic the natural process of defoliation or leaf abscission. Ethephon is an example of chemical that is commonly used in cotton as a pre harvest aid treatment to induce defoliation and enhance boll opening (Morgan, 1969). Ethephon is applied to the under alkaline conditions producing ethylene, phosphate and chloride ions (Yang, 1969). Ethylene is the main hormone that promotes abscission by inducing the productions of various cell wall hydrolysis in the abscission zone to stimulate cell wall breakdown and even total shedding (Campillo and Lawis, 1992; Sexton and Roberts, 1982).

Defoliation is a natural physiological process which usually is inadequate or not timely enough for a complete mechanical harvest. Therefore, defoliation is often induced to manage the crop so that senescence, abscission layer development and leaf drop are encouraged. Cotton, being an indeterminate in growth habit, produces stems and leaves continuously along with the reproductive development. At boll bursting stage, the defoliants can be used to encourage the process of defoliation. One of the most important benefits from defoliation is improved harvest or picking efficiency (Kumari *et al.,* 2013). In agriculture defoliants are used to eliminate the leaves of a crop plant so they will not interfere with the harvesting by machinery. Defoliant, any one of several chemical compounds that, when applied to plants, can alter their metabolism, causing the leaves to drop off (Fishel, 2015).

If cotton is defoliated too early, yields can be compromised significantly because boll development is incomplete, whereas delayed defoliation allows immature bolls to develop and potentially enhancing yields. Early harvesting with good boll opening can be achieved by use of defoliants. The use of defoliants also reduces the trash content in picked cotton which will also help in improving the quality of cotton (Snipes and Baskin, 1994). In India, with continuously increasing labour cost, farmers find manual harvesting of cotton very expensive and they would like to increasingly opt for mechanical harvesting. Singh and Rathore (2015) also suggested that research should focus to reduce cost of cultivation substantially by promoting the use of synchronized maturity varieties, defoliants and machineries.

Importance of synchronized maturity with uniform harvesting in cotton crop

In developed countries such as Australia, Canada and USA, crops like pulses, cotton *etc.* are harvested mechanically which have distinct advantages. In India, with continuously increasing labour cost, farmers find manual harvesting of cotton very expensive and they would like to increasingly opt for mechanical harvesting. As the currently available varieties of cotton are not suited to mechanical harvesting and are harvested manually. The majority of the pulse growers in India are anxious to switch over to chickpea cultivars suited to mechanical harvesting and they demand for evolving and supplying such varieties. Experts, also, suggest that research should focus to reduce cost of cultivation substantially by promoting the use of synchronized maturity varieties, defoliants and machineries (Anonymous, 2015).

In agriculture defoliants are used to eliminate the leaves of a crop plant so they will not interfere with the harvesting by machinery. Defoliant, any one of several chemical compounds that, when applied to plants, can alter their metabolism, causing the leaves to drop off. Plant defoliation does not hasten maturity; for maximum yield and crop quality, potential defoliants should not be applied until physiological maturity of crop. Defoliants function in several primary ways, both resulting in more rapid development of abscission layers. The abscission layer is the zone where leaf petioles meet stems. Once adequately formed, leaves drop from the abscission layer. The older materials work by contact - rapid destruction of green tissue, which indirectly favors formation of abscission layers (Fishel, 2015).

Further the indeterminate flowering habit of cotton coupled with accumulation of more dry matter, can pose many harvesting problems. Further, in mechanical harvesting, weeds in the field may also pose problems to the performance of harvesting machines. Defoliants, desiccants and growth regulators are chemicals used in agricultural production to accelerate the preparation of crops for mechanical harvest. Defoliation allows to produce an earlier harvest than if the cotton bolls matured naturally, but it can reduce the yield and deteriorate the fibre quality, if the application is premature (Sindarov, 2007). In order to conduct an effective defoliation, it is important to consider the biological development of cotton in a field, plant density, irrigation norm, nutritional factors to provide efficiency of defoliation (Fatullateshaev and Khaitov, 2015).

Harvesting techniques and methodology

Cotton is harvested in three or four pickings by hand as the boll matures. Cotton should be picked clean (free from dry leaves, bracts *etc*.) and dried to get a good price in the market. Cotton crop is ready for first picking by the middle of October in north India. Picking should be done when bolls burst fully and when kapas begins to hang down. The picked kapas should be spread in the sun to dry for two to four hours on a clean surface. Do not keep the picked cotton in wet water channels in the field, as this practice impairs the quality of cotton. Soon after the last picking, pull out the cotton sticks along with roots from the field and bury the remaining plant debris with a soil turning plough as a sanitary measure against pests and disease.

Cotton harvesting is done by two methods *viz.,* by hand and by machine. Machine harvesting is practised in countries where mechanisation is widely adopted. Two methods are followed for cotton harvesting by hand. The first method is known as “cotton picking” that involves the picking of seed cotton for every boll and should be as far as possible free leaves, bracts and trash. The other method, referred to as “cotton snapping” includes the collection of cotton from the plant bodily, including burs, seed cotton *etc* and cleaned afterwards.Plant water relations, nitrogen management and defoliant applications are three other crop management factors that affect crop defoliation (Fishel, 2015).

Physiological changes that occur with senescence

Plant maturity or senescence state of development, is not always related to age in days or month but it is more often a reflection of conditions under which plant develops. Leaves can become senescent and shed from the plant through the influence of member of stress situations. The application of chemicals for defoliation merely involves the use of an applied injury that ultimately induces the plant to abscise its leaves (Cathey, 1986). Abscission wherein developmental or induced senescence, usually proceeded by a variety of senescence changes a loss of chlorophyll; increased anthocyanin; reduced level of proteins, carbohydrates an inorganic ions (Addicot, 1982). Further the following changes were observed and received by many due to induced or natural senescence.

1. The leaves lose RNA and chlorophyll

Ribonucleic acids (RNA) are very important in protein synthesis. Chlorophyll is the pigment that makes the plants look green and it also captures the light energy from the sun to produce chemical energy in the form of carbohydrates.

2. Protein, carbohydrate and inorganic ion levels in the leaf drop

The plant converts proteins and carbohydrates in the leaves into simpler forms and then transports them along with inorganic ions out of the leaves to the bolls, which are the highest priority locations (or sinks).

3. Anthocyanins increase in the leaves

The anthocyanins are colored pigments that commonly occur in red, purple and blue flowers. They are also present in various other plant parts.

4. Hormone concentrations change

The environment in which a plant is growing plays an important role in the hormone balance within the plant. Hormones affect defoliation by stimulating or inhibiting the production of enzymes (Felix Ayala and Silvertooth, 2015).

Defoliants

1. Hormonal defoliant

Ethylene as a defoliant

Ethylene - Studies have shown that ethylene increases the rate of chlorophyll, protein and RNA degradation in leaf tissue. Rates of chlorophylldegradation decrease when inhibitors such as silver nitrate andaminoethoxy vinyl glycine (AVG) block ethylene production. Althoughethylene plays an important role as a signal to initiate senescence as planttissue ages, the process can occur without it. Zacarias and Reid (1990) found that ethylene-insensitive mutants of *Arabidopsis thaliana* senesce ata slower rate than the wild type. In these situations it usually is best tothink of ethylene as a senescence-promoter hormone, rather than as thecause of the senescence process. Ball and Charles Glover, (1999) stated that ethylene stimulates the activity of

IAA-oxidase system, reducing the auxin concentration and promoting abscission. Further they found that ethylene decreases and inhibits auxin transport, promoting abscission. Stimulates the synthesis of pectinase and cellulase and increases the secretion of these two enzymes into cell walls.

Ethephon

The mode of action of ethephon is auxin transport inhibitor. Beaudry and Kays (1988) opined that the breakdown of ethephon to ethylene occurs primarily onthe leaf surface. According to the abscissionmodel, cell wall hydrolases are induced by ethylene into the separation layerof abscission zones to promote leaf shedding (Walhood and Addicott, 1968).

Ethephon + cyclanilide

Cyclanilide is an auxin transport inhibitor that,when combined with ethephon, enhances cellulase activity in abscissionzones more than does ethephon alone (Pedersen *et al.,* 1997). Activity isenhanced at two different pH optima, suggesting that cyclanilide andethephon may induce more than one type of cellular isozyme.

Ethephon + AMADS

Ethephon stimulates production of ethylene and AMADS is an ethylene synergist.

Dimethipin

Themode of action for dimethipin is summarized as an induced, slow disintegration ofepidermal cell walls and a subsequent gradual water loss that triggers the release ofethylene and abscission. It is classified as a hormonal defoliant. Metzger and Keng (1984) found that dimethipin causes an initial inhibition of protein synthesis that is responsible for the loss of stomatal control. Loss of stomatal control is associated with highrates of transpiration and loss of leaf turgor that leads to desiccation and, ultimately, abscission. Further the labelling work with ^{14}C-leucine and ^{3}H-uridine and suggested that dirnethipin acts primarily on the processes associated withtranslation rather than transcription. Auxin synthesis and transport also are inhibitedand ethylene synthesis is triggered, subsequently inducing cellulase production. With the induction of cellulase, digestion of cellulose occurs in the abscission zone of the petiole base. This activity weakens the abscission layer and the leaf falls.

2. Herbicidal defoliants

Butifos, merphos, tribufos and tribufate these are the herbicidal defoliants that injure the palisade cells of leaves, causing release of ethylene and leaf abscission. These defoliants also cause an upsurge of stress-inducedethylene production through a mild leaf injury that stimulates the enzymes cellulase, pectinase and polygalacturonase. These enzymes are involved in the hydrolysis of insoluble pectates and cellulose associated with the adherence of cells in the abscission zones. The juvenile plant hormones, auxin and gibberellin, which antagonize the abscission process, also appear to be impaired. Suttle (1988) stated that the thidiazuron enhances ethylene production; it also has been shown to disruptthe polar auxin transport system and is an excellent inhibitor of regrowth. It is classified as a hormonal defoliant. Thidiazuron has been reported to have cytokine-like activity in sieva bean callus culture (Mok *et al.,* 1982).

Thidiazuron + diuron (DCMU)

Diuron is used to inhibit photosyntheticelectron transport. The site of action for diuron is at the quinone acceptor complex in the electron transport chain between the two photosystems, PSI and PSII. Compounds such as diuron occupy the secondary quinine (QB) binding site of D1 and D2 proteins, two membrane proteins that make up the core of PSII reaction centers (Zer and Ohad, 1995). Because diuron is unable to accept electrons, the electron cannot leave QA, the first quinine acceptor. As such, diuron binding effectively blocks electron flow and inhibitsphotosynthesis. An ensuing chain reaction of lipid peroxidation results in leakymembranes, which cause cells to dry rapidly. The combination of both chemistries thus enhances the potential for defoliation (Weed Science Society of America, 1994). Thidiazuron + Diuron (0.03%) and Sodium chlorate (0.9%) performed better and gave 98 to 99 per cent defoliation within 15 Days after defoliants spray (Chandrasekaran *et al*., 2021).

Effect of defoliants on physiological and biochemical properties of crops

Senescence in the final developmental phase of the leaf with nutrient salvages ends with all death. The first visible event during senescence is leaf yellowing, which typically starts at the leaf margin and progresses the interior of the leaf blade of cotton (Qurino *et al*., 2000).

The protein and RNA degradation parallels a loss in photosynthetic activity and the majority of the processes have occurred by the time yellowing of leaf can be seen (Buchanan-Wollaston *et al*., 2003). The degradation processes are transported one of leaves to the part of the plants. In this sense the senescing leaf continuous to function as asource of nutrients to the whole plant, best at the expense of its own ability to survive (Bleacker and Patterson, 1997).

Miller *et al.* (1957) found that the application of 4000 ppm of amino triazole and salts of amino triazole generally caused an initial stimulation of respiration of cotton leaf discs after four hours of application. Hall, (1951) reported that the defoliation was increased (97.5%) with significant reduction of the starch and dextrin content of leaf (1.51%) with spraying of 2% suspension of aero defoliant (60% calcium cyanamide) at cotton crop grown under the soil rich fertility state, adequate moisture level.

Rashkes *et al.* (1997) stated that the application of DS (containing carboxy derivatives and diphenylurea as impurities) at 0.6 kg ha^{-1} significantly reduce the sitosterol (1.02 mg g^{-1}) content over control (2.05 mg g^{-1}) present in the cotton leaves. Similarly reduce the stigmasterol (0.57 mg g^{-1}) content

also. Boersig and Negmthe (1987) stated that the combination of endothall (774 ppm) and ethephon (1080 ppm) decreased the starch and sucrose contents in the roots by 90% and 70% respectively. Starch concentration in non-sprayed field plants remained high in *Euonymus alata.* Sultanova *et al.* (1995) stated that the protein fractions were isolated after three days, from the cotton plant shoots made with the treatmental spray of defoliant ethylene in a concentration of 9 m mole liter^{-1} showed the appearance of new polypeptides with M 17, 25, 50 and 70 kDa and the disappearance ofpolypeptides with M 75 and 80 kDa.

Hall and Lane (1952) suggested that the plants which were defoliated with100 ppm ethylene was highest in starch (4.75%), reducing sugars (2.5%) and total carbohydrates (17.75%), intermediate in nitrogen (2.56%) and gave the highest percentage defoliation (96%) in cotton. Marianne *et al.* (2006) observed that cyclanilide (0.067 kg ha^{-1}) may be acting as an auxin antagonist or transport inhibitor, thereby enhancing ethephon efficacy.

Senescence and abscission involves active mobilization of cell wall hydrolases which weaken the cell wall of the cells in the abscission zone, along with mechanical forces which assist rupture. Ethylene accelerates the leaf abscission in a wide range of plant species (Sexton and Roberts, 1982). In general, the late sprayed (comparatively registered higher percentage of leaf fall than the earlier sprayed. It may be due to with defoliant spray at later stage the numbers of intact leaves in the plants were less compared to earlier spray and thus facilitating the harvest of seed cotton. The higher concentration defoliant spray accelerates higher senescence attributes. This was due to the fact that with the application of defoliants at higher concentration, there was mild to severe shedding of leaves Sarlach *et al.* (2010). When a defoliant is applied to the plant, the amount of diffusible auxin is reduced. In addition to that, ethylene stimulates IAA oxidase activity which promotes abscission. Similar results were also reported by Charles and Charles (1994).

Effect of defoliants on growth attributes of crops

Miller *et al.* (1957) reported that the application of 5000 ppm phosphate salt of ATA (3-amino-1,9,4-triazole) significantly increased the rate of defoliation (88.9%) after ten days of application. Further it was found that the, application of 5000 ppm of sodium salt of ATA reduce the regrowth in cotton under greenhouse condition. In field condition 0.75 lbA^{-1} (ATA equivalent basis) the nitrate salt of ATA increased the defoliation rate at 97.7% after ten days of application and controlled the regrowth after three weeks. Hall (1951) reported that the defoliation was increased (97.5%), spraying of 2% suspension of aero defoliant (60% calcium cyanamide) at cotton crop grown under the soil rich fertility state, adequate moisture level and full crop load condition. Charles and Charles (1994) stated that spraying of thidiazuron @ 0.2 kg a.i. ha^{-1} as defoliant increased the defoliation (99%) applied when 80% boll opening in cotton.

Defoliant application at different concentration significantly influenced the growth attributes. The reduction may be due to the arrest of growth as well as reduction of leaf size. Further, this may be attributed to the reduced rate of leaf emergence, leaf size, photosynthetic pigments and photosynthesis by the inherent physiological action of paraquat (herbicidal defoliant) at higher concentration (Grewal and Kolar, 1990). The application of defoliants at higher concentration in crop plants decreased the plant height, leaf area index and DMP. The dry matter production is the function of light interception and leaf area index. Earlier application resulted in higher reduction of plant height than the late application. This mechanism of reduction in the cell elongation is because of inhibitory effect of paraquat in the biosynthesis of gibberellins in the plant body (Charles and Charles, 1994).

Osman *et al*. (2010) found that the DU (Dropp Ultra) application as defoliant was found to be satisfactory in the applications made 60 days after flowering. However, delayed application was found to reduce defoliation due to low temperature in cotton grown under semi-arid condition. Suttle (1985) observed that the greater than 80% abscission was found on cotton leaves at the highest TDZ Thidiazuron concentration tested (100 gM) as defoliant. Singh and Rathore (2015) revealed that application of drop ultra at the rate of 250 ml ha^{-1} comparatively reduced the plant height and plant biomass due to maximum shedding of leaves, young flowers and fruiting bodies and even some developing immature bolls. Earlier application resulted in significant reduction of plant heightover the later application. Similarly, biomass production had also been statistically improved under later application as compared to early application in cotton.

Dinesh *et al.* (2014) suggested that foliar application of Ethylene (45 ppm) at squaring stageresulted in significant increase in the plant heightover control in cotton. Similarly application of Ethylene showed significant increase in number of main stem node and also the number of sympodial branches over control in cotton crop. Nelson (1992) revealed that the spraying of drop at 0.15 lb.a.i. acre^{-1} at 42 days from final irrigation was significantly increased the rate of defoliation 89% after 14 days of application in pima cotton. Rashkes *et al.* (1997) reported that application of DS (containing carboxy derivatives and diphenyl urea as impurities) at 0.6 kg ha^{-1} increased the cotton leaf fall percentage (80%). Owen Gwathmey and Robert Hayes (1997) stated that the application of tribufos @ 0.63 kg a.i. ha^{-1} along with ethephon @ 1.12 kg a.i. ha^{-1} increase the defoliation (85%) on 7 days after application in cotton under cooler condition. Yong-qi *et al*. (2015) stated diquat applied @ 120 g ha^{-1} resulted in effective desiccation in rice crop.

Marianne *et al.* (2006) reported that cyclanilide (0.067 kg ha^{-1}) combined with ethephon (0.067 kg ha^{-1}) induced 75 to 85% defoliation at all tested temperatures (except at 16/14°C, the lowest), in kidney bean (*Phaseolus vulgaris* L.). Guihong Bi and Scagel (2009) revealed that

spraying plants with 10,000 mg l^{-1} Def 6 significantly reduced plantheight compared with controls. Similarly seven days afterspraying plants with Def 6 at 7500 and 10,000 mg l^{-1}, plants were 90% to 98% defoliated in hydrangea. The application of paraquat @ 5 ml ha^{-1} caused the drying and fall of leaves in greengram, were recorded 96% by the first week and 99% by the end of second week after spraying (Padmaja *et al.,* 2013).

Effect of defoliants on yield attributes and yield components of crops

Charles and Charles (1994) suggested that, timing was more critical than choice of defoliants, since yield losses occurred irrespective of defoliant used if application was made at timings earlier than 60 per cent boll opening in cotton. Nelson *et al.* (1992) revealed that the spraying of Dropp at 0.15 lb.a.i. $acre^{-1}$ at 14 days from final irrigation was significantly increased the lint yield in pima cotton. The application of tribufos @ 0.63 kg a.i. ha^{-1} along with ethephon @ 1.12 kg a.i. ha^{-1} increased leaf fall percentage (85%) on 7 days after application in cotton under cooler condition (Owen Gwathmey and Robert Hayes, 1997).

The cotton yield increase due to defoliants spray might be due to higher translocation of nutrients and carbohydrates towards the reproductive parts soon after the defoliant spray facilitating the immature bolls to develop and burst within short time. Further, due to hastened process of abscission of leaves, due to application of ethrel the nutrients diverted toward the boll development and increased boll weight, which in turn, increased cotton yield. Similar results were reported by Bader *et al.* (2001). In case of hormonal treatment (ethrel), the nutrients were diverted towards the immure bolls that were intact at the time of spraying and contributed for the final increased yield. The results are in accordance with the findings of Wright and Brecke (2009). Hence, the defoliation not only improves the boll opening and seed cotton yield also help in reducing the trash content in the lint and provides an opportunity for mechanical picking.

Copur *et al.* (2010) stated that the highest seed cotton yields were obtained from dropp ultra sprayed @ 600 cc on 75 and 90 days after flowering. Further these results showed that seed cotton yield was significantly and negatively affected by early defoliation. The number of bolls showed significant differences according to application times but non-significant differences according to the type of defoliant. The days after flowering of 90 days treatments produced the highest number of bolls per plant, highest boll weight and fibre index. The highest seed cotton yield against control was achieved by the application of 2000 ppm ethrel at 160 DAS with very good boll opening percentage. The exogenously applied ethylene as defoliant could have resulted in remobilization of metabolites and assimilates from non-economic part to seed cotton yield were reported by Sarlach *et al.* (2010). The application of ethrel @ 2500 ppm at 145 days after sowing of the *Bt* cotton hybrid RCH 134 gave higher seed cotton yield (Buttar and Sudeep, 2013).

Ming-wei *et al.* (2013) stated that the application of thidiazuron @ 340 g ha^{-1} along with ethephon @ 100 g ha^{-1} increased the first harvest yield in cotton. Similarly 90 per cent defoliation and 80% boll opening occurs. The application of paraquat on castor increased the mean seed yield and was highest compared to pyraflufen ethyl and thidiazuron + diuron (Oswalt *et al.*, 2014). The application of dropp ultra at the rate of 200 ml ha^{-1} exhibited significantly better seed cotton yield as compared to its higher dose 225 ml ha^{-1} as well as that the ethrel at the rate of 2000 ppm and control. Significantly better seed cotton yield was observed at application on 150 DAS over the early application at 140 DAS owing to significantly improved boll count and better boll weight. These results showed that seed cotton yield was significantly and negatively affected by early defoliation (Singh *et al.,* 2015). Mrunalini *et al.* (2019) reported that Etherel @ 2000 ppm was found superior for boll opening (99.1%) and Dropp Ultra 540 SC (Thidiazuron 360 + Diuron 180) @ 200 ml ha^{-1} showed highest leaf defoliation (99.7%) for getting higher and clean seed cotton yield, under high density planting. cotton under high density planting system and defoliation with Dropp ultra @ 250 ml/ ha recorded higher yields without deteriorating fibre quality (Raghavendra *et al.*, 2020). Application of defoliant, ethrel @ 2,500 ppm at 150 DAS recorded the highest percentage of senescence attributes and seed-cotton yield were reported by Mohammed Ashraf *et al.* (2020).

CONCLUSION

During the crop growth due to insufficient soil moisture, increasing labour cost and shortage of labour being the major constraint to follow manual harvesting in staggered manner. Further, it is very expensive and the farmers would like to increasingly opt for mechanical harvesting. In this context, it is suggested that research should focus to reduce cost of cultivation substantially by promoting the use of synchronized maturity varieties in cotton and use of defoliants to encourage mechanical harvesting. There is an urgent need to identify suitable defoliant with suitable dose and time of application so as to facilitate mechanical harvesting in rainfed cotton.

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