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Keerti
Department of Agronomy,
UAS, Raichur, Karnataka, India

Raghuveer
Department of Agronomy,
UAS, Raichur, Karnataka, India

Correspondence
Keerti
Department of Agronomy,
UAS, Raichur, Karnataka, India

Role of defoliators in crop production - A review

Keerti and Raghuveer

Abstract
Defoliation is the detachment of leaves from plant. This is natural process occurs when leaves become physiologically mature. Defoliators are the chemical which brings early and uniform drying and shredding of leaves by removing moisture out of the plant system and create abscission layer at the base of the leaves. Defoliators applied 3 to 4 days before harvesting in order to enhance the brittleness of the harvesting plant stem there by helpful for efficient mechanical harvesting and also reduce damage of seeds to a greater extent, so they also named as harvest aiding chemicals. Leaf start drying within 12 hours after defoliator application. Herbicide like paraquat (4ml/l) can be used to achieve defoliation and desiccation. There was limited study conducted on effect of application of different concentrations of paraquat and stage for spray on different crops.

Keywords: defoliants, yield, quality and economics

Introduction
Defoliation can be manually achieved by the use of some chemicals called "defoliators" or harvest aids. Defoliators enhance the anthocyanin in leaf and plant systems, thereby reduce chlorophyll content and also reduce levels of proteins, carbohydrates and inorganic ions and alterations in hormone concentrations. Defoliation activity is highly temperature dependent. In general for most of the harvest aid chemicals, application rate should be lower when the temperature is warmer and higher when it is cooler. Leaf start drying within 12 hours after defoliator application and complete defoliation takes place, within 3-4 days. Paraquat is introduced as contact herbicide but now days beyond that paraquat used as defoliator. Herbicidal defoliants injure the plant causing it to produce ethylene in response. Ethylene promotes leaf abscission by increasing the activity of enzymes such as pectinase and cellulase, which degrade cell walls and middle lamellae in the abscission zone of the petiole (Padmaja *et al.*, 2013) [22]. Main objective of defoliation is to promote crop earliness, facilitate shedding of leaves before harvesting at an appropriate time and to ensure clean and fast picking of pods and reduce losses.

Effect of application of defoliator on yield and yield parameters of different crops
Eastin (1978) [8] reported that 10 days pre-harvest application of paraquat at 0.56 kg ha^{-1} had no negative effects on rice yield and 1000 grain weight.
The influence of 220 g ai ha^{-1} AC, glufosinate in three concentrations (263,222, 840 g ai ha^{-1}), 560 g ai ha^{-1} glyphosate, and 840 g ai ha^{-1} paraquat applied at R5, R6, R7, and R8 soybean growth stages as harvest-aid treatments on soybean. Soybean yield was severely reduced by all defoliators applied at R5. Only paraquat and glufosinate reduced soybean yield when applied at R6, and none of the defoliators reduced yield when applied at R7 or R8. Paraquat and glufosinate reduced seed weight when applied at R5 and R6 (Sunil and David, 1992).
Darwent *et al.* (1994) [7] studied that the application of glyphosate at rates of 0, 0.45, 0.9 and 1.7 kg ai ha^{-1} to wheat at different seed moisture contents ranging from 80 to 11%. Average yields decreased as the rate of glyphosate increased from 0 to 1.7 kg ha^{-1}. Application at seed moisture of 40% or less caused little or no yield loss.
Snipes and Baskin (1994) reported that ethephon (ethylene precursor) which is used primarily as a boll-opening compound in cotton, also enhanced defoliation. Defoliation before 60% open bolls, resulted in yield losses of 7 to 15%. The use of defoliant thiadiazuron, lowered the leaf water potential (6.3 and 16.9 bars), decreased the moisture content of bolls and increased the canopy temperature of the crop by 2.6 to 4.8 °C as compared to water sprayed control. Thiadiazuron 75 g ha^{-1} enhanced 17.0 to 18.6 per cent boll opening and increased the mean

seed cotton yield by 6.5 to 7.4 per cent as compared to untreated control (Thakar and Brar, 2000) [30].

Robert and John (2002) [25] reported that dry bean seed weight and seed yield were reduced by all harvest aid treatments (glufosinate, glyphosate and paraquat) applied at early stage when only 5 to 7% of the seedpods were yellow. Herbicides did not affect dry bean seed yield, weight, or germination if treatments were done at physiological maturity stage when 77 to 85% of the seedpods had turned yellow.

Jason *et al.* (2006) [14] determined the effect of paraquat and sodium chlorate which were applied as pre harvest desiccants on rice yield and quality. They reported that paraquat at 0.071 kg ha^{-1} did not reduce ratoon rice yield compared to non treated control. However, paraquat at 0.14 kg ha^{-1} reduce ratoon rice yield. Neither ratoon nor total rice yields were affected when applications were made 3days prior to harvest compared to application at 7days prior to harvest which reduced 24% of yield.

The effect of thidiazoron + diuron application at 40, 50, 60 and 70% boll opening stage of cotton. They reported that 100 seed weight, seed and seed cotton yield were not affected by the treatments but picking percentage, fiber uniformity were affected significantly (Emine *et al.*, 2007) [10].

Joseph and James (2008) [16] reported that yields were reduced by 17% when the harvest aid treatments of Gramoxone Inteon and sodium chlorate were applied at 60 per cent average seed moisture compared with the application at 50% moisture. When harvest aid was applied at 40 per cent moisture, soybeans were harvested 7-15 days earlier than the nontreatd soybeans.

Joseph and Frank (2009) [15] reported that application of glyphosate applied on wheat at the milky stage of development reduced the yield by 20 to 77% depending on the year, variety, and glyphosate rate.

Esfahani *et al.* (2010) [11] conducted an experiment at Guilan, Iran and reported significant effect of paraquat application on grain moisture reduction rate, grain yield and oil content. Paraquat at 0.8 l ha^{-1} promoted daily grain moisture reduction (2.94% day^{-1}) compared to the control (1.75% day^{-1}) and harvest time (5-7 days earlier than control) with no adverse effects on grain yield and had no adverse effect on oil content and fatty acids profile of rapeseed.

Mehrdad *et al.* (2012) [20] carried out a study in Rasht (North of Iran) In order to investigate the effect of different concentrations of Paraquat and different time of consumption in varied planting dates of faba bean on Seed yield and toxin residues effects. Results indicated that 0.2 kg ha^{-1} paraquat was used in faba bean at 40% grain moisture gave highest yield and less lethal toxin residue on seeds as compared to 0.6 kg ha^{-1} at 60% moisture.

Sarlach *et al.* (2010) [27] conducted an experiment at Ludhiana, to study the effect of defoliant (ethrel) through foliar application on yield and fibre quality traits of a late maturing Bt cotton hybrid (RCH 134 Bt). No significant differences for seed cotton yield were recorded when the ethrel was applied (500, 650 and 800 ppm) at 130 and 145 DAS. However, the treatments recorded, numerically, higher seed cotton yield than that of the control. Higher increase of 12.5% in seed cotton yield was observed when ethrel was applied @ 800 ppm at 145 DAS.

Rajni *et al.* (2011) [23] carried out an experiment at Ludhiana. To study the effect of thidiazuron (100, 150 and 200 g ha^{-1}), ethrel (1.0 and 1.5 l ha^{-1} applied at 40 or 60 per cent of bolls opened) and gramoxone (1.0 l ha^{-1} applied after first picking of cotton) on yield of cotton. Defoliation with ethrel 1.5 l ha^{-1} at 60 per cent of bolls opened resulted in higher number of picked bolls plant^{-1} when compared with control. However, higher seed cotton yield was obtained with ethrel at 1.0 l ha^{-1} (2.27 and 1.96 t ha^{-1}) and it was followed by thidiazuron 100 g ha^{-1} (2.21 and 1.92 t ha^{-1}) applied at 60 BOP. Gramoxone (paraquat) application at 1.0 l ha^{-1} after first picking failed to exert any significant influence on seed cotton yield and yield contributing characters.

Ratnakumari *et al.* (2013) [24] indicated that spraying of ethrel @ 3000ppm at 145 DAS increased the seed cotton yield significantly (2577 kg ha^{-1}) followed by ethrel @ 1500ppm at 130 DAS (2431 kg ha^{-1}) and ethrel @ 1500 ppm at 145 DAS (2358 kg ha^{-1}) without loss in fibre quality. No yield reduction was noticed even with the weedicide sprays as defoliants.

The higher seed cotton yields at all the levels of ethrel were obtained when defoliant was applied at 145 days after sowing (DAS) as compared to 130 DAS, application of ethrel irrespective of stage of the crop resulted in significantly reduction in crop duration from 24-29 days as compared to control and resulted in higher productivity day^{-1} than control (Buttar and Sudeep, 2013) [2].

Kulvir *et al.* (2015) [18] conducted the experiment at Punjab to determine the effect of selected defoliants *i.e.* dropp ultra® and ethrel, their optimal dose and suitable time of application on earliness and seed cotton yield in 3 American cotton cultivars. They reported that among tested defoliants, Dropp ultra® @ 200 ml ha^{-1} resulted in better, lint and seed yield.

Effect of application of defoliator on quality parameters of different crops

Seeds of grain sorghum plants desiccated with 1.12, 2.24 and 4.48 kg ha^{-1} of glyphosate [(*N*phosphonomethyl) glycine] produced a high percentage of abnormal seedlings with varying amounts of interveinal areas completely devoid of chlorophyll. Seed damage was greatest when treatments were applied at 25 days after flowering when the grain had a moisture content of 30 to 40%. Damage decreased as time of treatment after flowering (30, 35, and 40 days) increased (Baur *et al.*, 1977) [1].

Eastin (1980) [9] reported that diquat, ghlyphosate, paraquat or sodium chlorate application don't have any adverse effects of on seed germination of rice.

A field experiment was conducted by Sunil and David (1992) at Mississippi. They reported that glyphosate and AC 263,222 reduced seed germination when applied at R5, R6, and R7 growth stages of soyabean and normal seedling percentages were also reduced by glyphosate at these growth stages. Glufosinate and AC 263, 222 affected seed germination only at R5 and R6. Paraquat did not affect seed germination. Glyphosate applied at R5 reduced shoot weight in one month old soybean plants. No effects were observed on seed germination and seedling development when any of these chemical applied at R8 stage.

Darwent *et al.* (1994) [7] reported that application of glyphosate at rates of 0.45, 0.9 and 1.7 kg ai ha^{-1} to wheat resulted in little or no difference in 1000seed weight, sample density, seed germination and protein content.

Darwent *et al.* (2000) [6] reported that the dependence of the grain on pods after physiological maturity reduces gradually therefore the application of desiccants may not impose adverse effect on grain yield and quality of canola.

Santi *et al.* (2000) [26] examined chemical application for leaf defoliation before harvesting at Bangkok (Thailand). They reported that paraquat residue analysis indicated that there was no paraquat left on mungbean seed in the dry season.

Emine *et al.* (2007) [10] conducted experiment in Diyarbakır, Turkey, to study the effect of thidiazoron + diuron application at 40, 50, 60 and 70% boll opening stage of cotton. They showed no significant difference with respect to ginning percentage, seed germination percentage, fiber fineness, fiber length, fiber strength. Which means quality parameters of cotton were not affected by the treatments.

Joseph and Frank (2009) [15] reported that glyphosate applied at the milk stage of development, affected germination per cent from 2 to 46% compared to untreated wheat.

Application of defoliators result into 5-7 days earlier harvested than control and paraquate application had no negative effect on rape seed grain yield and enhanced grain moisture reduction rate (Esfahani *et al*., 2010) [11].

Keerti *et al*. (2017) [17] reported that Application of paraquat as defoliator did not impose adverse effect on germination of seed i.e, 92% germination and its quality (protein content).

Effect of application of defoliator on per cent defoliation

Gwathmey and Robert (1997) [13] reported that tribufos or dimethipin produced more defoliation by 7 and 14 days after treatment than control plot under both warm (79-90%) and cool (63-83%) conditions.

Charles *et al.* (1995) [3] conducted the experiment at stoneville and Tifton. Result revealed that 7 DAT (days after treatment) of tribufos on cotton resulted into 52-79% defoliation in Stoneville and defoliation of tribufos at Tifton was 32 -72%. Thidiazuron showed 55 - 82% defoliation in Stoneville and 36 - 51% defoliation in Tifton at 7DAT respectively.

Experiments were conducted at the Texas to evaluate the effect of paraquat application @ 280 g a.i. ha^{-1} to cotton variety D&PL 50 in the morning (06:00-08:00am), noon (12:00-14:00pm), and evening (18:00-20:00pm). Result revealed that application of defoliator after 3 and 14 days after treatment recorded significantly greater per cent desiccation and per cent defoliation for evening applications, compared to morning applications (Cothren *et al.*, 1999) [5].

Santi *et al.* (2000) [26] examined chemical application for leaf defoliation before harvesting of mungbean at Bangkok (Thailand). They found that urea at a rate of 2.5 (dry season) and 5.0 per cent (wet season) showed no effect on leaf abscission, whereas paraquat at the rate of 80-160 g (ai) rai^{-1} sprayed 57 days after sowing caused complete leaf abscission without affecting pod abscission and seed yield.

Thakar and Brar (2000) [30] reported that use of defoliant thiadiazuron, lowered the leaf water potential (6.3 and 16.9 bars), decreased the moisture content of bolls and increased the canopy temperature of the cotton by 2.6 to 4.8 °C as compared to water sprayed control. Thiadiazuron 75 g ha^{-1} caused 92.1 to 99.6 per cent shedding of leaves.

Gautam *et al.* (2008) [12] reported that three defoliants namely Dropp (Thidizuron) (50% WP), Roundup (41% SL) & Ethrel (39% SL) were applied at 1% concentration over varieties of cotton PKV 081, Khandwa-2, G cot 16, and NH 452 of cotton verities. Among the four varieties tested, variety Khandwa-2 gave higher per cent defoliation (78%) which was significantly superior over all other varieties. Ethrel gave higher per cent of defoliation (73%) and was statistically at par with Dropp (71%). Where defoliant 02 (Round up) recorded less (60%) of defoliation.

Osman *et al.* (2010) [21] conducted a study to determine the effect of different defoliants (Dropp ultra® (DU): thidiazuron + diuron and Roundup (RU): glyphosate) and application times [60, 75 and 90 days after flowering (DAF)] on cotton. The research was carried out at the Harran. Results of the study indicated the variation in performance of defoliants. Using DU, the average number of leaves for 60, 75 and 90 DAF applications was 3-2, 7-10 and 25-35 leaves per plant. Using RU, the average number of leaves for 60, 75 and 90 DAF applications was 60-65, 55-53 and 40-46 leaves per plant, respectively.

Padmaja *et al.* (2013) [22] revealed that spraying of Paraquat @ 5 ml l^{-1} at physiological maturity caused drying and falling of mungbean leaves to 96% by the first week and 99% by the end of second week after spraying, followed by Glyphosate @ 10 ml l^{-1} which influenced the defoliation to 93 and 97 per cent, respectively in comparison to other treatments.

Keerti *et al*. (2017) [17] reported that paraquat sprayed treatments recorded significantly lower number of leaves $plant^{-1}$, dry matter production $plant^{-1}$ and crop growth rate (7.28 - 7.73, 10.04 - 10.64 g $plant^{-1}$, 0.020 - 0.031 g dm^{-2} day^{-1}, respectively) compared to control. Application of paraquat three days before harvesting reduce the weight of leaf and stalk to a greater extent and was resulted into reduction of dry matter at the time of harvest.

Effect of application of defoliator on Economics

Rajni *et al.* (2011) [23] carried out an experiment at Ludhiana, to study the effect of thidiazuron 100, 150 and 200 g ha^{-1}, ethrel 1.0 and 1.5 l ha^{-1} applied at 40 or 60 per cent of bolls opened and gramoxone (paraquat) 1.0 l ha^{-1} applied after first picking of cotton. The B:C ratio of thidiazuron 100 g ha^{-1} at 60 BOP was comparatively higher when compared with rest of the defoliation treatments.

Kulvir *et al.* (2015 a) [18] conducted the experiment at Punjab to determine the effect of selected defoliants *i.e.* dropp ultra® and ethrel, their optimal dose and suitable time of application. They reported that application of defoliants at 150DAS resulted in significantly improved net returns (Rs 79288 ha^{-1}) as compared to earlier application (Rs 73632 ha^{-1}) at 140 DAS. Dropp ultra® @ 200 ml ha^{-1} further lead to significantly better net returns (Rs 85373 ha^{-1}) and B:C ratio (2.31) over other treatments.

Paraquat spray recorded significantly higher net return (Rs 39,853 ha-1) and B:C ratio (2.91) compared to no spray. The higher economic returns with paraquat spray were mainly due to higher economic yield associated with these treatments (Keerti *et al*. 2017) [17].

Conclusion

Application of defoliators before harvesting maintain the uniform moisture level in crop, facilitate shedding of leaves before harvesting and make the stalk brittle, there by enhance the cutting efficiency of machine. Help for harvest at the right time and at optimum moisture content. Also help for promoting crop earliness, bring synchronised harvesting, ensure clean and fast picking of pods and reduce total harvest losses.

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