

**Compensatory response of cotton plants to simulated carpophagic pest injury****Resposta compensatória de plantas de algodoeiro a injúria simulada de pragas carpofágicas**

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**ABSTRACT**

Due upland cotton crop has a relatively long cycle on Brazilian Savannah areas, varying from 180 to 220 days, abscission and replacement of floral structures is frequent although variable along the phenological phases. The reproductive phase occurs from 45 days after plant emergence until close to the harvest. The objective of this study was to measure the ability of cotton plants to compensate losses caused by carpophagic insects by producing new floral structures. Four cotton cultivars (FM913GLT, FM980GLT, FM966LL and FM975WS) were sowed in an irrigated area, whose soil is characterized as dystrophic latosol. The treatments were arranged in a factorial scheme, with the cultivar being the main factor and the intensity of the injury caused manually by the removal of floral structures as the secondary factor. Simulated damages consisted of five levels of removal of floral buds, flowers and bolls at 75 days after emergence (DAE). We recorded the number of floral structures present in the plants at 140 DAE and at the harvest. The damage boundary (Db) varied among the cultivars, demonstrating a differentiated response of tolerance to injury. FM980GLT and FM975WS were able to compensate and overcompensate the losses; the same does not happen to FM913GLT and FM966LL. We observed tolerance and linearity phases in all the cultivars but FM966LL. FM980GLT showed highest response capability after be injured. The cotton plants compensated for the loss of structures up to a certain limit of injury, which varies with the cultivar. Overcompensation and compensation occurred through the replacement of new structures while the compensatory response into increase in the weight of bolls did not happen.

**Keywords:** *Gossypium*, shedding, abscission, compensation, insect.

**RESUMO**

Devido à cultura do algodoeiro ter um ciclo relativamente longo em áreas do Brasil Central, variando de 180 a 220 dias, a abscisão e a substituição de estruturas florais é frequente, embora variável ao longo das fases fenológicas. A fase reprodutiva ocorre a partir de 45 dias após a emergência da planta até

próximo à colheita. O objetivo deste estudo foi medir a capacidade das plantas de algodão em compensar perdas causadas por insetos carpófagos, produzindo novas estruturas florais. Foram semeadas quatro cultivares de algodão (FM913GLT, FM980GLT, FM966LL e FM975WS) em uma área irrigada, cujo solo é caracterizado como latossolo distrófico. Os tratamentos foram organizados em esquema fatorial, sendo a cultivar o fator principal e a intensidade da lesão causada manualmente pela remoção de estruturas florais o fator secundário. Os danos simulados consistiram em cinco níveis de remoção de botões florais, flores e capulhos aos 75 dias após a emergência (DAE). Foi registrado o número de estruturas florais presentes nas plantas aos 140 DAE e na colheita. O nível de dano econômico (NDE) variou entre as cultivares, demonstrando uma resposta diferenciada entre elas quanto à tolerância a injúrias. FM980GLT e FM975WS foram capazes de compensar e supercompensar as perdas; o mesmo não aconteceu com FM913GLT e FM966LL. As fases de tolerância e linearidade foram observadas em todas as cultivares, menos FM966LL. FM980GLT apresentou a maior capacidade de resposta após ser injuriada. As plantas de algodão compensaram a perda de estruturas até um certo limite de injúria, o qual variou com a cultivar. A supercompensação e a compensação ocorreram através da substituição de novas estruturas, enquanto a resposta compensatória de aumento do peso de capulhos não aconteceu.

**Palavras-chave:** *Gossypium*, abortamento, abscisão, compensação, inseto.

## 1 INTRODUCTION

The plant-, insect- and environment- interaction is complex and the results may benefit both plants and insects. An injured plant may compensate or even overcompensate injury promoted by any stress. While compensation allows plants to avoid yield loss despite being damaged (TRUMBLE et al., 1993; TIFFIN, 2000; FÜRSTENBERG-HÄGG et al., 2013), herbivory may even increase production compared to undamaged plants by overcompensation (STRAUSS & AGRAWAL, 1999; POVEDA et al., 2010). Although overcompensation has been described mostly for wild plants (OLEJNICZAK, 2011), there is enough evidence for important crops that overcompensatory responses are possible (STIEHA et al., 2016; POVEDA et al., 2018).

In the course of the development cycle of cotton plants, flower structure abscissions are frequent. Abscission is an active physiological process that occurs through the dissolution of cell walls at predetermined positions, the abscission zones (SAWICKI et al., 2015). Among their causes we can highlight genetic timing mechanisms (BOTTON et al., 2011; PATHARKAR & WALKER, 2016), environmental stimuli as temperature, humidity or luminosity changes (AGUSTÍ et al., 2012; ECHER et al., 2014), soil fertility (ASCOUGH et al., 2005; ZHANG et al., 2010) and pests injury (ARMSTRONG et al., 2010; LUCAS, 2011). On the other hand, plants have higher fitness when they are damaged by herbivores compared with related plants that are undamaged (DICKE & BALDWIN, 2010; LUCAS-BARBOSA et al., 2011). Nonetheless, insects and diseases also have their development and herbivory behavior influenced by climatic and edaphic conditions (REDDY, 2013; SCHOWALTER, 2016).

Several pests have the carpophagic habit, attacking and feeding on floral structures of the Brazilian cotton varieties (OLIVEIRA et al., 2016). As a reaction to be attacked by these pests, after

having its floral organs damaged, typically hormone process is activated to promote the abscission (ALBA et al., 2015). This biological phenomenon is frequently observed after injury caused by feeding or oviposition of insect pests on the plants (CARMONA & FORNONI, 2013; POVEDA et al., 2018).

The determination of the pest control strategies requires the evaluation and understanding of how certain pest affects the growth, development or reproductive capacity of the plant. In studies on the impact of herbivory, the manipulation of insect populations is a constant cause of errors in field trials. Likewise, uncontrolled biotic and abiotic factors in the field may compromise the results. To avoid these mistakes, the mechanical simulation of injury dispenses the presence of insects and allows the measurement of the resilience of the injured plant (SILLA et al., 2008; KOZLOV & ZVEREVA, 2014). By the increase in vegetative growth, bud production or boll weight the cotton plant may compensate the losses occurred along the crop due the carpophagic insect injury.

Cotton crop have a relatively long cycle, with fruiting time starting from 45 days after emergence, and the abscission of floral organs is commonly variable with the phenological stage. Despite of abscission may have several causes it is notorious the high impact of several species of pests damaging and shedding cotton reproductive structures such as *Helicoverpa armigera*, *Spodoptera frugiperda* and *Anthonomus grandis* on Brazilian cotton crops (GORE et al., 2000; BELOT et al., 2016).

This study aimed to measure the capacity of four Brazilian cotton cultivars to compensate losses promoted by carpophagic insects.

## 2 MATERIAL AND METHODS

The experiment was developed at Embrapa Rice and Beans, Santo Antonio de Goiás, GO, Brazil (S 16.0280, W 49.0170), from March to October 2015. Four widely used cotton cultivars, two early-medium cycle cultivars (FM913GLT and FM966LL) and two late cycle cultivars (FM980GLS AND FM975WS) were sown in irrigated area of dystrophic latosol soil.

Each plot consisted of a randomized choice of ten plants in the center of 10-m<sup>2</sup> area, which had their floral structures removed. These selected plants were surrounded by not injured plants, assured by a rigorous program of cropping management, including supplemental irrigation, weed control, fertilization and weekly pest control by insecticides sprayings throughout the entire growing cycle to prevent real damage.

The damage consisted of five levels of manual flower buds, flowers and apples removal at 75 days after emergence (DAE). The intensity of the injury varied from no attack (no structure removed from the plant) to high damage (10 structures removed by plant), simulating occurrences of insects that attack reproductive structures such as *Helicoverpa armigera*, *Spodoptera frugiperda* caterpillars and

boll weevil *Anthonomus grandis*. To understand the behavior of the curve described by the increase of injury on the production of floral structures a nonlinear regression was adjusted.

We recorded the number of floral structures per injured plant at 140 days after emergence (DAE) and at harvest time. The number and weight of harvested bolls was registered. The plant relative maturity assumed when 60% of bolls were open, value empirically used to define the crop defoliation time. Data from boll weight were statistically analyzed by using analysis of variance and medium-sized cluster test (Scott-Knott,  $p < 0.05$ ).

Assuming as expected yield a volume of 4000 kg of cotton grain, population density of 100,000 plants per hectare and 4.5 grams as the average boll weight (values close to the average yield, stand and boll weight, respectively, for Brazilian cultivars), 12 bolls per plant was defined as equivalent yield default. We defined the damage boundary (Db) as the point where the response curve that draws the increase of the injury intensity crosses the equivalent yield line.

The method of pest injury simulation does not allow the evaluation of the influence of nutrients available in the structures that are translocated before abscission nor the eventual antibiosis induced by the plant against insect attacks. Nevertheless, we assumed that the data represent with good precision the insect attack and the consequent phenological response of the plant.

### 3 RESULTS AND DISCUSSION

The response to the simulated reproductive organ abscission through manual removal varied among cultivars, exhibiting compensation or overcompensation in different ways and different degrees. Considering the injury intensity injury model proposed by Pedigo et al. (1986), while the cultivar FM913GLT presented damage curve expressing tolerance, overcompensation, compensation and linearity (Figure 1b), another ones presented damage curve expressing not including tolerance (FM980GLT and FM975WS) (Figures 1a and 1c), and FM966LL expressed only compensation and linearity as response to injury (Figure 1d). Overcompensation and compensation stages shown by FM980GLT designed an elliptical curve with increased productivity with injuries of up to 10 structures and maintenance of expected productivity. FM980GLT showed high response capability after be injured, reaching peak of 32 bolls produced by plant when ca. 7 structures were removed, while FM966LL produced less than damage boundary (Db) and tended to significantly decrease production after 5 structures removed. FM975WS and FM913GLT tolerate, overcompensate or compensate losses of up to eight and nine floral structures, respectively. FM966LL did not present tolerance or compensation of losses of floral structures.

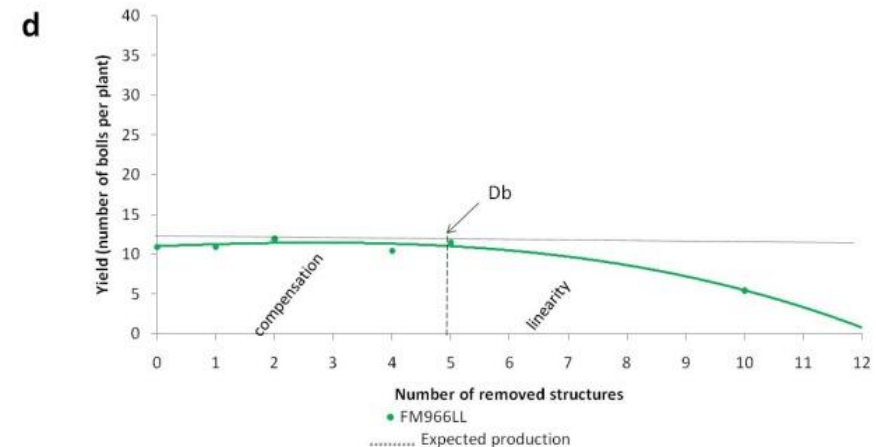
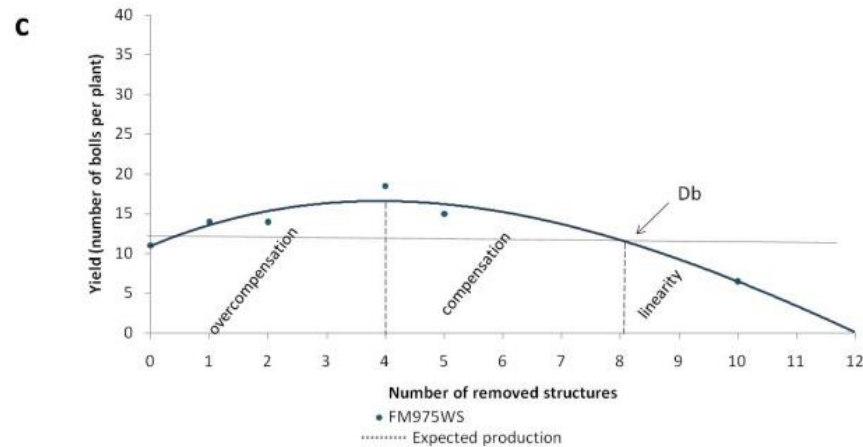
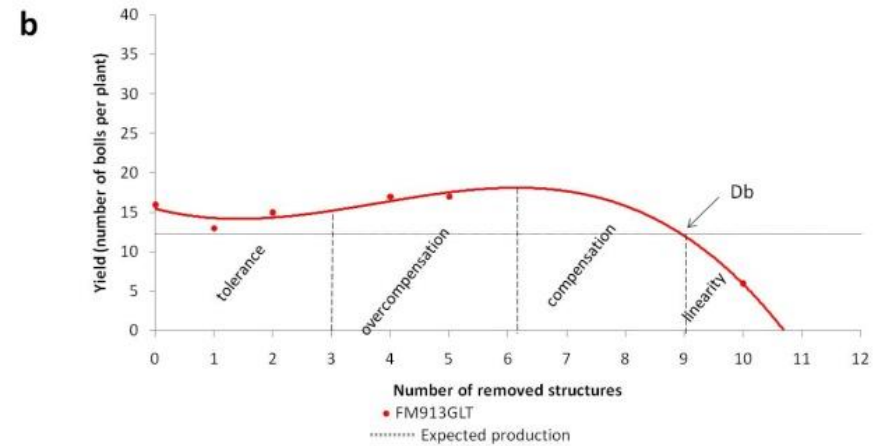
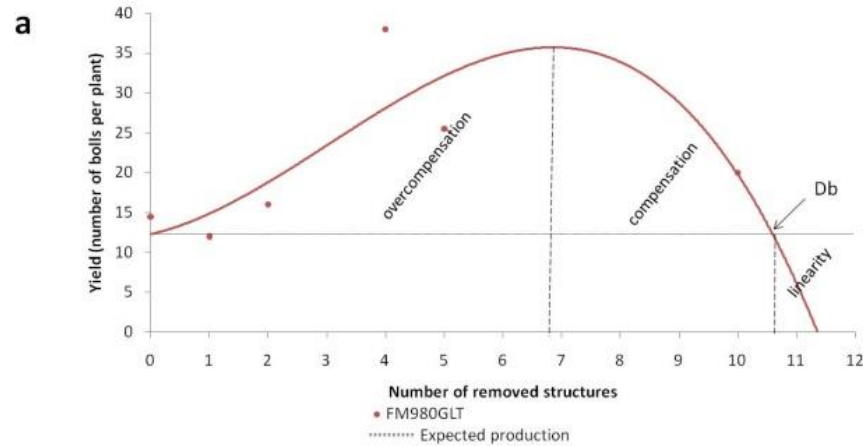
While three cultivars (FM980GLT, FM913GLT and FM975WS) presented a slope with an upward trend, reaching a maximum value and then decreasing, as the intensity of injury was increased;

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the another one (FM966LL), after a trend of stability despite the increase of the injury, showed marked trend of decreased productivity (translated by the number of fruiting structures).

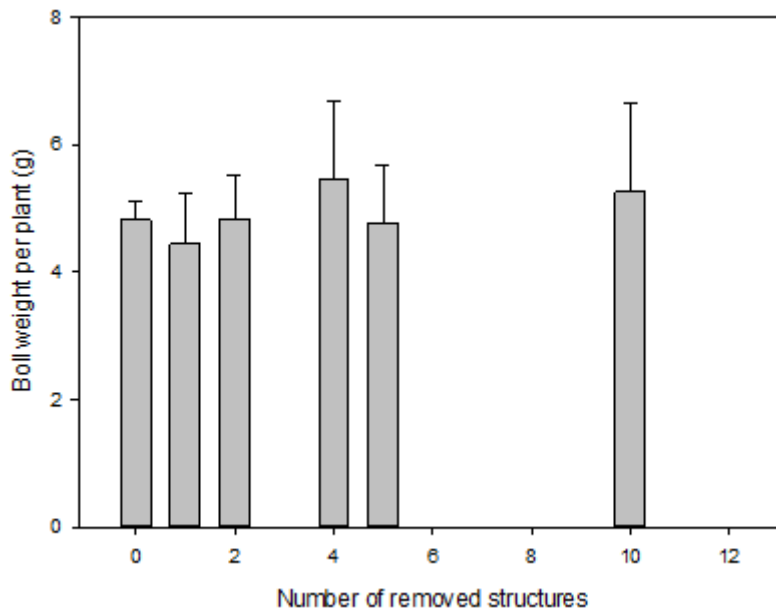
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Figure 1. Response of cotton plant production resulting from the relationship between removed structures and produced bolls at 75 days after emergence. Santo Antonio de Goiás, Brazil, 2015. Regression lines for a)  $y = -0.1107x^3 + 1.015x^2 + 1.6691x + 12.285$ ; b)  $y = -0.074x^3 + 0.85x^2 - 1.967x + 15.47$ ; c)  $y = -0.3043x^2 + 2.5707x + 11.144933$  and d)  $y = -0.1071x^2 + 0.5357x + 10.892$ . Db means damage boundary and represents the point where compensatory response is equal to expected production (no compensation nor yield loss) despite the damage.



A probable type of response by plants to losses that increase yield is caused by the increased on the reproductive structures weight. Brook et al. (1992) affirm that cotton boll weight often increase when boll numbers are reduced and vice versa, suggesting a mechanism operating to modify boll weight to compensate for change in boll numbers caused by an external agent such as insect damage. While Kletter & Wallack (1982), testing Acala SJ-2 cotton material in Israel corroborate this effect, in contrast we could not confirm this hypothesis in our study. Increased injury intensity did not affect boll weight (Figure 2).

Figure 2. Cotton boll weight on plants with different degree of removal of reproductive structures at 75 DAE. Santo Antonio de Goiás, 2015. No significance among the different intensity of injury.



Although Bt cotton accounts for more than 80% of the area under cotton cultivation in Brazil, important frugivorous pests such as *Anthonomus grandis*, *Helicovera armigera* and *Spodoptera frugiperda* are not efficiently controlled by transgeny. Therefore, cotton insect pest management in Brazil relies heavily on insecticide-based crop protection strategies. Up to a certain level of injury, cotton plants may overcompensate the lack of tissues by replacing structures, so the presence of a certain population density of such pest may even be beneficial for the plant production.

Quantifying insect feeding damage is an important step in developing economic threshold levels. Simulation of damage patterns can help to quantify expected damage thorough time, as affected by various variables concerned. Simulation can yield reasonable estimates of damage if the input parameters that could be used as provisional guidelines (HASSAN & WILSON, 1993). Through injury simulation, we verified different responses from cotton cultivars. Responsive cultivars can withstand the attack of



carpophagic insects on their structures to a level clearly superior to nonresponsive cultivars. Responsiveness seems to have a positive correlation with the duration of the development cycle.

The response capacity of cotton cultivars to insect injury is variable according to the intrinsic genetic characters, soil and climate conditions and other stressful causes. To compensate for eventual loss through the replacement of structures, the energy produced by photosynthesis tends to be diverted from the vegetative development to these reproductive organs. This response is also dependent on the age of the plant and tends to be more intense the earlier the event occurs, thus taking the plant time to replenish the loss. As Trumble et al., (1993) emphasize, the compensatory responses vary and the impact of that response on fitness or yield is determined by several habitat-, plant-, and damage-specific components. In our study, the later cycle cultivar FM980GLT was the one that presented more overcompensation capability than the medium cycle cultivars. Nevertheless, FM913GLT, a medium-early cycle cultivar, also presented tolerance and overcompensation, although at a lesser extent. Then, precocity may influence a compensation capacity, but it is not the unique cause. Other genetic traits may be related.

Injuries promoted in early-stage floral structures (flower buds, flowers and new bolls) may be more easily replaced. In contrast, carpophagic insect attacks in more advanced stages of plant development tend to be definitive, since the production schedule of the plant is typically executed. According to the availability of insect feeding substrate structures and the population size of the herbivorous species, the intrinsic ability to respond to injury may also vary (GORE et al., 2000).

Regarding the relationship between cotton boll weight and boll number, our results differ from those obtained by Kletter & Wallack (1992) and Brook et al. (1992). The divergent responses occur probably because of the differences between cultivars and the climate and soil conditions of each study. Another possibility is that early injury allows the plant to convalesce in time to produce new structures. From the reproductive point of view, seeking the perpetuation of the species, new structures containing new seeds are more advantageous than simply increasing the fruit weight.

In sum, we have been able to discriminate responsive and nonresponsive cultivars whose ability to overcompensate lost structures is variable and has genetic and environmental causes. The measurement of the capacity of compensation of commercial cultivars can help in the definition of economic threshold for secure decision and great accuracy, contributing to the sustainability and the guarantee of productivity.



**4 CONCLUSIONS**

Cotton plants replaced a number of structures lost by simulated pest injury through a mechanism that compensate injury until a damage boundary.

The intensity of the compensatory response vary among cultivars.

The most responsive cotton cultivar was FM980GLT, supporting a damage boundary corresponding to 10.5 injured reproductive structures per plant.

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