SYMPTOMS AND YIELD LOSS FROM 2,4-D EXPOSURE: A CASE STUDY
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Abstract
Severe damage was observed in part of a quarter-section cotton field adjacent to and down-wind of an 80-acre wheat stubble field that was treated with a 2,4-D acid formulation in early July. Another part of the field was asymptomatic and appeared unaffected. Plant response, yield and economic loss estimates were made comparing affected areas versus unaffected areas. In severely affected areas, fruit set was significantly reduced and development was retarded compared to unaffected areas. Yield in severely affected areas was reduced by 56% (257 lbs/acre versus 578 lbs/acre). Field-wide lint yield loss was reduced by 11% (64 lbs/acre). Quality, as measured by the loan rate, was reduced in severely affected areas by $0.049 per pound ($0.4340 versus $0.4833) due to grade reductions in color, leaf content, and micronaire. When the whole-field yield was compiled, the effect on the loan rate for the lint was negligible, in part because yield was reduced in the affected area. Turnout was significantly reduced (24% versus 34%) and cost per bale for ginning significantly increased ($16.77 cost per bale versus $1.91 credit per bale) where damage was severe.

Introduction
Damage to susceptible, non-target crops from auxin herbicides has occurred since they were first used (Carns & Goodman, 1956; Sciumbato et al., 2004; Marple et al. 2007). Damage is typically expressed in foliage malformation (“leaf strapping”), fruiting delay, reduction and malformation, and reduced yield. The severity of damage is related to the timing and degree of exposure (Miller, et al., 1963). The on-going effort to make hormone-type herbicides safe has been and continues to be elusive, although significant progress is being made. Current efforts include searching for new, less volatile formulations of the auxin herbicides, e.g., dry or glycol-based amines, acids. An anticipated development is release of genetically modified soybean (Glycine max. and cotton (Gossypium hirsutum) cultivars that are resistant to the effects of exposure to dicamba (Banvel®, Clarity®) and or 2,4-D (Weedar® and many generic products). As new products are introduced, experience in the field is the true, final test for evaluating the safety of the formulations.

In 2013, two fields were observed where an acid formulation of 2,4-D (“Rugged®”, by Winfield Solutions) was applied to wheat stubble fields adjacent to and up-wind of a cotton field. The layout of the case presented in this report was ideal for identifying and confirming the timing and source of the damage, as the damaged field was a quarter section on the northern border of two eighty acre fields owned and operated by differing producers using differing practices (Figure 1). The SE 80 acres were no-till, sprayed with 16 oz/acre of 2,4-D, and the SW 80 acres were conventional tillage, not sprayed. The prevailing winds were at 13 mph, from the South / South-West. Signs of exposure were discovered on July 19th, when the plants had approximately 12 true leaves. A photograph from 7/10 (9-10 true leaves) shows no damage. The application was determined to have been made on 7/9. An unrelated study in the affected field was terminated due to the subsequent auxin damage, so efforts were diverted and re-focused on the developing situation in this field.
The purpose of this study is to document the impact of early-season 2,4-D exposure on plant fruiting, lint yield and quality, and economic losses.

**Methods and Materials**

**Classification of Observed and Sampled Areas**
Damage was initially observed as classic auxin strapping (Carns & Goodman, 1956), and proceeded to square And boll loss from nodes near the fruiting node at initial herbicide exposure. Later effects were the presence of many green, immature bolls on affected plants as the cotton compensated for prior boll loss. Symptoms were most evident in the area immediately down-wind from the 2,4-D application. This area was labeled the “most affected”. The overall affected area was taken to be that where initial leaf elongation and distortion was observed on the majority of the plants. The asymptomatic areas were labeled unaffected, although the possibility of unobserved effects cannot be excluded. Subsequent samples described as representing the entire field included all harvested yield.

Crop progress in the affected area of the field was photographed periodically from the early season, prior to observed damage, through harvest. Plant mapping, boll counts, and boll maturity data were collected on a set of five consecutive plants sampled in each of most affected and apparently unaffected areas on 10/9, prior to the application of a boll opener (ethephon). Data on boll numbers, maturity, and seed cotton weight were also collected from five-plant samples in most affected and unaffected areas on 11/14, just prior to harvest.

The impact of the 2,4-D exposure on yield and quality were determined by marking off and measuring acreage of unaffected (31.8 acres) and most affected (21.3 acres) areas. These areas were harvested, ginned, and graded separately. The entire field was then harvested for total lint weight and average loan rate. Lint weights and qualities from the total field were compared with the figures of the unaffected and affected areas.

**Results and Discussion**

**Plant Response-Prior to Boll Opener**
Plant response to early season 2,4-D exposure, when compared to growth of unaffected plants, suggests a reduction in boll numbers and a delay in maturity by the time boll opener was to be applied (Sample date:10/9; Table 1).
Table 1. Total numbers and maturity of Bolls on plants in unaffected and affected areas prior to application of boll opener (ethephon). Sample Date: 10/9. Sample size = 5 consecutive plants.

<table>
<thead>
<tr>
<th></th>
<th>Green Bolls</th>
<th>Open Bolls</th>
<th>Total Bolls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unaffected (5 plants)</td>
<td>17</td>
<td>48</td>
<td>65</td>
</tr>
<tr>
<td>Affected (5 plants)</td>
<td>54</td>
<td>2</td>
<td>56</td>
</tr>
</tbody>
</table>

The effect of the 2,4-D exposure on the distribution of the fruit on the plants was evidenced by the results from mapping the plants (Figures 1.A and 1.B). Compared to the unaffected plants, there was a sharp decrease in fruit on main stem nodes (MSN) =9, an absence of open bolls in the lower MSNs and greater numbers of green bolls in the upper MSNs (Figure 1.B). What is not evident by the mapping diagrams is that many of the green bolls on the lower MSNs of the affected plants, especially MSN 5 and 6, were on the distal ends of the vegetative branches, versus bolls on the proximal ends of the branches of the unaffected plants.

A.) Unaffected plant (average bolls per MSN)
B.) Affected plant (average bolls per MSN)

Figure 2. Mapping of plants in (A) unaffected areas and (B) affected areas. Plants collected on 10/4, prior to application of boll opener (ethephon). GB = Green Bolls; OB= Open Bolls. Map = average bolls of 5 consecutive plants x Main Stem Node (y-axis).

Plant Response-Prior to Harvest (11/14)

Boll counts of sample plants taken just prior to harvest (11/14), suggest a loss of many of the immature bolls that were present in the earlier sample, prior to the ethephon treatment (Table 2). Although the numbers of bolls retained to harvest are actually greater on the affected plants (44 versus 32), this does not accurately reflect their size or condition (Figure 3). Of those bolls classified as “open” for the affected plants (29), half of them (14) were smaller, only partially open and had significantly reduced lint, whereas the 32 open bolls of the unaffected plants were larger and all were fully open. The 15 green bolls from the affected plants were small, and deformed with partially desiccated lint and did not contribute to yield. The total effect of the 2,4-D on yield was a 56% reduction in seed cotton weight (51g versus 117g) in bolls from the affected plants versus unaffected.

Table 2. Total numbers and maturity of Bolls, and seedcotton weights in unaffected and affected areas prior to harvest. Sample Date: 11/14. Sample size = 5 consecutive plants

<table>
<thead>
<tr>
<th></th>
<th>Green Bolls</th>
<th>Open Bolls</th>
<th>Total Bolls</th>
<th>Seedcotton wt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unaffected (5 plants)</td>
<td>0</td>
<td>32</td>
<td>32</td>
<td>117 g</td>
</tr>
<tr>
<td>Affected (5 plants)</td>
<td>15</td>
<td>29*</td>
<td>44</td>
<td>51 g</td>
</tr>
</tbody>
</table>

*includes partially opened bolls

Figure 3. Total bolls from 5-plant samples taken prior to harvest (11/14): unaffected (L), and affected (R). 2,4-D Effect on Whole Field Yield and Lint Quality
Harvest of the unaffected (31.8 acres) and the “most affected” (21.3 acres) areas resulted in yield of 577 lbs/acre lint versus 283 lbs/acre lint, respectively, a loss of 294 lbs/acre (51%). The loss is substantial, but did not figure into the yield impact equation for the whole field. Yield for the entire field came to 513 lbs/acre lint, which, when compared to the unaffected area was an average loss of 64 lbs/acre (11%) over the whole field.

The impact of the 2,4-D exposure on lint quality on the unaffected and affected acres above are reported in Table 3. The most affected area showed grade differences primarily in color, leaf content, and micronaire, which resulted in a loan rate of $0.4340 / lb, a reduction of $0.0493/lb (10%) from the $0.4833/lb of the unaffected area. The loan rate for the harvested lint from the entire field was $0.4835/lb, which was a very small (but effectively zero) increase over the loan rate of the unaffected area. This is consistent with Smith and Wiese (1975), who demonstrated that lint quality was at most only slightly affected by 2,4-D exposure. A probable explanation for this observation is that the field was not uniform and the quality (and yield) was better in some places than where the unaffected area was used to estimate impact. Another possible explanation is that part of the field actually experienced a benefit in some areas over the gradient of concentration of exposure to the 2,4-D. Such efforts have previously been documented (Egan et al., in press).

The greatest difference between the most affected and unaffected areas is not so much in the grades, but in the ginning turnout, i.e., 24% versus 34.4%, including the percentage of trash taken to the gin, i.e., 45% versus 21%. In Table 3, it can be seen that the grade numbers for the unaffected area are essentially identical to those for the entire field, except for the turnout, which reflects the increase in trash from the poorer areas.

Table 3. Effect of 2,4-D on Fiber Quality and Value (Loan Rate), 2013.

<table>
<thead>
<tr>
<th></th>
<th>Color</th>
<th>Leaf</th>
<th>Staple 32nds</th>
<th>Mic</th>
<th>Strength g/tex</th>
<th>Uniformity %</th>
<th>% T.O.</th>
<th>% Trash</th>
<th>Loan Rate $ / lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unaffected</td>
<td>34.9</td>
<td>3.4</td>
<td>33.3</td>
<td>42.3</td>
<td>27.3</td>
<td>79.0</td>
<td>34.44</td>
<td>20.80</td>
<td>0.4833</td>
</tr>
<tr>
<td>Affected</td>
<td>41.9</td>
<td>5.6</td>
<td>34.9</td>
<td>35.1</td>
<td>28.4</td>
<td>80.0</td>
<td>24.04</td>
<td>44.71</td>
<td>0.4340</td>
</tr>
<tr>
<td>Whole Field</td>
<td>34.4</td>
<td>3.5</td>
<td>33.5</td>
<td>42.2</td>
<td>27.6</td>
<td>78.8</td>
<td>32.94</td>
<td>24.25</td>
<td>0.4835</td>
</tr>
</tbody>
</table>

**Economic Impact**

The economic impact of the 2,4-D exposure was calculated by combining the impact on yield (lint lbs/acre) with the impact on quality and value (as reflected by the loan rate), multiplied by the total number of acres in the field. However, to estimate the true value of the lint, the contribution of the marketing pool of which the producer was a member had to be included, which added an additional $0.23/lb, over-and-above the loan rate. The formula used to calculate the total economic impact then became:

\[
\text{Total Economic Impact} = (\text{Yield Unaffected} - \text{Yield Whole Field}) \times (\text{Loan rate} + \text{Pool Contribution}) \times (\text{Total Acres})
\]

\[
= (577\text{lbs/ac} - 513\text{ lbs/ac}) \times ($0.4835 + $0.23*) \times 149.1\text{ acres}
\]

\[
= 64\text{lbs/ac} \times $0.7135/lb \times 149.1\text{ acres}
\]

\[
= $6,808.50
\]

*per conversation with Dick Cooper, PCCA Marketing Pool.

**Summary**

The impact of the 2,4-D exposure was evident. The numbers of bolls was reduced, as was the apparent quality and maturity of bolls. The exposure also affected the distribution of fruit on the plant, showing a delay in fruit set with fewer lower bolls and more bolls higher on the plant. Accordingly boll maturation, as evidenced by high numbers of immature and partially developed bolls was adversely affected. On the field level, yield in the unaffected area was 577 lbs/acre. Yield loss in the most affected area 294 lbs/acre (51%) and 64lbs/acre (11%) overall. However, overall quality, as measured by loan rate, was not greatly affected, apparently due to the small proportion of the total harvested lint that was actually damaged. Many damaged plants did not mature harvestable lint. The total economic impact...
loss to a 149 acre field was due to loss of yield (lbs/acre) and came to a little over $6,800 total. One of the biggest impacts on the harvested lint was in the reduction of lint turnout, i.e., 24% (affected) vs 34.4% (unaffected), and the increase in the proportion of trash, i.e., 44.7% (Affected) vs 20.80% (Unaffected). These differences resulted in significantly increased ginning charges per bale, $16.77 / bale charge vs $1.45/bale credit to the producer.

Acknowledgements

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Robert Miller-producer, Wellington, KS
Curt Guinn-Farmers Coop, Wellington, KS

References

Carns, H. and V.H. Goodman. 1956. Responses of cotton to 2,4-D. Bulletin of the Mississippi Agricultural Experiment Station. 15p.

Eagn, J.F., K.M. Barlow, and D.A. Mortensen. A meta-analysis of the effects of 2,4-D and dicamba drift on soybean and cotton. (accepted by Weed Science December 2013).


APPENDIX 1

Herbicide Treatment
28 oz/ac Touchdown®
16 oz/ac Rugged®
1 qt/100 gal Choice®
6.5 oz/ac Powerlock®