SIMULATED DRIFT OF DICAMBA AND 2,4-D ON SOYBEANS: EFFECTS OF APPLICATION DOSE AND TIME

ABSTRACT: The use of soybean varieties resistant to the herbicides dicamba and 2,4-D may lead to drifts towards areas grown with non-resistant varieties. The aim of this study was to evaluate the effects of dicamba and 2,4-D underdoses applied at the phenological stages V4 and R2 of soybeans. Two experiments were conducted with dicamba or 2,4-D in a randomized block design with four replications. The 4 × 2 + 1 factorial scheme was composed of four doses (0.028, 0.28, 2.8, and 28 g ae ha⁻¹) of dicamba or 2,4-D applied at two phenological stages (V4 and R2) + a control treatment (without herbicide application). Dicamba underdoses caused damage to soybean crop affecting its vegetative growth and yield; the injuries caused by 2,4-D were neither enough to damage crop nor affect yield components. Dicamba underdoses applied at V4 caused injuries of up to 41%, while in R2 they reached 70%. Plant height decreased by up to 61% when treated with dicamba. Soybean yield was reduced by 29 and 76% when the simulated drift occurred at V4 and R2, respectively, and at a dose of 28 g ae ha⁻¹ of dicamba. For the tested underdoses, only 2,4-D had no effect in soybean crop yield.

KEYWORDS: Glycine max (L.) Merrill. Auxin herbicides. Soybean-resistant herbicides.

INTRODUCTION

The emergence of glyphosate-resistant eudicotyledonous weed species led to the need to seek alternative control measures such as the insertion of varieties resistant to the herbicides dicamba (BEHRENS et al., 2007) and 2,4-D (WRIGHT et al., 2010), which may be part of a management program for herbicide-resistant plants commonly used. However, the drift of these herbicides on non-resistant soybean plants can cause damage to the vegetative and reproductive development of the crop, reducing its yield.

Underdoses of auxin herbicides can cause abnormalities in sensitive eudicotyledonous plants (SILVA et al., 2018). Thus, the contamination of the spraying equipment, spraying drift, and volatilization of dicamba can cause phytotoxicity and reduce soybean yield (GROWE, 2017).

Drift is the deviation of the trajectory of particles released during the application, which do not reach the target and cause product losses (SOUZA; CUNHA; PAVANIN, 2011) and economic and environmental damages in nearby areas. Even after the herbicides reach the target, there is still a risk of drift due to their volatilization (JONES, 2018), as well as contamination of sprayer tanks by them.

Studies carried out by Wax, Knuth and Slife (1969), Auch and Arnold (1978), Solomon and Bradley (2014), Jones (2018), and Silva et al. (2018) showed the damages caused by underdoses of auxin herbicides can cause on the soybean crop. Robinson et al. (2013a) observed yield losses of 10% when exposed to dicamba at a dose of 22.7 g ae ha⁻¹. Johnson et al. (2012) observed yield losses of up to 85% with dicamba application at a dose of 41 g ae ha⁻¹. In addition, Andersen et al. (2004) observed that 5.6 g ae ha⁻¹ of dicamba, which corresponds to 1% of the use rate in corn crop, reduced soybean yield by up to 34%, while 112 g ae ha⁻¹ of 2,4-D was necessary to reduce productivity within a range of 25 to 32%.

Crop development stage at the time of exposure of soybean plants to auxin herbicides is a factor that significantly influences the formation of injuries and yield reduction. Soybean at the R1 stage is 2.5 times more sensitive to dicamba when compared to soybean plants at the V3 stage (GRIFFIN et al., 2013). Recently, commercial release of 2,4-D- and dicamba-tolerant soybeans has attracted attention and encouraged research to understand impacts on non-target crops. Thus, the aim of this study was to evaluate the effects of a simulated drift of dicamba and 2,4-D applied at two phenological stages of soybeans.
**MATERIAL AND METHODS**

Two experiments were conducted simultaneously, one with dicamba (Aectra®, 480 g L⁻¹) and one with 2,4-D (Nortox®, 806 g L⁻¹). These were installed in adjacent areas in Rio Verde-GO, Brazil, which is located at 17°48′55″ S and 50°56′28″ W, and 758-m mean altitude. According to Köppen-Geiger classification, the regional climate is Aw (tropical), with precipitation in the summer (October to April) and a well-defined dry period in the winter (May to September). During the experimental period, the recorded precipitation was 147, 244, 267, 136, and 20 mm and the average temperature was 25.0, 24.4, 24.8, 24.9, and 26.3 °C from November 2017 to March 2018, respectively. The soil of the site has a clayey texture, pH (CaCl₂) of 5.4, organic matter content of 3.9%, and base saturation of 71%.

The experiments 1 (dicamba) and 2 (2,4-D) were carried out in a randomized block design, with four replications. The treatments were arranged in a 4 × 2 + 1 factorial scheme of four underdoses (0.028, 0.28, 2.8, and 28 g ae ha⁻¹) applied at two soybean phenological stages (V₄ and R₂), plus an additional treatment without herbicide application. Doses were about 0.0058, 0.058, 0.58, and 5.8% of the commercial dose of dicamba, and about 0.0035, 0.035, 0.35, and 3.5% of the commercial dose of 2,4-D.

The soybean variety ADV 4672 IPRO, non-dicamba-tolerant, was mechanically sown in a no-tillage system with a 0.45 m interrow spacing and 18 seeds per meter. Fertilization and disease and pest management were carried out with the application of phytosanitary products according to the need and technical recommendations for the soybean crop (EMBRAPA, 2013). Weed control was performed with pre-planting glyphosate applications the day before sowing at a dose of 2150 g ae ha⁻¹ and post-planting applications at 25 and 35 days after sowing at a dose of 960 g ae ha⁻¹.

The experimental plots had 25.2 m², being considered as the useful area the 5 central meters of the 5 rows of each plot. Drift simulation was carried out with a CO₂-pressurized backpack sprayer adjusted to obtain a constant pressure of 150 KPa and a spray solution volume of 170 L ha⁻¹. The spray tips used were flat fan type model XR Teejet 8002VB. Weather conditions during V₄ stage applications were: wind speed, 1 m/s; temperature, 29.7 °C; relative humidity, 61.3%. Yet, during R₂ stage, conditions were: wind speed, 1 m/s; temperature 24.5 °C; relative humidity, 79%.

RESULTS AND DISCUSSION

At 7, 14, and 28 days after treatment application (DAA), plant height evaluations were carried out at 5 random points of each plot, taking as a reference the soil surface and the canopy. On the same dates, the phytotoxicity caused by drift simulation was evaluated by means of the visual evaluation and assignment of scores varying from 0 to 100%, where 0% represents no injury and 100% represents plant death, according to the SBCPD (1995).

The useful area was harvested manually at the R₈ stage (full maturation, with 95% of pods with mature coloration), followed by threshing in a mechanized thresher. At harvest time, the number of plants and seed yield in the useful area of each plot were evaluated to determine the yield (expressed at 13% of water content). Ten plants were taken to evaluate the final height, the number of branches, and the number of pods per plant, as well as the number of grains per pod in one hundred pods taken at random. The evaluation of one thousand-seed weight was carried out with eight replications of one hundred seeds for each plot on a precision analytical balance (0.01 g) (BRASIL, 2009).

Data were submitted to normality and homogeneity tests, analysis of variance (p ≤ 0.05), and Dunnett and Tukey tests (p ≤ 0.05), using the software Assistat in order to detect differences between treatments and the control and between treatments without presence of the control. For plant injury and height at 7, 14, and 28 DAA, only the doses were compared. The data of the variable injury at 7, 14, and 28 DAA for both experiments were transformed using the equation (X + 1)⁰.⁵ by using the software SISVAR version 5.6.

The induced injuries varied according to the herbicide, doses, and soybean phenological stage at application time (Table 1). At the dose of 0.028 g ae ha⁻¹, dicamba drift during V₄ caused no injury compared to the control in all evaluations. An opposite effect was observed at higher doses. A higher phytotoxicity was observed between 7 and 14 DAA, with symptoms reducing after 14 DAA. This shows that toxic effects of dicamba take longer to manifest, and that soybean plants have mechanisms allowing them to recover, at least partly, the drift damages. Solomon and Bradley (2014) observed that plants treated with dicamba sub-doses at V₃ recovered, but those treated in R₂, showed no signs of injury recovery.
Other authors also have reported higher injuries caused by dicamba at 14 DAA when compared to 7 DAA (AL-KHATIB; PETERSON, 1999; GRIFFIN et al., 2013; GROWE, 2017). Injuries caused by dicamba in soybean plants are observed in newly formed tissues, as it is translocated to meristematic tissues (SENSEMAN, 2007). Varieties of indeterminate growth habit present the formation of injuries in newly formed leaves since there is the formation of vegetative organs even after flowering (HEATHERLY; ELMORE, 2004).

The effects of dicamba applied at R$_2$ differed in relation to those of application at V$_4$ since no reduction in injury intensity was observed as a function of time, therefore, plants could not recover, except at the lowest dose (0.028 g ae ha$^{-1}$). At the lowest dicamba dose, the highest injury levels were 4.8 and 22.3% for V$_4$ and R$_2$, respectively, whereas for the highest dose it was 41.3 and 69.8% for V$_4$ and R$_2$, respectively. These results are supported by those observed by Silva et al. (2018), who observed increased levels of injury in soybean plants with increasing dicamba doses.

A higher percentage of injuries was observed at a dose of 2.8 g ae ha$^{-1}$ of 2,4-D at 14 DAA (Table 1). The other doses, evaluated at 7, 14, and 28 DAA, were unable to compromise soybean development, being classified as very light injuries according to the scale described by SBCPD (1995). Solomon and Bradley (2014) evaluated underdose of eight synthetic auxin herbicides, including dicamba and 2,4-D, applied at two phenological stages (V$_3$ and R$_2$) on soybeans and observed that all herbicides caused injury and reduced crop yield, except for 2,4-D.

The tested herbicides reduced the height of soybean plants evaluated at 7, 14, and 28 DAA, but more intense reductions were observed for the application of dicamba underdoses in relation to 2,4-D (Table 2). At 28 DAA, plant height reduction reached approximately 35 and 50% for doses of 2.8 and 28 g ae ha$^{-1}$ of dicamba applied at V$_4$, respectively (Table 2). Solomon and Bradley (2014) observed that dicamba reduced the height of soybean plants at 28 DAA for doses of 2.8 and 28 g ae ha$^{-1}$ applied at V$_3$ and R$_2$. Silva et al. (2018) observed a 60% reduction in plant height under dicamba drift at a dose of 42 g ae ha$^{-1}$ at V$_5$.

Similarly, the height of soybean plants evaluated at 7, 14, and 28 DAA was lower when exposed to higher dicamba underdoses applied in R$_2$, as well as in 2,4-D applications at a dose of 28 g ae ha$^{-1}$ in R$_2$. The application of 28 g ae ha$^{-1}$ of dicamba at R$_3$ reduced plant height by 53% at 28 DAA (Table 2). On the other hand, the application of 0.028 g ae ha$^{-1}$ of dicamba promoted a reduction in the height of soybean plants (109.9 cm) in relation to the control (116 cm).

The reduction in plant height promoted by dicamba may decrease crop yield (JONES, 2018). Solomon and Bradley (2014) also observed that reductions in plant height reduced yield, but less strongly than plant injuries. The reduction of plant

---

**Table 1.** Injury in soybean plants in response to the application of dicamba (experiment 1) and 2,4-D (experiment 2) doses at phenological stages V$_4$ and R$_2$ and evaluated at 7, 14, and 28 days after application (DAA)

| Herbicide | Dose (g ae ha$^{-1}$) | V$_4$ | R$_2$ |
|-----------|-----------------------|-------|-------|
|           | 7 DAA | 14 DAA | 28 DAA | 7 DAA | 14 DAA | 28 DAA |
| **Injury** |       |       |       |       |       |       |
| Dicamba   | 0.028 | 4a$^2$ | 5a | 1a | 9a$^{(+)}$ | 22a$^{(+)}$ | 11a |
|          | 0.28  | 9ab | 30ab$^{(+)}$ | 1a | 15a$^{(+)}$ | 26a$^{(+)}$ | 24ab$^{(+)}$ |
|          | 2.8   | 25b$^{(+)}$ | 31ab$^{(+)}$ | 16b$^{(+)}$ | 18a$^{(+)}$ | 31a$^{(+)}$ | 35b$^{(+)}$ |
|          | 28    | 38c$^{(+)}$ | 41b$^{(+)}$ | 24b$^{(+)}$ | 38b$^{(+)}$ | 33a$^{(+)}$ | 70c$^{(+)}$ |
| Control   | 0     | 0   | 0    | 0     | 0     | 0     |
| 2,4-D     | 0.028 | 0.3ab | 0.0 | 0.0 | 0.0 | 1.3 | 3.0 |
|          | 0.28  | 0.0a | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
|          | 2.8   | 1.4b$^{(+)}$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
|          | 28    | 0.6ab | 1.3 | 0.0 | 0.0 | 1.0 | 3.3 |
| Control   | 0     | 0   | 0    | 0     | 0     | 0     | 0    |
| CV (%)    | 13.97 | 0.00 | 0.00 | 0.00 | 26.38 | 50.65 |

Means followed by different letters within a row differ significantly from each other by the Tukey’s test (p<0.05). Means followed by (+) were higher when compared to those of control treatment by the Dunnett’s test (p<0.05). 1Injury scoring according to Frans (1972). 2Data transformed to (X+1)$^{0.5}$ for analysis.
Simulated drift of dicamba… COSTA, E. M. et al.

height by auxin herbicides is caused by an increase in abscisic acid, which may limit plant growth over a period until it overcomes these effects (ROBINSON et al., 2013a). The reduction of plant height decreases leaf area and photoassimilate production, resulting in lower yields (ROBINSON; SIMPSON; JOHNSON, 2013b).

### Table 2. Plant height in response to the application of dicamba (experiment 1) and 2,4-D (experiment 2) at V₄ and R₂ stages and evaluated at 7, 14, and 28 days after application (DAA)

| Herbicide | Dose (g ae ha⁻¹) | Phenological stage | V₄ | R₂ |
|-----------|------------------|--------------------|----|----|
|           | 7 DAA | 14 DAA | 28 DAA | 7 DAA | 14 DAA | 28 DAA |
| Dicamba   |       |        |        |      |        |        |
| 0.028     | 41 a  | 58 a   | 88 a   | 74 a | 93 a   | 109 a  |
| 0.28      | 35 ab | 50 b   | 83 a   | 65 b | 86 a   | 99 b   |
| 2.8       | 30 bc | 38 c   | 56 b   | 54 c | 74 b   | 73 c   |
| 28        | 27 c  | 33 c   | 44 c   | 47 d | 60 c   | 55 d   |
| Control   | 40    | 56     | 86     | 68   | 88     | 116    |
| CV (%)    | 7.60  | 5.56   | 4.55   | 5.48 | 5.33   | 2.55   |
| 2,4-D     |       |        |        |      |        |        |
| 0.028     | 38 a  | 60 a   | 91 a   | 73 ab| 95 a   | 114 ab |
| 0.28      | 39 a  | 59 a   | 92 a   | 75 ab| 93 a   | 115 ab |
| 2.8       | 37 a  | 56 ab  | 88 a   | 83 a | 98 a   | 119 a  |
| 28        | 38 a  | 54 b   | 89 a   | 65 b | 83 b   | 105 b  |
| Control   | 39    | 59     | 89     | 74   | 94     | 115    |
| CV (%)    | 3.14  | 3.83   | 3.25   | 5.37 | 2.72   | 3.91   |

Means followed by different letters within a row differ significantly from each other by the Tukey’s test (p<0.05). Means followed by (−) were higher when compared to those of control treatment by the Dunnett’s test (p<0.05).

Plant height at soybean harvest presented an effect of the interaction between dicamba doses and stages of application, with a reduction at a dose of 28 g ae ha⁻¹ applied in R₂ (Table 3). Dicamba applied at a dose of 28 g ae ha⁻¹ at V₄ and R₂ resulted in plants 30 and 61% lower when compared to those observed in control treatment, whereas the dose of 0.028 g ae ha⁻¹ applied at V₂ and R₂ had no significant difference from the control (Table 3). Auch and Arnold (1978) observed higher reductions in the height of soybean plants under applications performed at the beginning of flowering when compared to vegetative stages. However, Silva et al. (2018) observed a higher reduction in plant height when applications of dicamba underdoses were performed at vegetative stages.

### Table 3. Plant height (PH) at harvest time, number of lateral branches (NLB), and number of pods per plant (NPP) of soybeans treated with four doses of dicamba (experiment 1) and 2,4- D (experiment 2) at two development stages

| Herbicide | Dose (g ae ha⁻¹) | Phenological stage | V₄ | R₂ |
|-----------|------------------|--------------------|----|----|
|           | PH (cm) | NLB | NPP |
| Dicamba   |       |     |     |
| 0.028     | 102 aA | 3.8 aA | 68 aA |
| 0.28      | 100 aA | 3.6 aA | 54 bB |
| 2.8       | 85 bA  | 5.1 aA | 65 aB |
| 28        | 73 cA  | 4.5 aA | 67 aA |
| Control   | 103.8  | 4.6  | 54   |
| CV (%)    | 4.48   | 24.21 | 11.36 |
| 2,4-D     |       |     |     |
| 0.028     | 111 aA | 4.2 aA | 55 abB |
| 0.28      | 109 abA| 4.3 aA | 52 bA |
| 2.8       | 103 bB | 3.9 aA | 64 aA |
| 28        | 105 abA| 3.3 aA | 65 aA |
| Control   | 109.1 | 4.73 | 64.33|
| CV (%)    | 3.50   | 23.79 | 10.22|

Means followed by different lowercase letters within a row and uppercase letters within a column differ significantly from each other by the Tukey’s test (p<0.05). Means followed by (−) were lower when compared to those of control treatment by the Dunnett’s test (p<0.05).
The herbicide 2,4-D caused no reduction in the height of soybean plants at harvest time (Table 3). Similar results were observed by Solomon and Bradley (2014), who also noted no reductions in the height of soybean plants treated with 2,4-D at the highest tested dose (28 g ae ha\(^{-1}\)). However, Silva et al. (2018) observed a linear reduction in the height of soybean plants treated with 2,4-D, reaching 18% for the dose of 42 g ae ha\(^{-1}\).

The number of lateral branches was affected by the interaction between dose and stage of application. In this sense, dicamba reduced by 81% the number of lateral branches when applied at a dose of 28 g ae ha\(^{-1}\) at R\(_2\), with no differences between other treatments and control (Table 3). The death of the apical meristem of soybean plants can be compensated for by an increase in the number of branches, which produce flowers and pods that supply a possible yield reduction due to dicamba exposure (WEIDENHAMER; TRIPLETT; SOBOTKA, 1989). Injuries resulting from herbicide drift at vegetative stages do not always compromise crop yield (AL-KHATIB; PETERSON, 1999).

The number of pods, number of grains, and yield were affected by dicamba drift (Tables 3 and 4). The interaction between dose and stage of application for the number of pods per plant was significant, with an increase of 27% in the treatment with 0.028 g ae ha\(^{-1}\) of dicamba applied at V\(_4\) but a reduction of 50% for the application of 28 g ae ha\(^{-1}\) carried out in R\(_2\). Dicamba drift at reproductive stages may reduce crop yield due to the lower number of pods and grains produced. Solomon and Bradley (2014) observed a reduction of approximately 80% in the number of pods per plant for the treatment with 28 g ae ha\(^{-1}\) of dicamba applied in R\(_2\). Kelley et al. (2005) reported that a dose of 5.6 g ae ha\(^{-1}\) of dicamba applied at V\(_3\) and V\(_7\) on soybeans caused no reduction in the number of pods per plant, however, the application at R\(_2\) led to a decline of such variable.

### Table 4. Number of grains per pod (NGP), one thousand-seed weight (TSW), and grain yield (GY) of soybean treated with four doses of dicamba (experiment 1) and 2,4-D (experiment 2) applied at two development stages

| Herbicide | Dose (g ae ha\(^{-1}\)) | Phenological stage | V\(_4\) | R\(_2\) | V\(_4\) | R\(_2\) | V\(_4\) | R\(_2\) |
|-----------|------------------------|-------------------|---------|---------|---------|---------|---------|---------|
|           |                        | NGP               | TSW (g) | GY (kg ha\(^{-1}\)) | NGP               | TSW (g) | GY (kg ha\(^{-1}\)) | NGP               | TSW (g) | GY (kg ha\(^{-1}\)) |
| Dicamba   | 0.028                  | 2.3 aB 2.5 Aa     | 169 aA 174 aA | 3221 aA bA 3194 aA bA | 0.28                | 2.4 aA 2.3 Aa     | 174 aA 174 aA | 3597 aA 3471 aA | 2.8                  | 2.4 aA 2.4 Aa     | 170 aA 179 aA | 2831 bC 2811 bA | 28                   | 2.4 aA 1.9 bB (+) | 171 aA 176 aA | 2365 cA (+) 812 cB (+) |
| Control   | 2.34                   | 180               |  | 3337 | | | | |
| CV (%)    | 5.11                   | 4.21              | 3650 aA 3355 aA | 3672 aA 3417 aA | 3605 aA 3268 aA | 3260 aA 3231 aA | 3607 | | 6.74 |
| 2.4-D     | 0.028                  | 2.5 aA 2.3 Ab     | 186 aA 187 aA | 3650 aA 3355 aA | 0.28                | 2.5 aA 2.4 Aa     | 185 aA 184 aA | 3672 aA 3417 aA | 2.8                  | 2.4 aA 2.5 aA     | 181 aA 183 aA | 3305 aA 3268 aA | 28                   | 2.6 aA 2.3 aB     | 179 aA 186 aA | 3260 aA 3231 aA | |
| Control   | 2.5                    | 185               |  | 3607 | | | | |
| CV (%)    | 4.61                   | 3.91              | 3607 | 6.74 | | | | |

Means followed by different lowercase letters within a row and uppercase letters within a column differ significantly from each other by the Tukey’s test (p<0.05). Means followed by (−) were lower when compared to those of control treatment by the Dunnett’s test (p<0.05).

The interaction between doses and growth stages of herbicide application was significant for the number of grains per pod for both herbicides, especially the highest dose of dicamba and 0.028 and 28 g ae ha\(^{-1}\) of 2,4-D when applied in R\(_2\), leading to a lower number of grains per pod (Table 4). Solomon and Bradley (2014) observed a reduction in the number of grains per pod in a simulated drift of dicamba, but not for 2,4-D, concluding that applications of auxin herbicides carried out at R\(_2\) with higher doses affect the number of grains per pod in a more expressive way than applications carried out at vegetative stage. The weight of soybean seeds was not affected by treatments (Table 4).

The effects of treatments on the evaluated variables in dicamba-treated soybean resulted in a 29% and 76% reduction in yield at a dose of 28 g ae ha\(^{-1}\), when applications were carried out at V\(_4\) and R\(_2\), respectively. Griffin et al. (2013) verified that
Simulated drift of dicamba...  COSTA, E. M. et al.

17.5 g ae ha\(^{-1}\) of dicamba applied at V\(_4\) and R\(_1\) reduced soybean yield by 15% and 36%, respectively. Auch and Arnold (1978) found that dicamba drift at flowering is more damaging than in more advanced reproductive stages. Soybean yield was reduced with increasing doses of auxin herbicides, with a higher loss for dicamba when compared to 2,4-D (SILVA et al., 2018).

Damages promoted by herbicides applied in V\(_4\) were lower when compared to those applied in R\(_2\) due to the longer time interval to repair the damage caused by dicamba between the applications and the end of the cycle (ROBINSON; SIMPSON; JOHNSON, 2013b). Wax, Knuth and Slife (1969) observed a reduction of 23% in soybean yield with the application of 4.4 g ha\(^{-1}\) of dicamba at flowering, whereas 35 g ha\(^{-1}\) was required to reduce the yield by 20% when its application was carried out at the vegetative stage.

One of the factors that reduced soybean yield due to dicamba drift (Table 4) is attributed to non-recovery of height and architecture of plants, leading to a lower vegetative development, lower leaf area, and fewer nodes available for the formation of inflorescences, pods, and grains. Herbicides of the synthetic auxin group activate auxin response genes (ABEL; THEOLOGIS, 1996; KELLEY et al., 2004; ROBINSON et al., 2013a), leading to an overproduction of ethylene and then abscisic acid (GROSSMANN, 2003, 2010; ROBINSON et al.; 2013a). The increased concentration of abscisic acid causes the closure of the stomata, limiting CO\(_2\) assimilation (GROSSMANN, 2010; ROBINSON et al., 2013a).

The herbicide 2,4-D applied under different underdoses and phenological stages promoted no reduction in soybean yield (Table 4). Solomon and Bradley (2014) obtained similar results with a maximum dose of 28 g ae ha\(^{-1}\). However, Silva et al. (2018) observed a reduction of 34 and 17 kg ha\(^{-1}\) in the yield for each gram of 2,4-D applied at V\(_5\) and R\(_2\), respectively.

CONCLUSION

Dicamba underdoses reduced plant height, caused leaf injuries, and reduced crop yield. However, 2,4-D underdoses promoted less damage to soybeans. Therefore, affordable precautions must be taken to avoid damage by herbicides, as these can damage non-tolerant crops.

ACKNOWLEDGMENTS

This study was carried out with the support of the Coordination for the Improvement of Higher Education Personnel, Brazil (CAPES) under the financing code 001 and the Federal Institute of Goiás, Rio Verde Campus.

RESUMO: Com a inserção de variedades de soja resistentes aos herbicidas dicamba e 2,4-D os eventos de deriva destes herbicidas para áreas com variedades não resistentes será passível de ocorrência. Objetivou-se neste trabalho avaliar os efeitos de subdoses de dicamba e 2,4-D aplicados nos estádios fenológicos V\(_4\) e R\(_2\) da cultura da soja. Dois experimentos foram conduzidos com dicamba ou 2,4-D em delineamento experimental de blocos casualizados, com quatro repetições. Adotou-se o esquema fatorial de 4 x 2 + 1 composto por quatro doses (0,028, 0,28, 2,8 e 28 g ea ha\(^{-1}\)) de dicamba ou de 2,4-D, aplicados em dois estádios fenológicos (V\(_4\) e R\(_2\)) + um tratamento testemunha (sem aplicação de herbicida). As subdoses de dicamba provocaram danos na cultura da soja, afetando o desenvolvimento vegetativo e a produtividade, enquanto o 2,4-D não provocou injúrias suficientes para provocar danos que comprometessem a cultura, e desta forma, não afetou os componentes de produção. As subdoses de dicamba aplicadas no estádio V\(_4\) provocou injúrias de até 41%, enquanto em R\(_2\) chegaram a 70%. A altura das plantas reduziu em até 61% quando tratadas com dicamba. A produtividade da soja foi reduzida em 29 e 76%, quando a deriva simulada ocorreu nos estádios V\(_4\) e R\(_2\), respectivamente, e na dose de 28 g ea ha\(^{-1}\) de dicamba. Nas subdoses testadas somente o 2,4-D não afetou a produtividade da cultura da soja.

PALAVRAS-CHAVE: Glycine max (L.) Merrill. Herbicidas auxínicos. Soja resistente a herbicidas.

REFERENCES

AL-KHATIB, K.; PETERSON, D. Soybean (Glycine max) response to simulated drift from selected sulfonyleurea herbicides, dicamba, glyphosate, and glufosinate. Weed Technology, v. 13, n. 2, p. 264-270, 1999. https://doi.org/10.1017/S0890037X00041713
Simulated drift of dicamba…

ANDERSEN, S. M.; CLAY, S. A.; WRAGE, L. J.; MATTHEES, D. Soybean foliage residues of dicamba and 2,4-D and correlation to application rates and yield. *Agronomy Journal*, v. 96, n. 3, p. 750-760, 2004. https://doi.org/10.2134/ agronj2004.0750

AUCH, D. E.; ARNOLD, W. E. Dicamba use and injury on soybeans (*Glycine max*) in South Dakota. *Weed Science*, v. 26, n. 5, p. 471-475, 1978. https://doi.org/10.1017/S0043174500050347

BEHRENS, M. R.; MUTLU, N.; CHAKRABORTY, S.; DUMITRU, R.; JIANG, W. Z.; LAVALLEE, B. J.; HERMAN, L.; CLEMENNE, T. E.; WEEKS, D. P. Dicamba resistance: enlarging and preserving biotechnology-based weed management strategies. *Science*, v. 316, n. 5828, p. 1185-1188, 2007. https://doi.org/10.1126/science.1141596

BRASIL, Ministério da Agricultura, Pecuária e Abastecimento. *Regras para análise de sementes*. Ministério da Agricultura, Pecuária e Abastecimento. Secretaria de Defesa Agropecuária. Brasília, DF: Mapa/ACS, 2009. 395p.

EMBRAPA. *Tecnologias de produção de soja – Região Central do Brasil*. Londrina, PR: Embrapa Soja, 2013. 265p.

GRIFFIN, J. L., BAUERLE, M. J.; STEPHENSON, D. O.; MILLER, D. K.; & BOUDREAUX, J. M. Soybean response to dicamba applied at vegetative and reproductive growth stages. *Weed Technology*, v. 27, n. 4, p. 696-703, 2013. https://doi.org/10.1614/WT-D-13-00084.1

GROWE, A. M. *Effects of Sub-lethal Rates of Dicamba on Maturity Group V and VI Soybean Growth and Yield*. 2017. 114f. Thesis (Master of Science) - Graduate Faculty of North Carolina State University, North Carolina State University, Raleigh, 2017.

HEATHERLY, L. G.; ELMORE, R. W. *Managing inputs for peak production. Soybeans: improvement, production, and uses*. 2004. 85f. Agronomy Monograph, Madison (USA), 2004.

JOHNSON, V. A.; FISHER, L. R.; JORDAN, D. L.; EDMISTEN, K. E.; STEWART, A. M.; YORK, A. C. Cotton, peanut, and soybean response to sublethal rates of dicamba, glufosinate, and 2,4-D. *Weed Technology*, v. 26, n. 2, p. 195-206, 2012. https://doi.org/10.1614/WT-D-11-00054.1

JONES, G. T. *Evaluation of Dicamba Off-Target Movement and Subsequent Effects on Soybean Offspring*. 2018. 197f. Thesis (Master of Science in Crop, Soil & Environmental Sciences) - University of Arkansas, Fayetteville. 2018.

KELLEY, K. B.; WAX, L. M.; HAGER, A. G.; RIECHERS, D. E. Soybean response to plant growth regulator herbicides is affected by other postemergence herbicides. *Weed Science*, v. 53, n. 1, p. 101-112, 2005. https://doi.org/10.1614/WS-04-078R

ROBINSON, A. P.; DAVIS, V. M.; SIMPSON, D. M.; JOHNSON, W. G. Response of soybean yield components to 2,4-D. *Weed Science*, v. 61, n. 1, p. 68–76, 2013a. https://doi.org/10.1614/WS-D-12-00077.1

ROBINSON, A P.; SIMPSON, D. M.; JOHNSON, W. G. Response of glyphosate-tolerant soybean yield components to dicamba exposure. *Weed Science*, v. 61, n. 4, p. 526-536, 2013b. https://doi.org/10.1614/WS-D-12-00203.1

SBCPD - Sociedade Brasileira da Ciência das Plantas Daninhas. Procedimentos para instalação, avaliação e análise de experimentos com herbicidas. Londrina: SBCPD, 1995. 42p.

SENSEMAN, S. A. *Herbicide Handbook*. Champaign, KS: Weed Science Society of America, 9th Edition, 2007. 458p.
Simulated drift of dicamba…

COSTA, E. M. et al.

SILVA, D. R. O.; SILVA, E. D. N.; AGUIAR, A. C. M.; NOVELLO, B. D.; SILVA, A. A. A.; BASSO, C. J. Drift of 2,4-D and dicamba applied to soybean at vegetative and reproductive growth stage. Ciência Rural, v. 48, n. 8, p. 1-7, 2018. https://doi.org/10.1590/0103-8478cr20180179

SOLOMON, C. B.; BRADLEY, K. W. Influence of application timings and sublethal rates of synthetic auxin herbicides on soybean. Weed Technology, v. 28, n. 3, p. 454-464, 2014. https://doi.org/10.1614/WT-D-13-00145.1

SOUZA, L. A.; CUNHA, J. P. A. R.; PAVANIN, L. A. Eficácia e perda do herbicida 2,4-D amina aplicado com diferentes volumes de calda e pontas de pulverização. Planta Daninha, v. 29, n. 2, p. 1149-1156, 2011. https://doi.org/10.1590/S0100-83582011000500023

WAX, L. M.; KNUTH, L. A.; SLIFE, F. W. Response of soybeans to 2,4-D, dicamba, and picloram. Weed Science, v. 17, n. 3, p. 388-393, 1969. https://doi.org/10.1017/S004317450005431X

WEIDENHAMER, J. D.; TRIPLETT, G. B.; SOBOTKA, F. E. Dicamba injury to soybean. Agronomy Journal, v. 81, n. 4, p. 637-643, 1989. https://doi.org/10.2134/agronj1989.0021962008100040017x

WRIGHT, T. R; SHAN, G.; WALSH, T. A.; LIRA, J. M.; CUI, C.; SONG, P.; ZHUANG, M.; ARNOLD, N. L.; LIN, G.; YAU, K.; RUSSEL, S. M.; CICCHILLO, R. M.; PETERSON, M. A.; SIMPSON, D. M.; ZHOU, N.; PONSAMUEL, J.; ZHANG, Z. Robust crop resistance to broadleaf and grass herbicides provided by aryloxyalkanoate dioxygenase transgenes. Proceedings of the National Academy of Sciences, v. 107, n. 47, p. 20240-20245, 2010. https://doi.org/10.1073/pnas.1013154107