

Spread of Dicamba Through Resistant and Not Resistant Crops

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Executive Summary:

Dicamba is a broad spectrum herbicide that was developed in 1967 to kill stubborn weeds in large industrial farms. It has affected over 4% of the United States soybean population due to the new standard application, the “over the top” application when the herbicide is sprayed on the crops after sprouting to 6 inches in height[1]. In the last three years, Monsanto Company has created genetically-modified resistant crops to combat the destructive nature of this herbicide[2]. Growers using Dicamba have been given specific instructions on the over the top application of Dicamba but failed to follow the recommendations resulting in a large spread across the United States. When applied in high wind and/or before 7:30 a.m. or after 5:30 p.m., Dicamba drifts over multiple acres, causing nearby non resistant crops to be affected.

To begin, the team investigated the effects of the over the top application compared to the previous method of spraying the crops before they sprouted. This led to the conclusion that the over the top method produced more vaporized dicamba and resulted in a larger area affected by the herbicide. Because this method is now the standard way to apply Dicamba, the team chose to follow this method and explore what can be done to prevent Dicamba drift to non-resistant crops.

When searching for ways to reduce the diffusion of Dicamba through non-resistant crops, the team came across a diagram of wind speed reductions due to tree breaks[5]. This prompted us to create an experiment modeling the difference in crops infected with and without tree breaks.

Our model showed significant difference when tree breaks are used to slow the spread of Dicamba. The tree breaks diminished the number of infected trees from an average of 348 crops without tree breaks to 80 crops with tree breaks. We collected data from 10 different concentrations of Dicamba and every one had a decrease in infected crops with tree breaks.

Spread of Dicamba Through Resistant and Not Resistant Crops

Introduction:

First registered as a broad spectrum herbicide in 1967, dicamba has been used throughout the years in various weed killers, it's currently found in about 1,100 herbicide products [4]. Dicamba only attacks broad-leafed plants and kills them by mimicking the plant's growth hormones, causing growth abnormalities and eventual death [4].

Recently growers have been facing a war on weeds due to many becoming naturally resistant to the common herbicide called glyphosate (a popular herbicide used by planters and the active ingredient in Roundup) [4]. These "super weeds" have infested over 90 million acres of farmland, leaving many agricultural businesses in a race to find a new herbicide. Companies including Monsanto, BASF, and Dow-Dupont developed genetically modified seeds for soybeans and cotton that possessed a dicamba tolerance [1]. Starting in 2015, the Monsanto

Company, responsible for much of the crop industry, came out with new genetically modified cotton and soybean plant. Under the name Xtend, these plants are resistant to the killing effects of dicamba [1].

Due to dicamba becoming easily vaporized into the air, causing it to become susceptible to drift, it was only permitted to be applied to the soil prior to planting to kill off weeds [2]. A new type of dicamba with the promises of being drift resistant wasn't yet approved by the EPA when Monsanto released the new genetically modified crop to growers. Despite Monsanto stating that Dicamba shouldn't be applied to the crops in an “over the top method”, meaning spraying the herbicide after the crops have sprouted, many growers ignored the manufacturer. A big mistake that caused a massive widespread of the herbicide on non-GMO resistant crops.

Within two years, over two dozen states across the midwest region from Arkansas to North Carolina have been polluted with dicamba with 3.6 million acres of non-genetically modified soybean crops affected [7]. 2,708 complaints have been filed by non-GMO planters with many suing Monsanto. The situation has gotten so bad that a murder case was connected to a dispute over using the herbicide [1]. In addition to soybeans, crops like tomatoes, watermelon, cantaloupe, and pumpkins have been affected by the herbicide. Dicamba has devastating results once it comes in contact with non-genetically modified crops, causing leaves to pucker, pods to buckle, and stunted growth resulting in eventual death [2].

The federal crop insurance won't cover damages from the herbicide due to most policies only covering natural disasters[2]. This widespread issue affects not just planters, with their crops being their life earnings, but also the consumers where they'll end up having to pay more for all goods affected.

Arkansas and Missouri had issued temporary bans on the use and sale of Dicamba[2]. Well after farmers in the Midwest had pulled the last soy and corn plants from their fields and were deep into preparation for this year's planting season, the EPA approved three new formulations of dicamba. Monsanto hoped that its new formula under the name XtendiMax along with the EPA's prediction that carefully applying the new herbicide in certain environmental conditions will reduce the risk of drift [2]. Despite these new, supposedly less volatile formulations, the problem seems to be getting worse with more dicamba based complaints for the 2017 season.

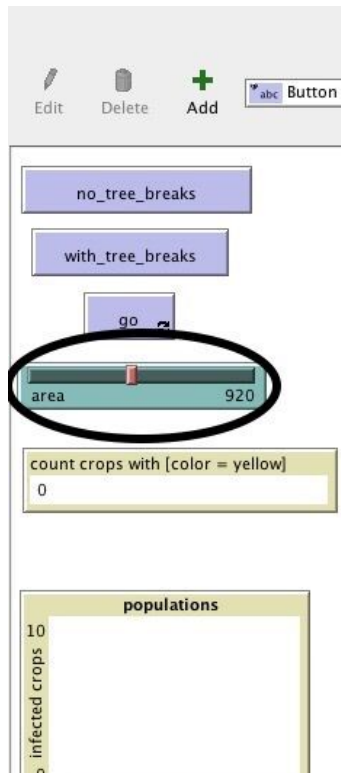
For the 2018 season, much research and testing was put in to reduce dicamba drift. On October 13th the EPA announced enhancements to Monsanto's branded XtendiMax with VaporGrip Technology in hopes of having a better growing season. Along with the new enhancements, new updates on how the herbicide should be applied were voluntarily proposed by Monsanto and supported by the EPA. With these new updates and regulations proposed, Monsanto's Global Regulatory lead hopes that, "Based on the science behind our low-volatility dicamba product and learnings from the 2017 season, we are confident the required training and record keeping can address the main causes of off-target movement" [10].

Despite new improvements made to the herbicide and the genetically modified crops we believe it's important to find a way to help prepare growers with the certain non-GMO crop if another spread were to occur. With an issue to this magnitude, it is important to find the necessary solutions to help prevent further and any additional widespread contamination of crops.

Description:

We solved this problem computationally with the NetLogo agent-based modeling program. Our model depicts crops that neighbor the genetically modified dicamba resistant crop where a planter has ignored Monsanto's recommendations and sprayed the herbicide. We chose an area in the upper northeastern part of New Mexico, next to Oklahoma due to 19 dicamba related cases coming from Oklahoma [8]. Based on wind maps and predicted weather forecasts we were able to depict the wind direction and speeds around the growing season [9]. As a possible solution, we studied the difference between crops with and without tree breaks.

A variable that we manipulated to find what extent tree breaks helped decrease the spread of the herbicide was the concentration of the herbicide. By depicting the land area the herbicide is applied to we're able to manipulate the concentration of dicamba used. In theory, the larger the area, the greater concentration of dicamba.



create-herbicides area / 40

Figure 1.1

We then had the slider value divided over 40. This value depicts the standard amount of gallons of water mixed with 16 ounces of dicamba per acre that is recommended by Monsanto.

In the interface tab, we sprouted multiple agents based on the patch color under the name crops. We created two setup buttons under the name `no_tree_breaks` and `with_tree_breaks`. The `no_tree_breaks` setup button sets up 30 black patches that are positioned in lines that are specially set up in columns.

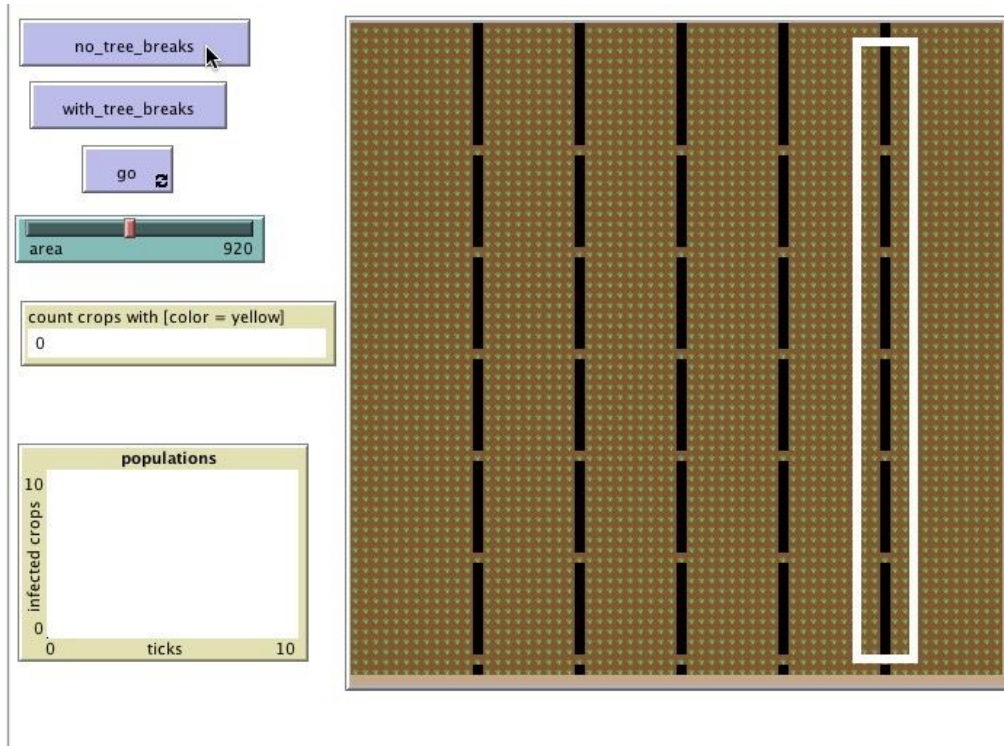


Figure 1.2

These black patches simulate roads. When our agent, under the name herbicide, hits this black patch it decreases its potency by 10%.

The `with_tree_breaks` setup button introduces the second agent named trees. This agent takes over all areas where the black patches were placed.

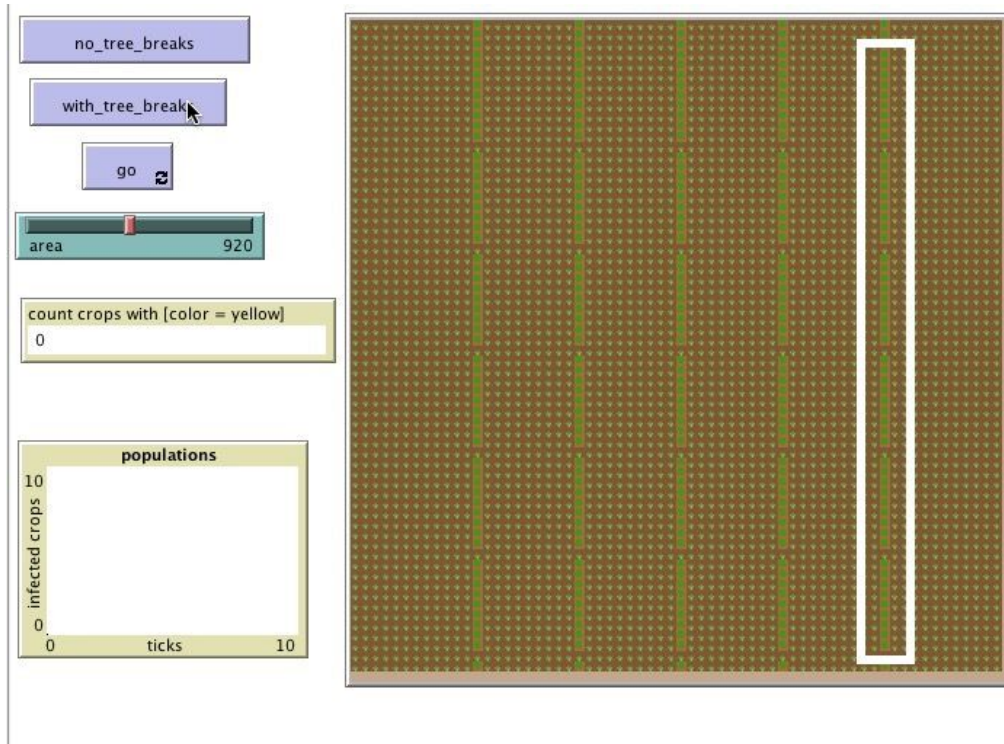


Figure 1.3

In order to simulate the effect of tree breaks on wind, the herbicide slows down by going forward from 1.0 (60 mph) down to .3 (18 mph). Also, the potency goes down by 70% and does a wiggle walk to simulate the air disruption from the trees.

To depict the herbicide diffusing through air, the herbicide follows a set of potency values that's randomly generated in the setup procedure as shown below:

set potency random 200 ;Able to adjust the potency of the herbicide based on the slider in the interface tab.

]

ask trees

[

set potency random 100

]

We chose this potency value as a baseline for how much dicamba is mixed in the solution that's sprayed onto the plants. If we were to convert this over to the real world data that random 200 would be equivalent to 12-16 oz of dicamba. Overtime the herbicide potency values will slowly decrease based on what patches or agents it interacts with. Once the potency level reaches zero the herbicide dies out.

For the go button we have the herbicide agent do a wiggle walk to simulate the herbicide going through the wind. The agents follow the sub set code below titled “to move”:

```
to move
ask herbicides
[
  let colorOfPatchAhead pcolor
  ask patch-ahead 1 ;defines colorOfPatchAhead
  [
    set colorOfPatchAhead pcolor ;sets colorOfPatchAhead to be pcolor
  ]

  if (colorOfPatchAhead = brown) ;; conditional statement that tells the herbicide to wigglewalk
  [
    ;pen-down

    right 1
    left 2
    fd .3
    set potency (potency * .3)
  ]
```

Using multiple conditional statements with defining the “colorOfPatchAhead” statement that tells the agent to look ahead at the patch in front of them. Certain patches cause the herbicide to move differently or lose a certain amount of potency. We also have the herbicide interact with the other agents. When it hits the crops it turns the crops yellow visualizing that they are affected

by the herbicide. This example of the interaction of the agents is under the sub set of code within the go button titled “to infect”:

to infect ;;makes non-resistant crops yellow and makes the potency go down for the herbicide

```
ask crops
[
  if color = green + 1
  [
    if any? herbicides-here
      [set color yellow]
  ]
]
```

To simulate the effects of dicamba the crop turns yellow and grows at a slower rate. To simulate the growth of the plant we followed three agent shapes “plant small” this represents the plant in the early phases of the growing season. “Plant medium” this simulates the plants growth during the middle of the growing season. Lastly there is “plant” this simulates a full grown plant at the end of the growing season and beginning of the harvesting season. After a certain amount of ticks the crops that are yellow die out, leaving a trail where the herbicide drifted through.

We finally used the behavior space tool in the NetLogo program to quickly and neatly organized our results. We ran a total of a hundred trails to test out varying concentrations based on the land size that dicamba is applied to.

Results:

To test our model, we first ran a hundred trials with both setups then averaged out the maximum amount of crops infected based on the variable sizes of the area controlled by a slider. For the first setup we ran the model with no tree breaks. We started off with 200 acres then increased by 200 acres until it hits the maximum of 2000 acres.

When the area increased in size we noticed that the amount of crops that were turning yellow (meaning they were infected) would increase. Starting at 200 acres, the average infection rate was 137 crops. When it reach the maximum area of 2000 acres the average infection rate was 473 crops. Rather interestingly, the number of affected crops increased at variable rate. For instance, the areas where we saw the number greatest number of crops infected was between 200 and 400 acres and where we saw the least amount of infected was between 1600 and 1800 acres.

We then ran the same test with the same increasing variables of acreage but with tree breaks included, we saw a dramatic difference between the model with and without tree breaks. The number of crops infected dramatically decreased with the largest amount infected reaching a peak at 107 crops. Looking through the averages of the variable acreages of land we see the same trend that we saw with no tree breaks. As the acreage increased the number of infected crops increased as well until it reached 2000 acres where the number of infected crops went down from 107 to 102 crops.

This is where we started to see a difference in trends between with and without tree breaks. That theory I stated in the description of our model proved correct, as the acreage went up, the amount of crops infected also went up. This is most likely due to an increasing concentration of the herbicide used in order to cover more land.

Results from an area with no tree breaks

size in acres	average amount of crops infected after ten trials
200	137
400	212
600	274
800	324
1000	357
1200	385
1400	412
1600	448
1800	459
2000	473

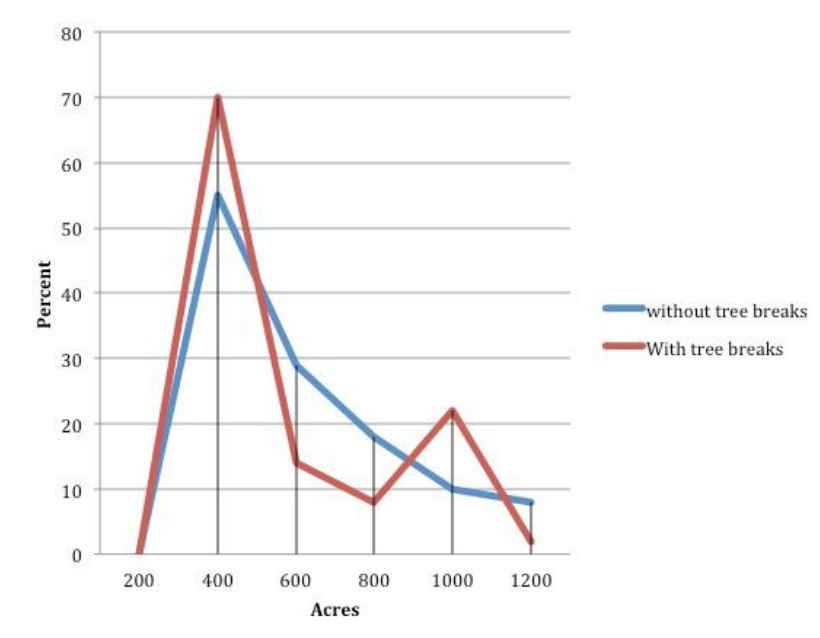
Table 1

Results from an area with tree breaks

Size in acres	average amount of crops infected after ten trials
200	33
400	56
600	64
800	69
1000	84
1200	86
1400	97
1600	102
1800	107

2000	102
------	-----

Table 2

Percent Increase of Infection Between Increasing Areas

Graph 1

Conclusion:

Our data supported our hypothesis that tree breaks would reduce the infection rate of the crops. On average, the Dicamba infected 348 crops without tree breaks and 80 crops with tree breaks. At every interval, tree breaks reduced the amount of infected crops to less than 25% of the amount before the tree breaks. By running ten trials of each model with and without tree breaks we are able to pinpoint where we would see the largest difference if we were to implement tree breaks.

In lower concentrations of Dicamba, the difference between tree breaks and no tree breaks is very apparent. At a rate of 400 acres sprayed, the Dicamba shows the greatest

difference between tree breaks and no tree breaks at 26%. At 1,200 acres sprayed, the difference was the least at 21%.

Recommendations:

In order to make our model more realistic we first had wanted to track different methods of application of the Dicamba. We narrowed it down to one solid model showing its travel and spread through the air. We had wanted to show it's spread through irrigation as well but we had trouble finding an algorithm to properly represent that spreading. Another idea we explored was the implication of wind turbines. This would increase the lengths of our growing seasons by warming up the ground and preventing frost. In conclusion we decided to have our model show the difference between having tree breaks and not having tree breaks.

Acknowledgements:

We want to thank our project mentors Susan Gibbs and Paige Prescott. They have been a huge help in establishing and refining our project ideas in order to further express them onto paper and Netlogo. We also want to give a huge thanks to our teacher Rhonda Crespo. She is the main reason why we joined the Supercomputing Challenge and has always kept us on track and ensured our project is going smoothly.

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Appendix A: Model Code

;;Team Members: Lia Fukuda, Robert Borrego and Stephen Herrera

;;Sponsoring Teacher: Rhonda Crespo

;;Dicamba Drift

breed [crops crop] ;Sets the breed called crops, will be the green plants in our model.

breed [herbicides herbicide] ;Sets the breed called herbicide, will be the floating white turtles that changes the crops to yellow then die out.

herbicides-own [potency] ;Herbicide's own variable that sets their potency level.

trees-own [potency]

breed [trees tree]

to no_tree_breaks

clear-all ;resets the world to the beginning default setup we have programmed.

reset-ticks ;Resets the tick counter\

create-herbicides area / 40 ;;creates the herbicide

[

set heading 240

set size .5

hide-turtle

set color white

setxy 31 30

set potency random 200 ;Able to adjust the potency of the herbicide based on the slider in the interface tab.

]

ask trees

[

set potency random 100

]

ask patches ;;sets up world with green stripes and in its grid form

[

set pcolor (brown - 1)

if pxcor > -1 and pxcor < 1

[set pcolor black]

if pxcor > -21 and pxcor < -19

[set pcolor black]

```

    if pxcor < 11 and pxcor > 9
    [set pcolor black]
    if pxcor < 21 and pxcor > 19
    [set pcolor black]
    if pxcor > -11 and pxcor < -9
    [set pcolor black]
    if pycor > -1 and pycor < 1
    [set pcolor brown - 1]
    if pycor > 9 and pycor < 11
    [set pcolor brown - 1]
    if pycor > -11 and pycor < -9
    [set pcolor brown - 1]
    if pycor > -21 and pycor < -19
    [set pcolor brown - 1]
    if pycor > -31 and pycor < -29
    [set pcolor brown - 1]
    if pycor > 19 and pycor < 21
    [set pcolor brown - 1]
    if pxcor = 32
    [set pcolor brown + 2]
    if pycor = -32
    [set pcolor brown + 2]
  ]
  ask patches with [pcolor = brown - 1] ;;makes crops sprout from each brown - 1 patch
  [
    sprout-crops 1
    [
      set shape "plant small"
      set color green + 1
      set size 1
    ]
  ]
]

```

end

```

to with_tree_breaks
clear-all
reset-ticks
ask patches

```

```

[
  set pcolor (brown - 1)
  if pxcor > -1 and pxcor < 1
  [set pcolor brown]
  if pxcor > -21 and pxcor < -19
  [set pcolor brown]
  if pxcor < 11 and pxcor > 9
  [set pcolor brown]
  if pxcor < 21 and pxcor > 19
  [set pcolor brown]
  if pxcor > -11 and pxcor < -9
  [set pcolor brown]
  if pycor > -1 and pycor < 1
  [set pcolor brown - 1]
  if pycor > 9 and pycor < 11
  [set pcolor brown - 1]
  if pycor > -11 and pycor < -9
  [set pcolor brown - 1]
  if pycor > -21 and pycor < -19
  [set pcolor brown - 1]
  if pycor > -31 and pycor < -29
  [set pcolor brown - 1]
  if pycor > 19 and pycor < 21
  [set pcolor brown - 1]
  if pxcor = 32
  [set pcolor brown + 2]
  if pycor = -32
  [set pcolor brown + 2]
]
ask patches with [pcolor = brown]
[
  sprout-trees 1
  [
    set shape "tree"
    set color green - 1
  ]
]
ask patches with [pcolor = brown - 1] ;;makes crops sprout from each brown - 1 patch
[

```

```

sprout-crops 1
[
  set shape "plant small"
  set color green + 1
  set size 1
] ;sets their shape to small plant small there color to green + 1 and their size to 1
]

create-herbicides area / 40 ;;creates the herbicide
[
  set heading 240
  set size .5
  ;set pen-size .5
  hide-turtle
  set color white
  setxy 31 30
  set potency random 200 ;Able to adjust the potency of the herbicide based on the slider in the
interface tab.
]

ask trees
[
  set potency random 100
]

end

to go ;procedure that the herbicide and crops will follow.
move
infect
death
grow
wilt
tick
end
to move
ask herbicides
[
  let colorOfPatchAhead pcolor

```

ask patch-ahead 1 ;defines colorOfPatchAhead

```
[
  set colorOfPatchAhead pcolor ;sets colorOfPatchAhead to be pcolor
]
```

if (colorOfPatchAhead = brown) ;; conditional statement that tells the herbicide to wigglewalk

```
[
  ;pen-down
```

```
  right 1
  left 2
  fd .3
  set potency (potency * .3)
]
```

if (colorOfPatchAhead = brown - 1) ;;wiggles on darker brown patches

```
[
  forward 1.0
  right random 7
  left random 6
  set potency potency - .01
]
if (colorOfPatchAhead = brown + 2)
[
  die
]
```

if (colorOfPatchAhead = black)

```
[
  forward 1.0
  set potency (potency * .9)
]
]
```

end

to infect ;;makes non-resistant crops yellow and makes the potency go down for the herbicide

ask crops

```
[
  if color = green + 1
  [
    if any? herbicides-here
      [set color yellow]
  ]
]
```

ask herbicides

```
[
  if any? crops-here
  [
    set potency (potency * .9)
  ]
]
```

ask trees

```
[
  if any? herbicides-here
  [
    set potency potency + .5
    set color yellow
  ]
]
end
```

to death ;;makes the herbicide die if the potency becomes less than 1

ask herbicides

```
[
  if potency < 1
  [
    die
  ]
]
if not any? herbicides
[
  show ticks
  stop
]
```



```
ask trees
[
  if potency > 110
  [
    die
  ]
]
```

```
end
```

to grow ;;makes crops grow by setting to a different shape at certain tick intervals

```
ask crops
[
  if ticks = 100
  [
    set shape "plant medium"
  ]
  if ticks = 200
  [
    ifelse any? crops-here with [color = yellow]
    [
      set shape "plant medium"
    ]
    [
      set shape "plant"
    ]
  ]
]
```

```
ask herbicides
```

```
[
  if ticks = 5
  [
    forward .8
  ]
  if ticks = 15
  [
    forward .2
```

```
]
]
end
```

```
to wilt ;;asks infected crops to die after 300 ticks
ask crops
[
  if ticks > 150
  [
    if any? crops-here with [color = yellow ]
    [
      die
    ]
  ]
]
end
```