Farm Irrigation Model

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Final Project

Overview

This model simulates a farm during the life cycle of a crop. The user acts like a farmer who chooses how to grow the crop. The farmer selects the type of crop, soil and irrigation method. The frequency and amount of crop irrigation is chosen so as to maximize the crop yield and make the most efficient use of water. The model runs for the life cycle of the crop. Each plant absorbs and uses the water from the soil. Water is also lost through evaporation and drains into the earth. Crops can die from an excess or lack of water. This model lets the user adjust the parameters in order to see what optimizes their objective.

Motivation

Drought is a major natural disaster that affects millions of people around the world every year. Whether in Asia, Africa, Europe or the Americas, people have suffered from drought at some point in their history. Agriculture is essential to the survival of humans. Most of our food is cultivated on farms. Not just plants and animals, but in fact the entire food chain suffers from the negative effects of drought. Climate change over the last few decades has increases the amount of drought worldwide. California is currently in its 5th year of statewide drought. This is why sustainable and efficient use of water is crucial to the survival or millions. Sustainability is a very important issue that faces the Earth. As the worlds population grows our need for food increases. The amount of fertile land currently available is limited. The rate at which we currently produce food cannot keep up with the rate the population is expanding. This is a vital issue especially in developing countries with limited resources and growing populations. Reducing water usage effectively on farms could have huge benefits to both farmers and consumers. Many farmers around the world are not aware of the best practices in water conservation and sustainable agriculture. Research in sustainable agriculture is on the rise. Agent based modeling allows the user to quickly observe an agricultural phenomenon that would take months to test in reality. This is why farm irrigation is an important concept to model.

What we can learn

The farm irrigation model has many input parameters. This gives the user a lot of control over the "climate" of the simulation. A user can see the effects of a certain combination of input parameters on the crop.

The driving question of this project is what combination of the amount and frequency of irrigation maximizes water irrigation efficiency and crop yield?

Other questions that we can use this model to answer are:

- Is it possible to have high crop yield while also using water efficiently?
- What combination of crop arrangement and irrigation method maximizes efficient use of water?
- What is the minimum amount of water needed for irrigation for the majority of the crop to successfully complete its life cycle?
- What irrigation method is best suited for what kind of crop?

Model Behavior

The model tries to create a realistic simulation of the interaction between plants and water on the farm. The model window represents the farm. The turtles are individual plants on the farm. Patches represent the soil.

Turtles or plants have the following properties:

crop-lifespan: The length of the life-cycle or growing period of thetype of crop that the turtle is.

pmin-water-content – the minimum water content of the patch soil it is on for it to be alive.

pmax-water-content - the minimum water content of the patch soil it is on for it to be alive.

cur-water-content – the amount of water stored in the plant at the moment

Patches have the following properties:

pwater-content - the water content of the patch of soil.

Parameters:

Eg. param1 [range of values] : description

num-plants [1 to 600]: the initial number of plants sown in the farm.

Evaporation-rate [0 to 10]: the amount of water lost by a patch to the atmosphere every tick.

arrangement [evenspread, rows] – the way in which the plants are arranged spatially on the farm.

- evenspread – plants are spread evenly across the field
- rows – the plants are in vertical rows with set spacing in between the rows

crop-type [maize, peppers, rice] – the species of crop grown on the field. Each species has its own range of patch min and max water content and lifespan.

soil-type [sand, loam, clay] – the type of soil on the farm. Each type has a different rate of water retention. Sand retains the least water while clay retains the most.

irrigation-type [surface, drip, channel] – The method of irrigation delivery system chosen. Surface allows water to be applied evenly across the field. Drip discharges water via a nozzle places above the plant itself. Channels allow water to flow in between rows on the field.

periodic [True, False] – True if irrigation is applied periodically on the field. False otherwise.

period [1 to 100] – the time period in ticks between successive application of irrigation.

irrigation-per-patch [1 to 100] – the amount of water applied per patch during irrigation.

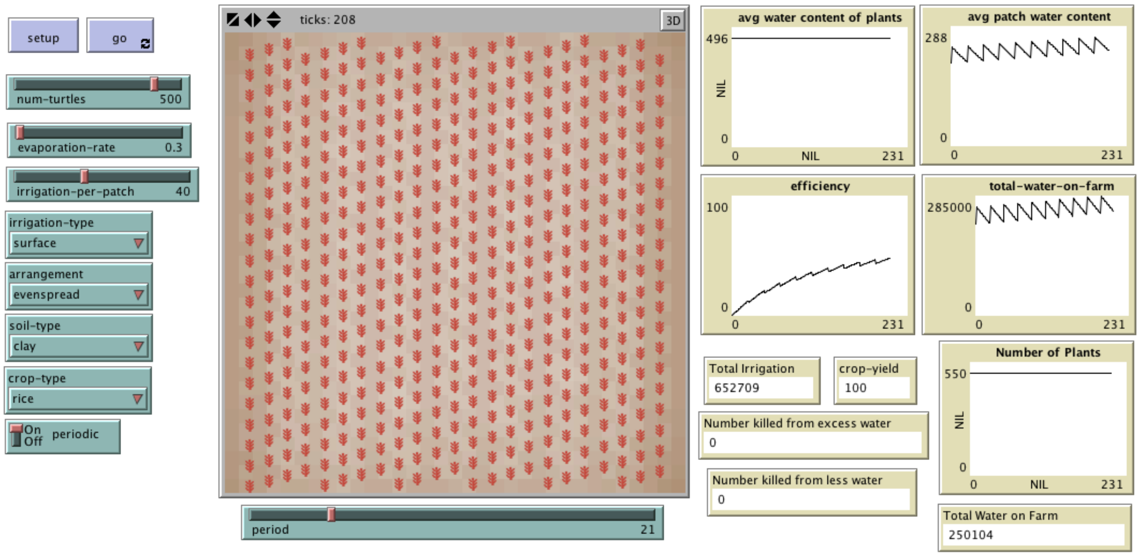

Figure 1: The model

Patches diffuse 10% of their water content to their neighbors at every tick.

Patches lose some amount of water directly to the atmosphere via evaporation.

More water is lost down to the earth due to drainage. This depends on the type of soil chosen: sand, clay or loam.

Plants absorb water from patches at every tick. If the patch has more water than the pmax-water-content of the plant then the plant dies. If the patch has less water than the pmin-water-content of the plant then it dies as well. Thus the plant dies from too much or too little water content in the soil. Individual plants are not identical. Plants of the same crop have pmin-water-content and pmax-water-content values that very by about 10% between each other. This adds a level of heterogeneity in the crop. This is more realistic as no two peppers are exactly the same.

Based on the parameter values irrigation water is applied to the field every period number of ticks. The color of the patches indicates how much water is present. Dark brown means lots of water, light brown means less water. When the crop starts dying one by one plants die and disappear from the model.

The data for the properties like crop-lifespan and min and max water content has been taken from Chapter 2 of *Irrigation Water Management: Water Needs by* C.J. Bruower. In the analysis section of this paper we will attempt to validate the model by comparing our results with the information in C.J.Bruower's book.

<u>Output Measures</u>

Number of plants: the total number of plants alive at the moment

Total-irrigation: the total amount of irrigation water used on the farm

Total-water-on-farm: The total amount of water currently on the farm. It is the sum of the patch water contents of all patches.

Total-killed-from-excess-water: As the name suggests the total number of plants killed from too much water.

Total-killed-from-less-water: As the name suggests the total number of plants killed from too little water.

crop-yield- the percentage of the initial number of plants that have survived till the end of the life cycle.

efficiency- the ratio of water used by the plants to the total amount of water applied on the field by irrigation.

avg-patch-water-content – the average water content per patch.

Maximizing crop yield and maximizing irrigation efficiency are the driving objectives of this project. They are the two most important quantities being measured.

According to the Food and Agriculture Organization of the United Nations irrigation efficiency is calculated as:

$$\textit{Irrigation efficiency} = \textit{field application efficiency} \times \textit{conveyance efficiency} / 100$$

Conveyance efficiency measures the loss of water during transport from irrigation source to point of application (Brouwer). We assume that the transportation methods are secure and well maintained and thus conveyance efficiency to be 100% in our model. We make this assumption as we wish to focus on the use of water by the plants and how to optimize that. Not how to optimize water transport.

Assumptions

This model is a simplified version of a real farm. Real farms are affected by many more factors like storms, rain, sunlight, and clouds. The effect of sunlight and clouds is meant to be encapsulated by the variable evaporation rate. Other additives to soil like fertilizers and pesticides are not considered.

We assume that the only form of irrigation is artificial and not from rain. This is because the model emphasizes the actions of the human controlled irrigation methods.

There are also some limitations on the type of irrigation used in certain situations. Drip irrigation cannot be used on rice crops because the infrastructure for drip irrigation (pipes, nozzles etc) cannot be laid on dense close-growing crops like rice. Drip irrigation and surface flood irrigation is not used on maize because the plant gets damaged if water is applied directly on the stem of the plant.

Analysis and Validation

Many variations of the model were run and the following results were observed.

Peppers:

Behavior Space Experiment:

In order to find the best combination of period of irrigation and irrigation amount to maximize yield and efficiency, a behavior space experiment was run. Peppers are commonly grown on sand soil. We test the results using drip irrigation in this set up.

The experiment is run with the following parameters:

num-plants: 197

arrangement: rows

period: [1 1 100]

irrigation-type: drip

evaporation-rate: 0.3

crop-type: peppers

soil-type: sand

periodic: true

irrigation-per-patch: [1 1 100]

The following results were obtained:

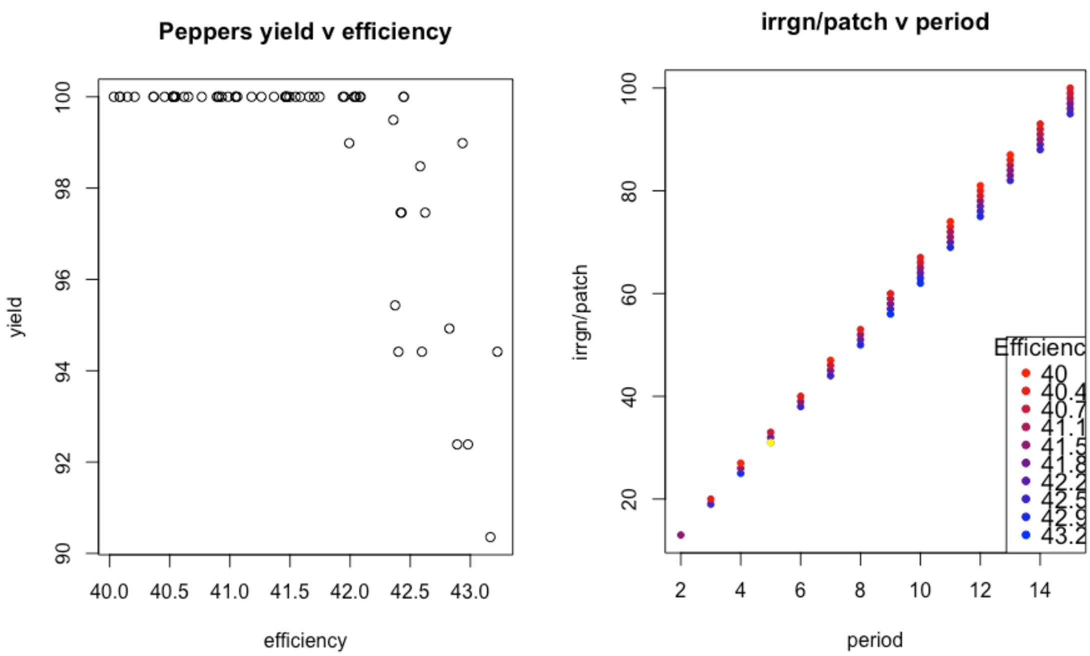

Figure 2: Behavior Space plots. On the right, the more efficient points are in blue. Less efficient in red.

This plot focuses on runs with efficiency of >40% and yield >90%. In the first plot we see that it is possible to get a very high yield of 100% with efficiency in the low 40%s. However a further increase in efficiency causes yield to decrease. In the figure on the right, the point with the highest efficiency has efficiency of 43.22% and yield of 94.41%. The period of irrigation is 5 ticks and 31 units of water applied per patch per period. This point is shown in yellow on the figure on the right. We can see a linear relationship between period and irrigation per patch. The blue dots represent more efficient points, which make sense as they have a lower irrigation per patch amount. The results of this Behavior Space experiment are that for drip irrigation on sandy soils, irrigation must be frequent and with small amounts of water. This finding is consistent with C.J. Brouwer's book, *Irrigation Water Management*, Chapter 6.1.

<u>Growing pepper plants closer v further apart:</u>

A model was tested for growing peppers on sandy soil using drip irrigation in the row arrangement. It was observed that the distance between peppers on the farm affects the efficiency of water usage. If the peppers are two close to each other the competition for water is too much as the drip releases water to only a small area. If the plants are more spread out we see the efficiency increase. But as the spacing increases the efficiency goes down again. The more plants on the field the closer they are.

The results can be seen in the images below.

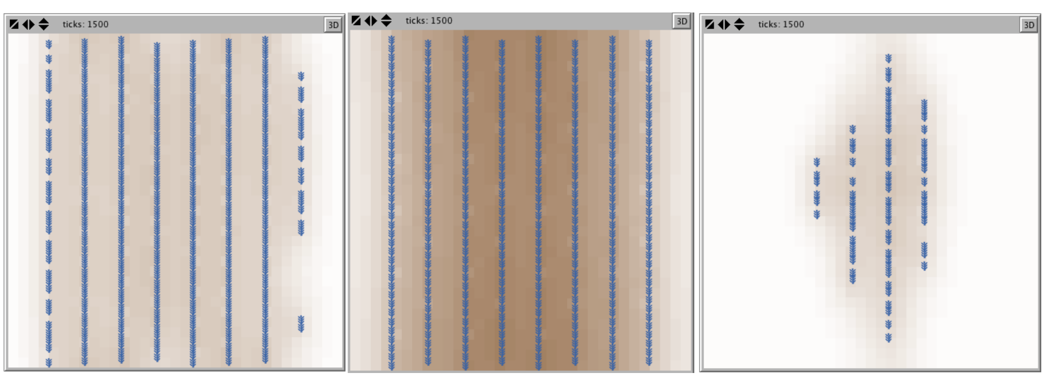

Figure 2: The above 3 windows show the final states of the pepper farm. Left to Right: Number of turtles = 300, 350, 400. Yield=91%,100%,19%. Efficiency=51%, 57%, 56%.

The above tests were carried out with evaporation rate =0.3, period=5, irrigation-per-patch =31. From the results of the above we see that a farm with 350 peppers had higher crop yield and higher efficiency than those with 300 and 400 peppers.

<u>Maize:</u>

To investigate the what combination maximizes yield and efficiency for maize, another behavior space experiment is run.

Maize is commonly grown on loam soil. The only method of irrigation that maize can use is channel because if water hits the stem it can get damaged. This rules our drip and surface flood irrigation.

A behavior Space experiment is run with the following parameters:

num-turtles: 300

arrangement: rows

period: [1 1 100]

irrigation-type: channel

evaporation-rate: 0.3

crop-type: maize

soil-type: loam

periodic: true

irrigation-per-patch: [1 1 100]

period and irrigation amount are the parameters that are varied.

The following results were obtained:

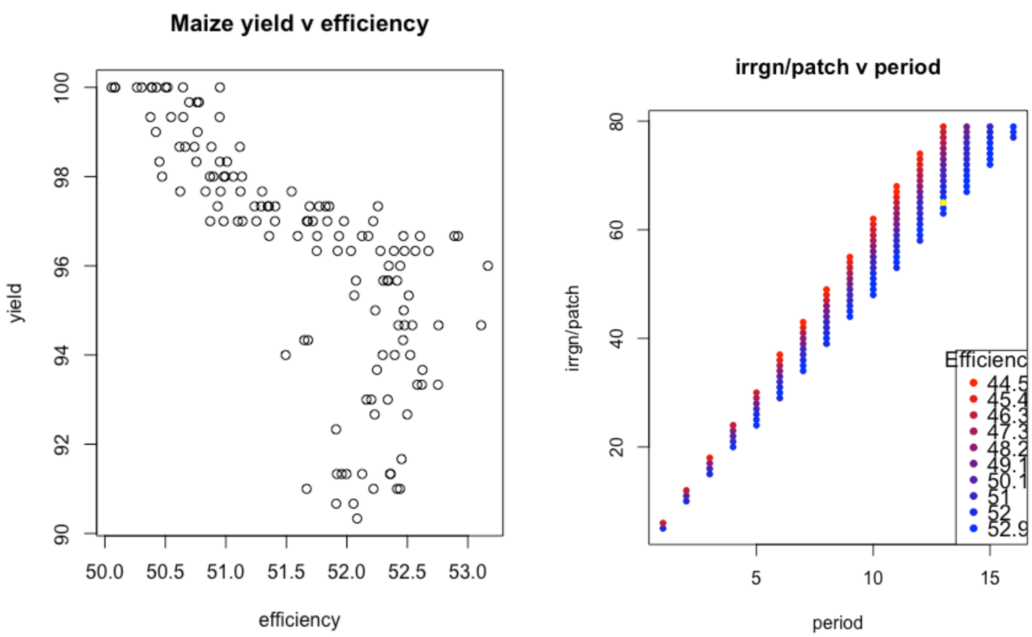

Figure 3: Behavior space plots for maize experiment

In the left figure we notice a slight negative trend between efficiency and yield. The above graph focuses on runs with efficiency > 50% and yield greater than 90%. The point with the highest efficiency has efficiency of 52.88% and yield of 96.67%. The period of irrigation is 13 ticks and 65 units of water applied per patch per period. This point is shown in yellow on the figure on the right. We can see a linear relationship between period and irrigation per patch. The blue dots represent more efficient points, which make sense as they have a lower irrigation per patch amount.

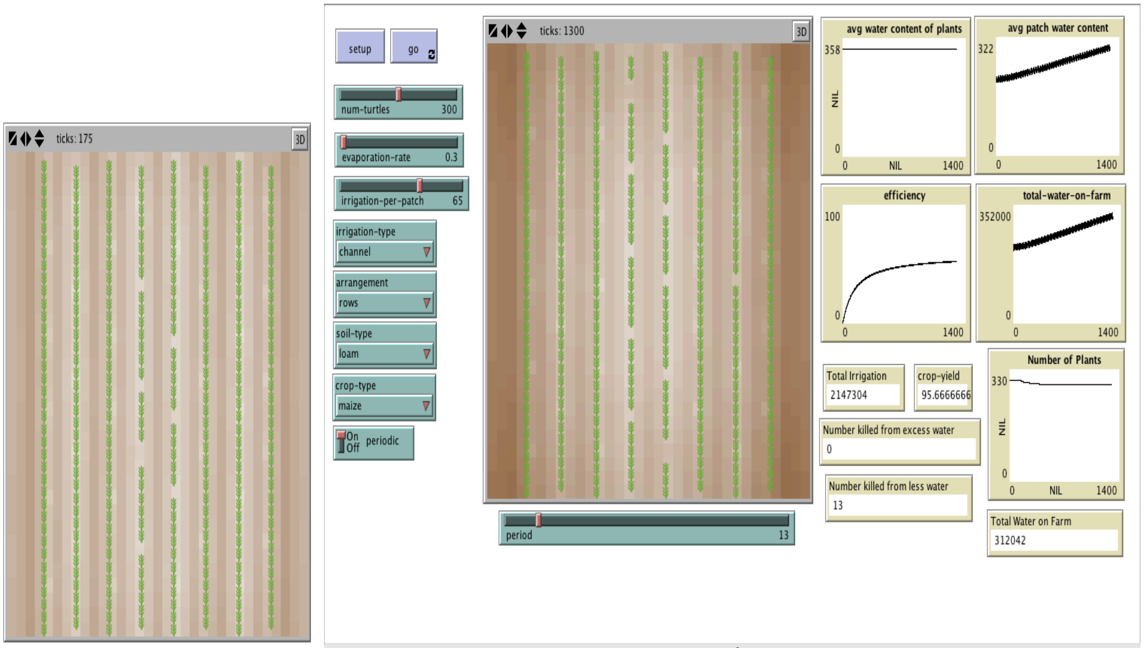

Figure 4: (Left) Maize at the start of the model, and (Right) maize at the end of the life cycle.

<u>Rice:</u>

Rice is commonly grown on clay soil. Rice is a close grown crop. Surface flood irrigation is widely used for this crop. By running a behavior space experiment we can find the values of period and irrigation amount that maximize the objective of high yield and efficiency.

A behavior Space experiment is run with the following parameters:

num-turtles: 500

arrangement: spread

period: [1 1 100]

irrigation-type: surface

evaporation-rate: 0.3

crop-type: rice

soil-type: clay

periodic: true

irrigation-per-patch: [1 1 100]

The following results were obtained:

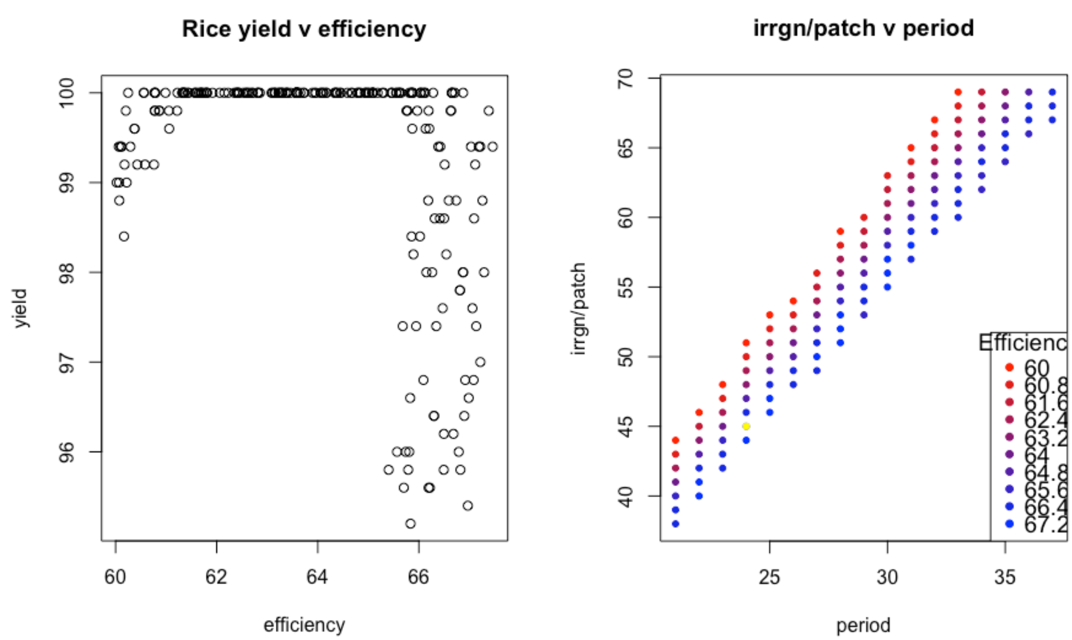

Figure 5: Behavior Space plots for Rice experiment

The above two graphs focus on those runs with efficiency > 60% and yield > 90%. The point with the highest efficiency has efficiency of 67.18% and yield of 99.4%. The period of irrigation is 24 ticks and 45 units of water applied per patch per period. This point is shown in yellow on the figure on the right. We can see a linear relationship between period and irrigation per patch. The blue dots represent more efficient points, which make sense as they have a lower irrigation per patch amount.

According to the FAO, an irrigation efficiency level of more than 50% is considered to be “good” (Brouwer, Annex 1). The behavior space experiments show what combinations of parameters are needed to achieve these good efficiency levels.

Broadly we have obtained the following results:

- For efficient irrigation on sandy soil (soil with low water retention) more frequent irrigation in smaller amounts leads to higher irrigation efficiency.
- Clay soils retain more water. Thus less frequent irrigation in higher amounts gives best results.
- In drip irrigation systems the distance between plants affects efficiency. Too far or too close causes lower efficiency. Depending on other parameters there is an optimal spacing.

The results of model’s experiments reflect the phenomenon observed in the real world. The data regarding the lifecycle of the crops and the water needs was taken from *Irrigation Water Management by C.J. Bruowers*. This model produced similar results to what is described in the book. The Farm Irrigation model has been verified and validated in this way.

Conclusion

This model has provided some valuable insights into possibly successful irrigation strategies. This model has helped us learn what kind of crops different irrigation systems are best suited for. Crops in more water retentive soil seem to grow well less frequent but large amounts of irrigation. The opposite is true for crops in less water retentive soil. This model simply focuses on the water part of agriculture. In the future the model could be extended to include fertilizers, pesticides, and other chemicals. It could also consider soil factors like aeration of the soil and nutrient values. Agent based modeling allows us to observe such complicated phenomenon at a fast pace. The flexibility afforded by the parameters lets researches run wide ranges of experiments that cannot be done in the field.

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