

# Garden Optimizer

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## Overview

When planning a garden, quite a few requirements come into play. Historically, I have figured out how much of each crop I would like to harvest, worked backwards to figure out how much I should plant, and then filled in any leftover space with bonus crops. This process does not allow for easily testing different crops, and it certainly does not always produce an optimal result. I set out to automate the calculation and optimization portion of my garden planning, while still leaving the fun part (crop selection and layout) up to my non-computing skills.

## Reduction to Linear Programming

Since this problem is an optimization problem with a clearly defined set of constraints, it is a natural fit for linear programming.

## Simplifications

I originally attempted to model an entire garden, complete with shade and companion planting, in one run of the model. This is not easily reducible to linear programming as it requires mutating model parameters during the run. To illustrate this, consider a garden that starts with 100 sqft of full sun land, and 100 sqft of partial shade. If 50 sqft of tomatoes are planted, you now have 50 sqft of sun, and 150 sqft of partial shade. However, 50 of those square feet are under tomatoes, so can only have plants that grow well with tomatoes. Since the plants that grow in the shade and the ones that grow in the sun are completely disparate, it makes sense to solve them as two distinct optimization problems: optimize the yield in the shade garden, and the yield in the sun garden, because they are really two separate gardens. This still left the issue of companion planting. To make companion planting work with LP, I decided to model a pair of plants as one “compound crop”. Take, for example, carrots and tomatoes. Carrots produce best in part shade, tomatoes produce best in full sun, and carrots can grow well under tomatoes. To model this, I created a crop “carrot-tomato” that represents a planting of tomatoes *with carrots underneath*.

## Succession Planting

A common practice in gardening is *succession planting*, in which new crops are planted as space becomes available from harvesting mature crops. As my original reduction did not model time, it was not immediately obvious to me how I could incorporate succession plantings. I settled on creating a variable for each plant, for each week. That variable would hold how many square feet of plant  $x$  are planted in week  $y$ . Then, to make sure that the garden does not overflow, I added a space constraint for each week. Here is the constraint for week  $y$ :

$$\left( \sum_{i=0}^y \sum_{p=0}^{num\_plants} planting[i][p] \text{ if } i \geq y - lifespan[p] \right) \leq total\_sqft$$

Where:

- $Planting[i][p]$  represents how many square feet of plant  $p$  are planted in week  $i$
- $Lifespan[p]$  is the number of weeks from planting plant  $p$  to harvesting it
- $Total\_sqft$  is the total number of square feet available in the garden.

## Objective Function

The objective is to maximize the total yield, in pounds of produce, of the available garden space. There is also a small bonus for a positive change in soil Nitrogen. The objective function is:

$$\text{maximize} \quad \sum_{p=0}^{\text{num\_plants}} (\text{yield}[p] * \text{sqft}[p]) + (0.1 * \text{nitrogen}[p])$$

Where:

- *yield[p]* is the yield of crop p, in pounds per square foot planted.
- *sqft[p]* is how many square feet of crop p are planted, across all weeks.
- *nitrogen[p]* is the change in soil nitrogen (in grams) per square foot of crop p planted. Most plants have a negative nitrogen[p], but a few types of crop are able to fix atmospheric nitrogen in the soil.

## Constraints

There are two different classes of constraints in this problem: Gardener-imposed constraints and Ecological constraints.

### Gardener Constraints

- Min and Max yield for each plant – defines an acceptable range of yield for each plant
- Max percent yield for each plant – what percent of the whole garden yield can be made up from this plant
- Greywater per week – 100% of the greywater supplied must be used, every week
- Water per week – total water requirement of the garden cannot exceed this number
- Space – total planted area cannot exceed the space available in the garden. See “succession planting” for a detailed look at the space constraints.

### Ecological

- Soil nitrogen change cannot be negative. Put a different way, the nutrient uptake of all crops must be offset by a cover crop.
- Only compatible plants can be planted together. This constraint is handled by only creating compound plant variables for plants that are compatible.
- Crops can only be planted if there is enough time left in the season for them to be harvested. This is because the yield numbers are based on plants at maturity so are not accurate for plants that are only given a portion of their lifespan to grow.

## Using the Model

The model can be run from the command line by running

```
python main.py <garden_file> <output_filename>.xls
```

Which will read in the model stored in *garden\_file* and save the Excel file as

*output\_filename.xls*, if an optimal solution exists. The garden file is json, and the schema for what is expected can be found at *schemas/garden\_schema.json*.

## Solution Structure

The output Excel file will have three tabs: summary, plantings, and sensitivity. Summary is a summary of the yield and change in soil N, plantings is a detailed planting and harvest schedule, and sensitivity is the same data as summary, but for a 50% reduced rainfall estimate.

## Results

I modelled my SLO spring garden and manually inspected the results and planting schedule to make sure that they are reasonable. In order to make the results easier to review, I output the planting schedule and summary data as an Excel workbook (will\_garden.xls). The yields were higher than I expected, but they match the planting schedule. The yields look high to me because they are maximum yields, and I have not been working my garden as intensively as is recommended by my model. Other than the yields of each crop, the amount of rainfall is the least accurately predictable variable. Since it is difficult to accurately predict the value of the rainfall, it makes sense to determine how sensitive the overall yield is to the rainfall. The shadow prices indicated that, as we would expect, rainfall and yield are positively correlated. To be conservative, I ran the model again, with a 50% reduction in rainfall. This produced a yield that is 31% lower than the yield with 100% rainfall. However, even with 50% rainfall, the model was still able to satisfy all of the constraints, including the minimum yields for each type of vegetable.

## Learning Outcome

Through this project, I learned how to break a complex problem down into a form that can be translated into a linear programming problem. Here are some of my key takeaways from this process.

- You can always add more variables! Many small variables can be summed to get the value that you are interested in, so variables should be kept very specific.
- If the problem isn't a clear fit for LP, the objective function will likely need to be tuned. Maybe they should call it the subjective function...
- LP really is a sledgehammer. It doesn't fit all real-world problems perfectly, but with enough sledgehammering, you can break all kinds of problems down to LP!
- Finally, the hardest part of the whole process is figuring out appropriate constraints to ensure that your model is satisfying the real-world constraints. Sometimes this is obvious, sometimes it is downright convoluted.

## Future work

I believe that the model works for my use case, but it does not fully model what is going in the garden. As the saying goes, all models are wrong, but some are still useful. The model currently does not keep track of non-edible parts of plants produced for compost, captured carbon, other soil nutrients, and long-term crop rotation best practices. The data exists for other soil nutrients, so integrating them would be very similar to the existing nitrogen constraint, except with the key difference that the decrease in nutrients has to be made up by fertilizer or compost amendment. Compost feedstock can be considered another type of yield, and the minimum amount produced should be constrained to be enough to offset the soil nutrient

deficit from growing crops. This could be difficult to get correct, because it is hard to accurately estimate the nutrient content of compost without knowing a lot about the method of production. An easier, and possibly more helpful, solution would be to output the amount of compost produced and change in soil nutrients, without constraining or including either of them in the objective function. This would leave the balancing up to the gardener. Soil carbon captured is also difficult to estimate, because it varies dramatically with gardening practices. It is possible to measure how much carbon is sequestered in the produced feedstock, but that is not equal to the amount captured in the finished compost, because some of the carbon will be released as carbon dioxide as the compost decomposes. I think that the most useful improvements would be measuring the compost feedstock production and adding more sensitivity analysis on the individual yields.

## Sources

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