

Crop Rotation Documentation

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Synopsis

The Crop Rotation model attempts to allocate crops to fields such that the consumption needs of the user are satisfied while adhering to a set of constraints, described below.

Elements of the model

There are some basic components of the model that are required for the model to exist. These are:

- A **Farm**, which is a collection of Fields
- **Fields** in the farm. A field is defined, in this model, as the unit of land that will be planted, as a whole, with a single crop. Thus it is the minimal, indivisible, planting unit. The fields can be used in the determination of the rotation or can be set aside. The fields have a *measure* to determine how we calculate yield and produce amount, which is under user control and there is an amount of that *measure* in each field. In a vegetable crop setting, the measure will likely be *length* of row (feet or meters of beds or rows, depending on setup); in a farm crop setting, the measure will likely be *surface* of each field (acres or hectares in each field).
- **Demand** is defined as the amount of each product that the user wants to produce in one year.
- The most complex component of the model are the **Crops** which are to be planted in **Fields** to meet the **Demand** for products. In the rotation model one of the more important characteristics of **Crops** is the month(s) in which they can be planted in the **Field** for the specific plant zone in which the **Farm** is located as well as the duration the **Crops** occupy the **Field** before releasing it potentially for the next **Crops**.

Importing Farm Data

The model accepts its data from an Excel spreadsheet with tab names that identify the elements of the model and tab columns that identify the attributes of the element. Both tab names and column structure must adhere to the standard format that follows. Three tabs are required in the model:

- Farmland
- Demand
- Crops

The spreadsheet must have at least three tabs named with the labels listed; without them the data import will fail.

Farmland

The **Farmland** tab identifies the **Fields** in the **Farm** by name, their *Measure* and how much land is *Available*, and whether or not they should be *Included* in the rotation (acceptable values are Y or N). The contents of the **Farmland** tab looks like this:

	A	B	C	D
1	Field	Measure	Available	Include?
2	Row 1	Row Feet	25	Y
3	Row 2	Row Feet	25	Y
4	Row 3	Row Feet	25	N
5	Row 4	Row Feet	25	N
6	Row 5	Row Feet	25	N
7	Row 6	Row Feet	25	N
8	Row 7	Row Feet	25	N
9	Row 8	Row Feet	25	N
10	Row 9	Row Feet	25	N
11	Row 10	Row Feet	25	N
12				

Demand

The **Demand** tab identifies the Crop using a measure called **Is Same Crop As** (described under the Crop tab) and the amount of the crop required for a year or **Yearly Demand**. The unit of measure of the **Yearly Demand** is determined by the user and it requires consistency with the measure of yield in the Crop and by reference to the **Field** unit of measure; i.e., if the crop yields are expressed in pounds per foot of row then the demand should be expressed in pounds per year and the fields should be measured in row feet. The contents of the **Demand** Tab looks like follows:

	A	B	C
1	Is Same Crop As	Yearly Demand	
2	Bean	30	
3	Broccoli	10	
4	Daikon radish	0	
5	Chard	30	
6	Onion	150	
7	Potatoes	250	
8	Tomatoes	20	
9	Sauce	75	
10			

Crops

The **Crops** tab identifies the crops the user considers planting and a large collection of attributes about those crops. It also indicates whether a crop is to be planted or not in column **Plant?**. The contents of the **Crops** tab that follows shows the columns of the spreadsheet in three images for clarity.

Crop Rotation Sample Template.xlsx - Excel

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	A	B	C	D
1				
2	Crop	Family	Is Annual or Perennial?	Is Same Crop As
3	Asparagus	Asparagaceae	P	Asparagus
4	Barley	Poaceae/Graminaceae	A	Winter Hardy Grasses
5	Beans (bush)	Leguminosae/Fabaceae	A	Bean
6	Beans (pole)	Leguminosae/Fabaceae	A	Bean
7	Broccoli (early season)	Cruciferae	A	Broccoli
8	Broccoli (late season)	Cruciferae	A	Broccoli
9	Brussels Sprouts	Cruciferae	A	Brussels Sprouts
10	Buckwheat	Polygonaceae	A	Frost Kill Grasses
11	Clover, Red	Leguminosae/Fabaceae	A	Winter Hardy Legumes
12	Daikon radish	Cruciferae	A	Daikon radish
13	Cabbage (early season)	Cruciferae	A	Cabbage
14	Cabbage (late season)	Cruciferae	A	Cabbage
15	Carrots (early season)	Apiaceae/Umbelliferae	A	Carrot
16	Carrots (late season)	Apiaceae/Umbelliferae	A	Carrot

Farmland Crops Demand ...

Ready 100%

The tab above collects the name of the **Crop**, its botanical **Family**, whether the crop **Is Annual or Perennial?**, although the model currently excludes perennial crops from the rotation and whether the crop contributes to meet the user demand as other crops, column **Is Same Crop As**. In the image you can see how both bush beans and pole beans produce the same product: bean.

Crop Rotation Sample Template - Botanical Fa...

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	A	E	F	G	H	I	J
1							
2	Crop	Is Heavy Feeder?	Is Weed Contributor?	Is Nitrogen Fixer?	Is Cover Crop?	Months between plantings on same field	Yield per Unit of Field
3	Asparagus	Y	Y	N	N		0.25
4	Barley	N	N	N	Y		
5	Beans (bush)	N	N	Y	N		0.75
6	Beans (pole)	N	N	Y	N		0.75
7	Broccoli (early	Y	N	N	N	24	0.5
8	Broccoli (late season)	Y	N	N	N	24	0.5
9	Brussels Sprouts	Y	N	N	N	36	0.5
10	Buckwheat	N	N	N	Y		
11	Clover, Red - 1	N	N	Y	Y		
12	Clover, Red - 2	N	N	Y	Y		
13	Clover, Red	N	N	Y	Y		
14	Daikon radish - 1	N	N	Y	Y		
15	Daikon radish - 2	N	N	Y	Y		
16	Daikon radish - 3	N	N	Y	Y		

Farmland Crops Demand

Ready 90%

The tab above repeats the **Crop**, as well as adding some attributes of the crop itself (**Is Heavy Feeder?**, **Is Weed Contributor?**, **Is Cover Crop?**, which the model will attempt to plant to keep the soil from laying bare) and constraints that the user wants to impose on the crop (**Years between plantings on the same field**). Finally, column J identifies **Yield per Unit of Field**, which represents the amount of product that the field will produce of the crop in the same units of measure as in the **Demand** tab and the **Farmland** tab.

The Model

The model we use to generate a crop rotation is a mixed integer linear programming model of the general form:

$$\begin{aligned} \text{Min } & \sum dX + eY + fZ \\ \text{s.t. } & \sum AX + \sum BY + \sum CZ = 0 \\ & X \in R \\ & X \geq 0 \\ & Y \in \{0, 1\} \\ & Z \in I \end{aligned}$$

In this type of model we optimize (maximize or minimize) a linear function subject to a set of constraints over a collection of variables, some of which are continuous and some of which are discrete, either integer or binary.

Objective Function

In general terms, we try to minimize the unmet demand, i.e., we want to produce as much of each crop as needed and, if it isn't possible to produce all that is needed, then we minimize the gap. In addition, we want to always have something planted in the field, so we will encourage the use of cover crops or crops in general at any point in time. The objective function will also try to minimize the failure of meeting the crop rotation constraints.

Variables

The variables that interest us the most have to do with the crops planted and the demand we have not met. In addition, we will use other variables to interconnect all the elements of the model.

Because the model's time is set to months, and the indivisible unit of land is the field, the key crop variables are represented by Y_{cfym} , which indicate whether a crop (c) is planted in a field (f) on a certain year (y) and month (m). The variable will be 1 if the field is planted to the crop and 0 otherwise.

The unmet demand will be represented by the variables that identify the product whose demand is not met in a certain year: X_{py} . This unmet demand can be any non-negative value, $X \geq 0$, that identifies the product (p) and the year(y) in which the demand was not met.

Constraints

There are a number of types of constraints that we will implement to manage the rotation. Fundamental to the rotation is the transfer of land (fields) used by a crop or unused from period to period. The set of constraints that define land transfers are the most complex in this model and will be addressed first.

Constraints that manage land transfers/availability over time periods

Succinctly, every field in the farm can be either planted or not planted in every month of every year; if it is planted, it will become available again once the crop is harvested and, if it is not planted, the field will be available for planting next month. Thus, we will have constraints C_{fym} for each field in each month and year to represent the balance of land in the field: the sum of Field f freed (harvested) in year y month m + Field f not planted in year y month m-1 must equal the Field f not planted in year y month m + the sum of field f planted in crop c in year y and month m. In mathematical terms:

$$C_{fym} : - \sum_f F - \sum_{y(m-1)} N + \sum_{ym} N + \sum_c P = 0 \quad \forall fym$$

$F : \text{Freed/Harvested}$
 $N : \text{Not Planted}$
 $P : \text{Planted}$

Constraints that manage unmet demand for the year

Every field planted will eventually produce a crop that meets the demand for one of the **Is Same Crop As** crops. These constraints summarize the production balance of those crops by all fields for every year: the crop **Yield per Unit of Field** of all fields that produce a similar crop during the year y plus the **Unmet Demand** for the year must be greater than the **Demand** for the product, d_c , loaded from the data spreadsheet. In mathematical terms:

$$C_{cy} : \sum_c yC + \sum_s U \geq d_c \quad \forall cy$$

$y : \text{Yields of planted "same as" crops}$
 $U : \text{Unmet Demand of "same as" crops}$

Constraints that manage crop rotation and planting rules

There are a number of constraint sets implemented in the model. eventually the user will be able to determine which sets to implement and enforce strictly, which sets to implement with relaxed enforcement and which sets to ignore completely.

The list of such rules/constraints is as follows:

- After a field is release by a crop, plant crops of a different botanical family in that field. We can restate this principle slightly to simplify our modeling: After a field is released by a crop, do not plant crops of the same botanical family in the field for a period determines by *Months between plantings on same field* or 12 months if that is not defined.
- Include cover crops at any time when there is a field released by a crop. Cover crops can follow a crop of any family.
- Keep the fields planted all the time or as much of the time a possible.
- Nitrogen demanding crops follow Nitrogen fixing crops.
- Heavy feeder crops, such as tomatoes, peppers, corn or lettuce, follow Light feeder crops, such as carrots, turnips or beets.
- Weed suppressing crops (leafy crops) follow weed permitting (slow growing and nt bushy) crops.
- High root biomass crops (red clover or orchard grass) follow low crop biomass crops.
- Deep rooted crops follow Shallow rooted crops.
- Fast growing crops (buckwheat, radishes or sun hemp) follow slow growing crops.

Crop Family Rotation For each crop c of botanical family b planted on field f in year y and month m , we need to prohibit plantings of crops of the same botanical family in that field for the period determined by *Months between plantings on same field*. This strict constraint may be relaxed by defining (high objective function penalty) relaxation variables R for each combination of field, botanical family and year and month of planting, $fbym$. Thus, we implement the following constraints:

$$\begin{aligned}
C_{fbym} : \quad & \sum_{\in b_{fym}} P + \sum_{fbym} R \leq M \delta_{fbym} \quad \forall fbym \\
S_{fby(m+1)} : \quad & \sum_{\in b_{fy(m+1)}} P + \sum_{fby(m+1)} R \leq M (1 - \delta_{fbym}) \quad \forall fby(m+1) \\
& \delta \in 0, 1 \\
& P \in 0, 1 \\
& M = 1 \\
& P : \textit{Planted} \\
& R : \textit{Relaxation of Rotation} \\
& \delta : \textit{Botanical family indicator}
\end{aligned}$$