PLANT-GROWTH EXPERIMENT

PROBLEM FORMULATION

This experiment will grow bean plants mainly to find the optimum seed type (small, medium, large), soil (grams) to water (mL) ratio (1:0.4, 1:1, 1:2.5, 1:5), and water type (tap water, washing machine water) to grow kidney bean plants. The data will be analysed by Matlab to make statistical conclusions.

All plant bags will be randomly ordered to remove any possible bias that might come with the order of the plants.

We will measure plant growth everyday by measuring the height of the plant's stem, from the surface of the soil to the top of the plant. Every plant will be watered once a week by their water to soil ratio. The experiment will end in 25 days.

We will also keep track of the weather conditions of each day.

After the data are collected, the following questions will be answered:

1. What is the effect of seed variety on the plant growth? Do plants obtained from one seed grow faster than the other?
2. What is the effect of water to soil ratios on plant growth? Do plants with one water to soil ratio grow better than the other?
3. What is the effect of type of water (washing machine water or tap water) on plant growth? Do plants watered with one type of water grow better than the other?
4. Is there any interaction between seed variety, water to soil ratio and type of water in their effect on the plant growth? How strong is the interaction?

EXPERIMENTAL DESIGN

Plant growth is affected by many factors, however we will only be using three variables, water type, soil to water ratio, and seed type.

Our three seed types are calculated by taking a random sample of seeds, measure their heights and widths, and multiplying the two values for each individual seed. The 0-33rd percentile of seeds are small seeds, 33rd-66th are medium seeds, and 66th - 99th are big seeds

```
x1 = BeanSizes_1_(:, 1)
```

x1 = 54×1 table

	Width
1	7
2	10
3	10
4	9
5	9

	Width
6	12
7	8
8	12
9	9
10	11
11	10
12	11
13	12
14	9

⋮

```
y1 = BeanSizes_1_(:, 2)
```

y1 = 54×1 table

	Height
1	18
2	22
3	20
4	20
5	21
6	23
7	18
8	22
9	17
10	19
11	22
12	21
13	22
14	19

⋮

```
x = table2array(x1)
```

```
x = 54×1
     7
    10
    10
     9
     9
```

```
     12
      8
     12
      9
     11
      ⋮
```

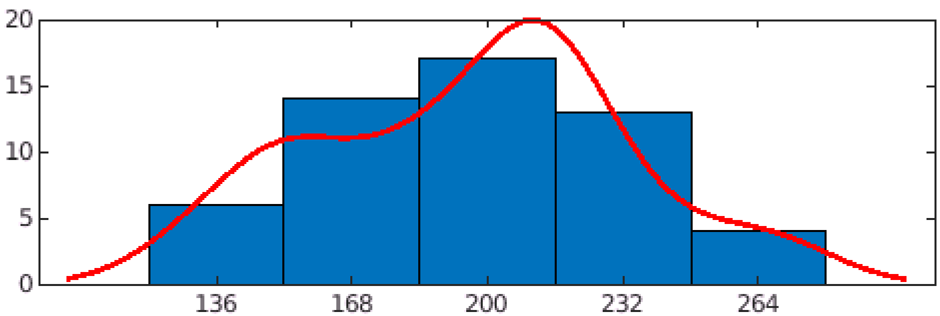
```
y = table2array(y1)
```

```
y = 54×1
     18
     22
     20
     20
     21
     23
     18
     22
     17
     19
      ⋮
```

```
b = x.*y
```

```
b = 54×1
    126
    220
    200
    180
    189
    276
    144
    264
    153
    209
      ⋮
```

```
histfit(b,5, 'Kernel')
```




```
f = 0
```

```
SmallBeanEnd = prctile(b, 33)
```

```
SmallBeanEnd = 180
```

```
MediumBeanEnd = prctile(b, 66)
```

```
MediumBeanEnd = 210
```

```
LargeBeanEnd = prctile(b, 99)
```

```
LargeBeanEnd = 275.5200
```

Any bean with a width (mm) times height (mm) less than 180mm^2 is considered a small bean, between 180 and 210 is considered a medium bean, and greater than 210 is considered a large bean.

Our four watering plans (soil to water ratio) go from 1:0.4, 1:1, 1:2.5, and 1:5, since these ratios are commonly used in agriculture.

The two types of water that will be tested are washing machine water and tap water. The brand of the washing machine is ____, and the brand of the detergent is ____. Both brands are representative of conventional washing machines and detergents.

The experimental design used will be a randomized factorial experiment. There will be 24 samples, originally two 4 by 3 squares. However, the placement of each type of plant will be randomized to reduce any potential bias in the experiment.

Small Bean, 1:0.4 Soil:Water Ratio, Tap Water	Medium Bean, 1:0.4 Soil:Water Ratio, Tap Water	Large Bean, 1:0.4 Soil:Water Ratio, Tap Water
Small Bean, 1:1 Soil:Water Ratio, Tap Water	Medium Bean, 1:1 Soil:Water Ratio, Tap Water	Large Bean, 1:1 Soil:Water Ratio, Tap Water
Small Bean, 1:2.5 Soil:Water Ratio, Tap Water	Medium Bean, 1:2.5 Soil:Water Ratio, Tap Water	Large Bean, 1:2.5 Soil:Water Ratio, Tap Water
Small Bean, 1:5 Soil:Water Ratio, Tap Water	Medium Bean, 1:5 Soil:Water Ratio, Tap Water	Large Bean, 1:5 Soil:Water Ratio, Tap Water

Small Bean, 1:0.4 Soil:Water Ratio, Washing Machine Water	Medium Bean, 1:0.4 Soil:Water Ratio, Washing Machine Water	Large Bean, 1:0.4 Soil:Water Ratio, Washing Machine Water
Small Bean, 1:1 Soil:Water Ratio, Washing Machine Water	Medium Bean, 1:1 Soil:Water Ratio, Washing Machine Water	Large Bean, 1:1 Soil:Water Ratio, Washing Machine Water
Small Bean, 1:2.5 Soil:Water Ratio, Washing Machine Water	Medium Bean, 1:2.5 Soil:Water Ratio, Washing Machine Water	Large Bean, 1:2.5 Soil:Water Ratio, Washing Machine Water
Small Bean, 1:5 Soil:Water Ratio, Washing Machine Water	Medium Bean, 1:5 Soil:Water Ratio, Washing Machine Water	Large Bean, 1:5 Soil:Water Ratio, Washing Machine Water

Here is the randomized order of plants.

Large Bean, 1:5 Soil:Water Ratio, Tap Water	Large Bean, 1:5 Soil:Water Ratio, Washing Machine Water	Small Bean, 1:1 Soil:Water Ratio, Tap Water	Large Bean, 1:2.5 Soil:Water Ratio, Tap Water
Large Bean, 1:1 Soil:Water Ratio, Tap Water	Medium Bean, 1:2.5 Soil:Water Ratio, Tap Water	Medium Bean, 1:0.4 Soil:Water Ratio, Washing Machine Water	Small Bean, 1:0.4 Soil:Water Ratio, Washing Machine Water
Medium Bean, 1:1 Soil:Water Ratio, Tap Water	Small Bean, 1:2.5 Soil:Water Ratio, Tap Water	Medium Bean, 1:1 Soil:Water Ratio, Washing Machine Water	Medium Bean, 1:0.4 Soil:Water Ratio, Tap Water
Small Bean, 1:0.4 Soil:Water Ratio, Tap Water	Small Bean, 1:5 Soil:Water Ratio, Washing Machine Water	Small Bean, 1:2.5 Soil:Water Ratio, Washing Machine Water	Large Bean, 1:1 Soil:Water Ratio, Washing Machine Water
Large Bean, 1:2.5 Soil:Water Ratio, Washing Machine Water	Large Bean, 1:0.4 Soil:Water Ratio, Tap Water	Medium Bean, 1:2.5 Soil:Water Ratio, Washing Machine Water	Medium Bean, 1:5 Soil:Water Ratio, Washing Machine Water
Large Bean, 1:0.4 Soil:Water Ratio, Washing Machine Water	Small Bean, 1:5 Soil:Water Ratio, Tap Water	Medium Bean, 1:5 Soil:Water Ratio, Tap Water	Small Bean, 1:1 Soil:Water Ratio, Washing Machine Water

Next we have to measure the weight of the amount soil we want to use, and correspond it with the mL of water we would need for each plant.

There are approximately **57 grams of potting soil in a cup**, since there are 50 quarts in a bag of soil that weights 11.4 kg, 200 cups in a bag that weighs 11400 grams, divide 11400 by 200, resulting in one cup per 57 grams.

We decided to put approximately two cups of potting soil in each bag, equating to approximately **114 grams of potting soil for each plant.**

For plants that have a 1:0.4 soil:water ratio, they need **45.6 mL of water or 1.541919 oz**

For plants that have a 1:1 soil:water ratio, they need **114 mL of water or 3.8548 oz**

For plants that have a 1:2.5 soil:water ratio, they need **285 mL of water or 9.637 oz**

For plants that have a 1:5 soil:water ratio, they need **570 mL of water or 19.274 oz**

DATA COLLECTION

```
Seed =[3 3 1 3 3 2 2 1 2 1 2 2 1 1 1 3 3 3 2 2 3 1 2 1]';
Water = [5 5 1 2.5 1 2.5 0.4 0.4 1 2.5 1 0.4 0.4 5 2.5 1 2.5 0.4 2.5 5 0.4 5 5 1]';
Height = [8.5 11 6.5 19 10.5 15 0 0 0 9 0 8 0 0 0 12 8.75 2.25 11 12 0 7.25 0 7.5]';
WaterType = [1 0 1 1 1 1 0 0 1 1 0 1 1 0 0 0 0 1 0 0 0 1 1 0]';
IsDead = [1 1 1 1 1 1 0 0 0 1 0 1 0 0 0 1 1 1 1 1 0 1 0 1]


T = table(Seed, Water, Height, WaterType);

T
```

T = 24×4 table

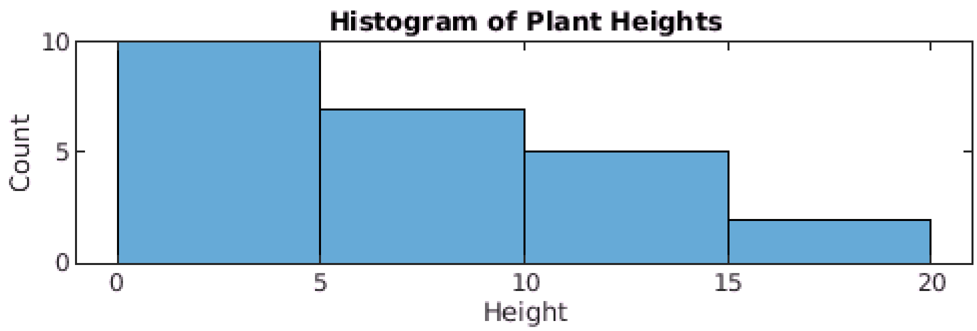
	Seed	Water	Height	WaterType
1	3	5.0000	8.5000	1
2	3	5.0000	11.0000	0
3	1	1.0000	6.5000	1
4	3	2.5000	19.0000	1
5	3	1.0000	10.5000	1
6	2	2.5000	15.0000	1
7	2	0.4000	0	0
8	1	0.4000	0	0
9	2	1.0000	0	1
10	1	2.5000	9.0000	1
11	2	1.0000	0	0
12	2	0.4000	8.0000	1
13	1	0.4000	0	1
14	1	5.0000	0	0

⋮

DATA EXPLORATION

Histogram of Height

```
histogram(Height)
hold on;
xlabel('Height')
ylabel('Count')
title('Histogram of Plant Heights')
hold off;
```



Box Plots

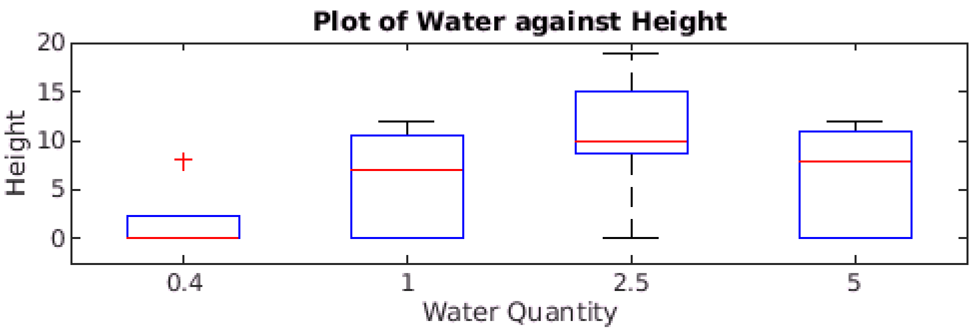
```
T1 = sortrows(T, 1);
T
```

T = 24×4 table

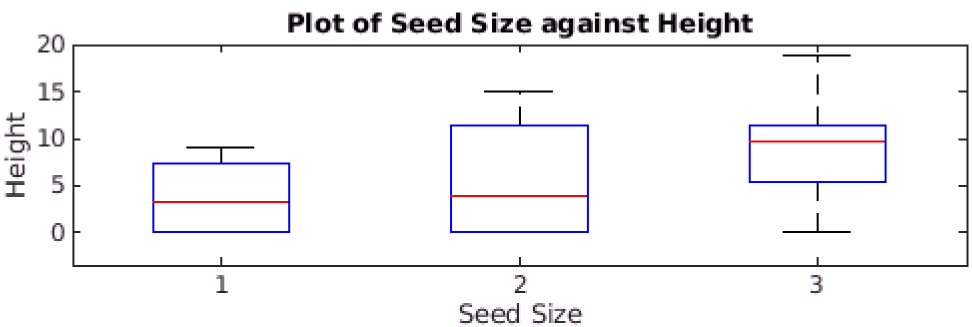
	Seed	Water	Height	WaterType
1	3	5.0000	8.5000	1
2	3	5.0000	11.0000	0
3	1	1.0000	6.5000	1
4	3	2.5000	19.0000	1
5	3	1.0000	10.5000	1
6	2	2.5000	15.0000	1
7	2	0.4000	0	0
8	1	0.4000	0	0
9	2	1.0000	0	1
10	1	2.5000	9.0000	1
11	2	1.0000	0	0
12	2	0.4000	8.0000	1
13	1	0.4000	0	1
14	1	5.0000	0	0

⋮

```
boxplot(T1.Height, T1.Water)
hold on;
xlabel('Water Quantity')
ylabel('Height')
title('Plot of Water against Height')
hold off;
```




```
boxplot(T1.Height, T1.Seed)
hold on;
xlabel('Seed Size')
ylabel('Height')
title('Plot of Seed Size against Height')
hold off;
```



Check interaction

```
T2 = grpstats(T,{'Seed','Water'},'mean','DataVars', 'Height')
```

T2 = 12×4 table

	Seed	Water	GroupCount	mean_Height
1 1_0.4	1	0.4000	2	0
2 1_1	1	1.0000	2	7.0000
3 1_2.5	1	2.5000	2	4.5000
4 1_5	1	5.0000	2	3.6250
5 2_0.4	2	0.4000	2	4.0000
6 2_1	2	1.0000	2	0
7 2_2.5	2	2.5000	2	13.0000
8 2_5	2	5.0000	2	6.0000
9 3_0.4	3	0.4000	2	1.1250
10 3_1	3	1.0000	2	11.2500
11 3_2.5	3	2.5000	2	13.8750

	Seed	Water	GroupCount	mean_Height
12 3_5	3	5.0000	2	9.7500

```
h = gscatter(T2.Water,T2.mean_Height,T2.Seed)
```

```
h =
  3×1 Line array:

  Line    (1)
  Line    (2)
  Line    (3)
```

```
set(h,'LineStyle','-')
hold on;
xlabel('Water Quantity')
ylabel('Plant Height')
title('Plot of Water Quantity v/s Plant Height by Seed Size')
hold off;
```

ANOVA

```
% Rows are seed and columns are water
T4 = [35 38 41 45; 37 38 39 43; 31 39 44 47; 33 37 40 45; 38 34 39 46; 38 36 37 44;]
```

```
T4 = 6×4
    35    38    41    45
    37    38    39    43
    31    39    44    47
    33    37    40    45
    38    34    39    46
    38    36    37    44
```

```
[p,tbl, stats] = anova2(T4, 2)
```

```
p = 1×3
    0.0000    0.7408    0.0073
tbl = 6×6 cell
```

	1	2	3	4	5	6
1	'Source'	'SS'	'df'	'MS'	'F'	'Prob>F'
2	'Columns'	324.0000	3	108.0000	49.8462	4.7687e-07
3	'Rows'	1.3333	2	0.6667	0.3077	0.7408
4	'Interaction'	68.0000	6	11.3333	5.2308	0.0073
5	'Error'	26	12	2.1667	[ ]	[ ]
6	'Total'	419.3333	23	[ ]	[ ]	[ ]

```
stats = struct with fields:
      source: 'anova2'
     sigmasq: 2.1667
    colmeans: [35.3333 37 40 45]
        coln: 6
    rowmeans: [39.5000 39.5000 39]
        rown: 8
```

```
inter: 1
 pval: 0.0073
   df: 12
```

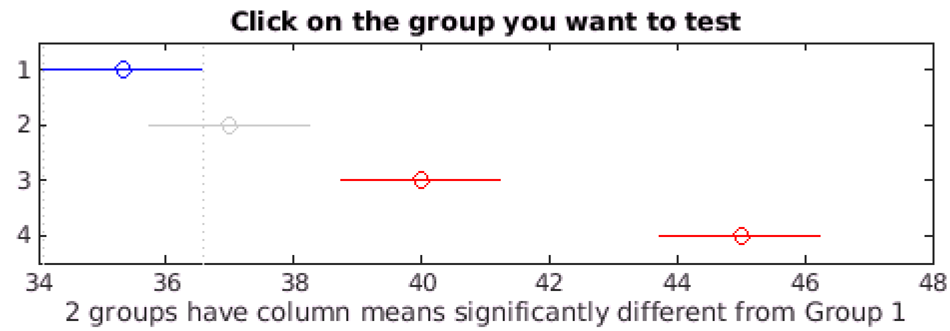
Multi Group Comparisons

The first two columns of c show the groups that are compared. The fourth column shows the difference between the estimated group means. The third and fifth columns show the lower and upper limits for 95% confidence intervals for the true mean difference. The sixth column contains the *p*-value for a hypothesis test that the corresponding mean difference is equal to zero.

The figure shows the multiple comparison of the means. By default, the group 1 mean is highlighted and the comparison interval is in blue. Because the comparison intervals for the other two groups do not intersect with the intervals for the group 1 mean, they are highlighted in red. This lack of intersection indicates that both means are different than group 1 mean. Select other group means to confirm that all group means are significantly different from each other.

```
multcompare(stats,'Estimate','column', 'Alpha', 0.05, 'CType', 'tukey-kramer' )
```

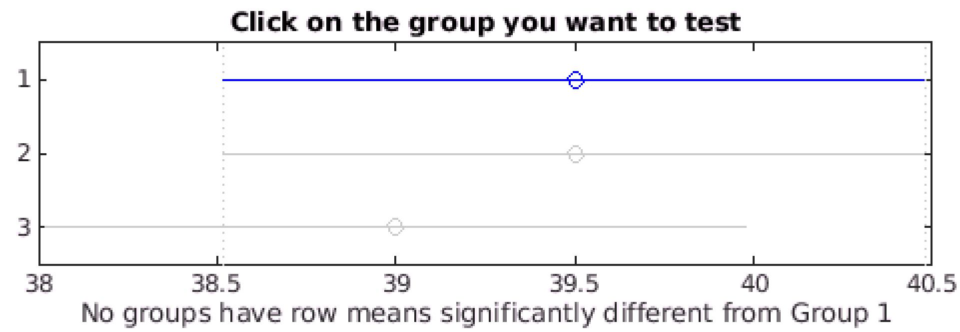
```
Note: Your model includes an interaction term that is significant at the level
you specified. Testing main effects under these conditions is questionable.
```




```
ans = 6×6
    1.0000    2.0000   -4.1897   -1.6667    0.8564    0.2552
    1.0000    3.0000   -7.1897   -4.6667   -2.1436    0.0007
    1.0000    4.0000  -12.1897   -9.6667   -7.1436    0.0000
    2.0000    3.0000   -5.5231   -3.0000   -0.4769    0.0188
    2.0000    4.0000  -10.5231   -8.0000   -5.4769    0.0000
    3.0000    4.0000   -7.5231   -5.0000   -2.4769    0.0004
```

```
multcompare(stats,'Estimate','row', 'Alpha', 0.05, 'CType', 'tukey-kramer')
```

```
Note: Your model includes an interaction term that is significant at the level
you specified. Testing main effects under these conditions is questionable.
```




```
ans = 3×6
```

```
    1.0000    2.0000   -1.9635         0    1.9635    1.0000
    1.0000    3.0000   -1.4635    0.5000    2.4635    0.7796
    2.0000    3.0000   -1.4635    0.5000    2.4635    0.7796
```

```
%% anovan
%% https://itectec.com/matlab/matlab-multcompare-function-does-not-compare-all-variable
```

```
Seed_Group =[1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3 3];
Water_Group = [1 1 2 2 3 3 4 4 1 1 2 2 3 3 4 4 1 1 2 2 3 3 4 4];
Height_Response = [35 37 38 38 41 39 45 43 31 33 39 37 44 40 47 45 38 38 34 36 39 37 46
```

```
height_t = T2.mean_Height.';
seed_t = T2.Seed';
water_t = T2.Water';
```

```
[p,tbl,stats,terms] = anovan(Height_Response, {Seed_Group, Water_Group}, 'model','inter
```

```
p = 3×1
    0.7408
    0.0000
    0.0073
tbl = 6×7 cell
```

	1	2	3	4	5	6	7
1	'Source'	'Sum Sq.'	'd.f.'	'Singular?'	'Mean Sq.'	'F'	'Prob>F'
2	'Seed_Group'	1.3333	2	0	0.6667	0.3077	0.7408
3	'Water_Group'	324.0000	3	0	108.0000	49.8462	4.7687e-07
4	'Seed_Group...	68.0000	6	0	11.3333	5.2308	0.0073
5	'Error'	26.0000	12	0	2.1667	[]	[]
6	'Total'	419.3333	23	0	[]	[]	[]

```
stats = struct with fields:
         source: 'anovan'
          resid: [24×1 double]
         coeffs: [20×1 double]
            Rtr: [12×12 double]
       rowbasis: [12×20 double]
            dfe: 12
            mse: 2.1667
    nullproject: [20×12 double]
          terms: [3×2 double]
        nlevels: [2×1 double]
     continuous: [0 0]
         vmeans: [2×1 double]
```

```
       termcols: [4×1 double]
     coeffnames: {20×1 cell}
           vars: [20×2 double]
       varnames: {2×1 cell}
       grpnames: {2×1 cell}
        vnested: []
            ems: []
          denom: []
        dfdenom: []
        msdenom: []
         varest: []
          varci: []
       txtdenom: []
         txtems: []
        rtnames: []
terms = 3×2
     1     0
     0     1
     1     1
```

```
[c,m,h,gnames]  = multcompare(stats,'Dimension',[1:2])
```

```
c = 66×6
    1.0000    2.0000   -1.8439    4.0000    9.8439    0.3189
    1.0000    3.0000   -7.8439   -2.0000    3.8439    0.9520
    1.0000    4.0000   -7.8439   -2.0000    3.8439    0.9520
    1.0000    5.0000   -7.8439   -2.0000    3.8439    0.9520
    1.0000    6.0000   -4.8439    1.0000    6.8439    0.9998
    1.0000    7.0000   -9.8439   -4.0000    1.8439    0.3189
    1.0000    8.0000  -11.8439   -6.0000   -0.1561    0.0423
    1.0000    9.0000   -7.8439   -2.0000    3.8439    0.9520
    1.0000   10.0000  -13.8439   -8.0000   -2.1561    0.0051
    1.0000   11.0000  -15.8439  -10.0000   -4.1561    0.0007
     ⋮

m = 12×2
   36.0000    1.0408
   32.0000    1.0408
   38.0000    1.0408
   38.0000    1.0408
   38.0000    1.0408
   35.0000    1.0408
   40.0000    1.0408
   42.0000    1.0408
   38.0000    1.0408
   44.0000    1.0408
     ⋮

h = 
  Figure (4: Multiple comparison of population marginal means) with properties:

      Number: 4
        Name: 'Multiple comparison of population marginal means'
       Color: [1 1 1]
    Position: [671 932.3000 577 161.7000]
       Units: 'pixels'

  Show all properties
gnames = 12×1 cell
'Seed_Group=1,Water_Group=1'
'Seed_Group=2,Water_Group=1'
```

```
'Seed_Group=3,Water_Group=1'
'Seed_Group=1,Water_Group=2'
'Seed_Group=2,Water_Group=2'
'Seed_Group=3,Water_Group=2'
'Seed_Group=1,Water_Group=3'
'Seed_Group=2,Water_Group=3'
'Seed_Group=3,Water_Group=3'
'Seed_Group=1,Water_Group=4'
     ⋮
```

The

Repeated Measures Models

RepeatedMeasuresModel class

https://www.mathworks.com/help/stats/repeatedmeasuresmodel.margmean.html

https://www.mathworks.com/help/stats/repeatedmeasuresmodel-class.html

RESULTS

```
rm = fitrm(T,'Height ~ Seed + Water')
```

```
rm = 
  RepeatedMeasuresModel with properties:

   Between Subjects:
         BetweenDesign: [24×4 table]
         ResponseNames: {'Height'}
     BetweenFactorNames: {'Seed'  'Water'}
          BetweenModel: '1 + Seed + Water'

   Within Subjects:
          WithinDesign: [1×1 table]
     WithinFactorNames: {'Time'}
           WithinModel: 'separatemeans'

   Estimates:
          Coefficients: [3×1 table]
            Covariance: [1×1 table]
```

```
ranova(rm)
```