

# Lab 4a

Jas Sur

2/27/2022

## Question 1

Setup data for pressure, temperature and yield

```
temp.data <- rep(c(150,160,170), each=6)
pressure.data <- rep(c(200,215,230), each=3, times=2)
yield <- c(90.4, 90.2, 90.7,90.6,90.2,90.4,90.1,90.3,90.5,90.6,89.9,90.1,90.5,90.7,90.8,90.9,90.4,90.1)
chem.process <- data.frame(temp.data, pressure.data, yield)
attach(chem.process)
```

```
## The following objects are masked _by_ .GlobalEnv:
##
##      pressure.data, temp.data, yield
```

```
chem.process$temp <-factor(temp.data, levels =c(150,160,170), labels=c("150C", "160C", "170C"))
chem.process$pressure <-factor(pressure.data, levels =c(200,215,230), labels=c("200Psig", "215Psig", "230Psig"))
head(chem.process)
```

```
##   temp.data pressure.data yield temp pressure
## 1      150          200  90.4 150C  200Psig
## 2      150          200  90.2 150C  200Psig
## 3      150          200  90.7 150C  200Psig
## 4      150          215  90.6 150C  215Psig
## 5      150          215  90.2 150C  215Psig
## 6      150          215  90.4 150C  215Psig
```

```
str(chem.process)
```

```
## 'data.frame':   18 obs. of  5 variables:
##  $ temp.data    : num  150 150 150 150 150 150 160 160 160 160 ...
##  $ pressure.data: num  200 200 200 215 215 215 230 230 230 200 ...
##  $ yield        : num  90.4 90.2 90.7 90.6 90.2 90.4 90.1 90.3 90.5 90.6 ...
##  $ temp         : Factor w/ 3 levels "150C","160C",...: 1 1 1 1 1 1 2 2 2 2 ...
##  $ pressure     : Factor w/ 3 levels "200Psig","215Psig",...: 1 1 1 2 2 2 3 3 3 1 ...
```

```
attach(chem.process)
```

```
## The following objects are masked _by_ .GlobalEnv:
##
##   pressure.data, temp.data, yield

## The following objects are masked from chem.process (pos = 3):
##
##   pressure.data, temp.data, yield

## The following object is masked from package:datasets:
##
##   pressure
```

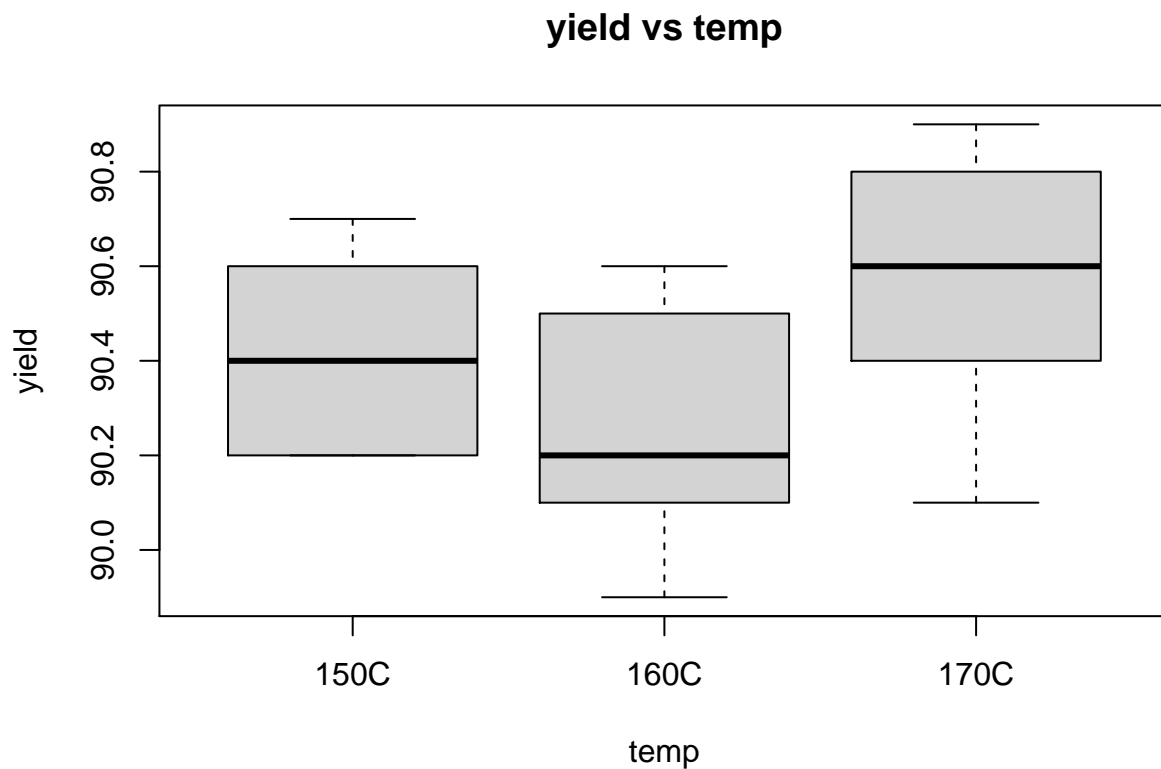
a. Analyze the data and draw conclusions, Use  $\alpha = 0.05$

a1. Plotting: boxplot of yield vs temp, yield vs pressure, yield vs temp and pressure, interaction plot

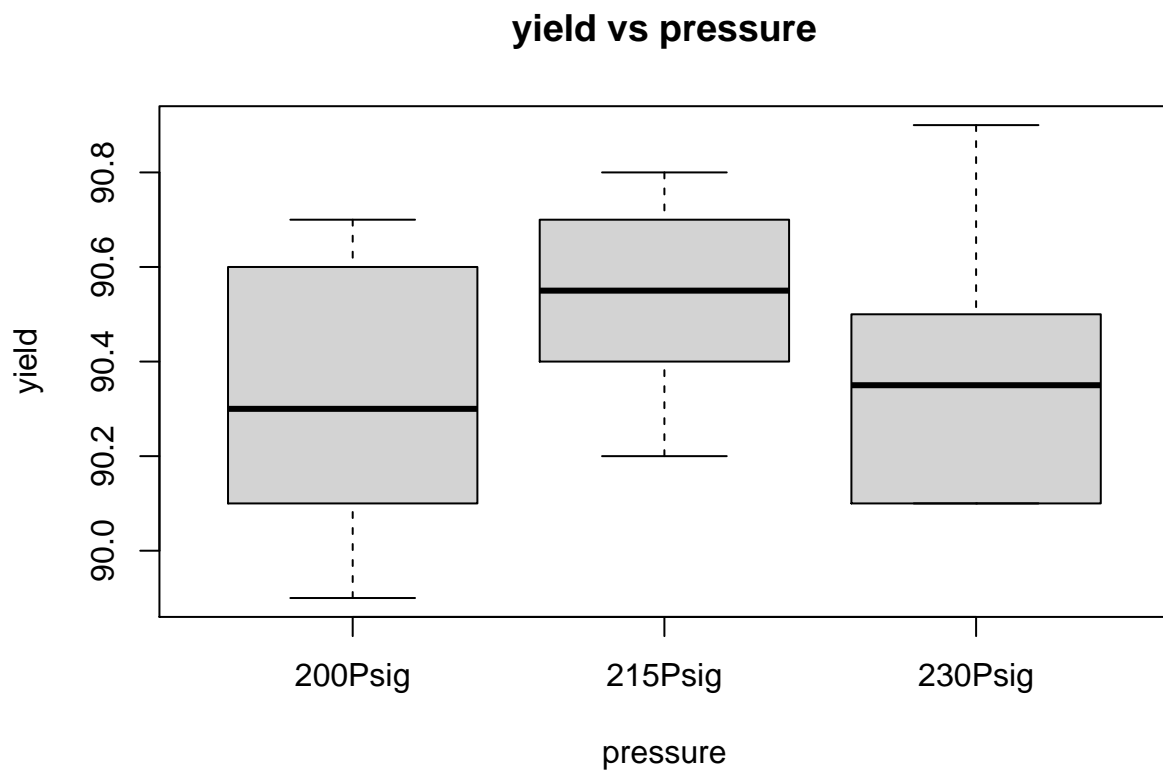
```
tapply(yield, list(temp,pressure), mean)
```

```
##      200Psig  215Psig  230Psig
## 150C 90.43333 90.40000      NA
## 160C 90.20000      NA 90.30000
## 170C      NA 90.66667 90.46667
```

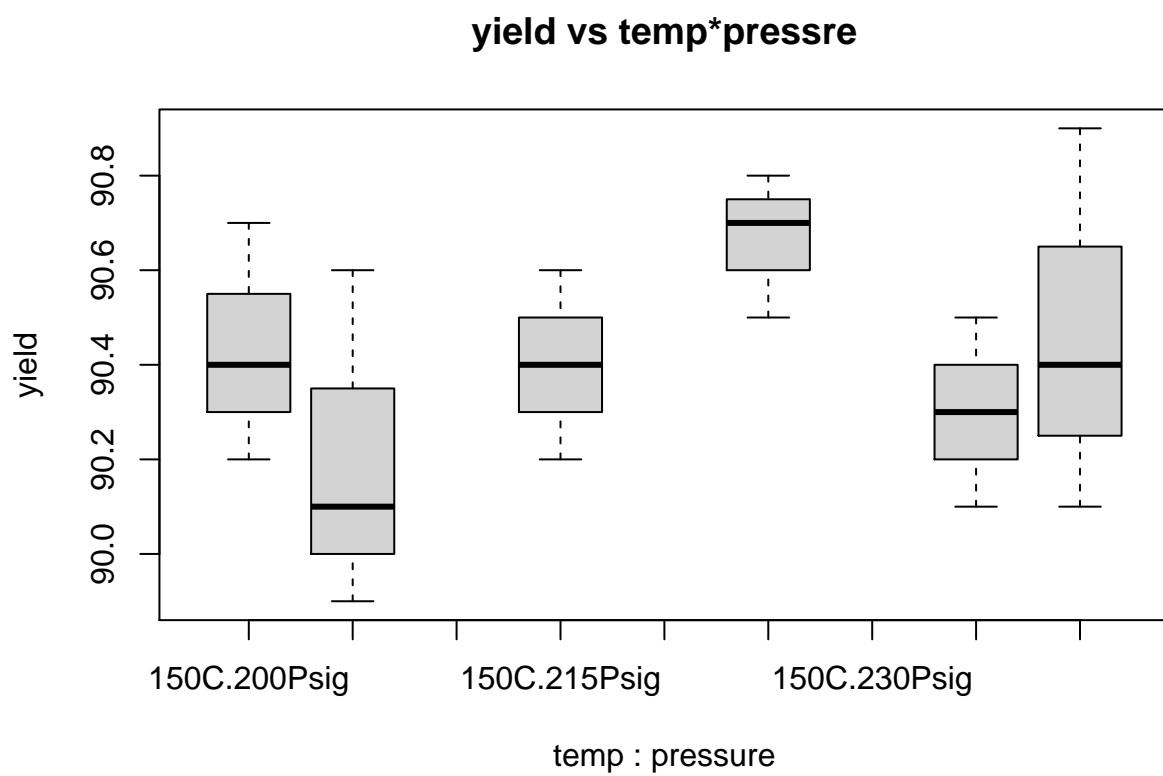
```
boxplot(yield~temp, main="yield vs temp")
```



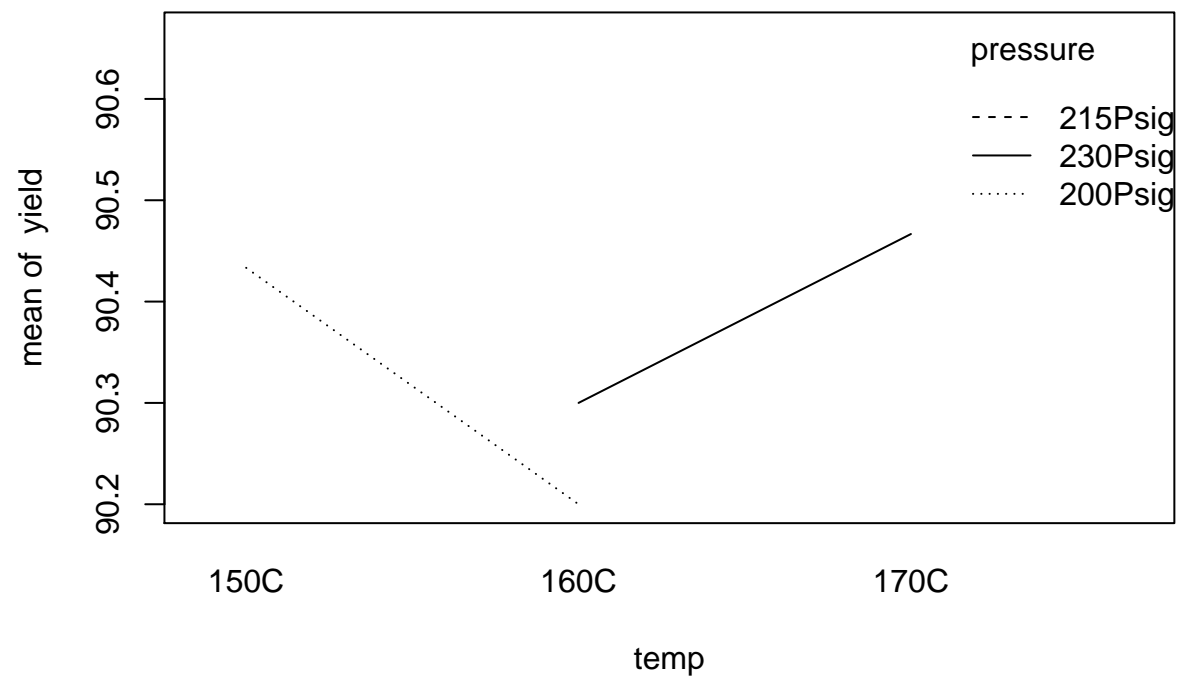
```
boxplot(yield~pressure, main="yield vs pressure")
```



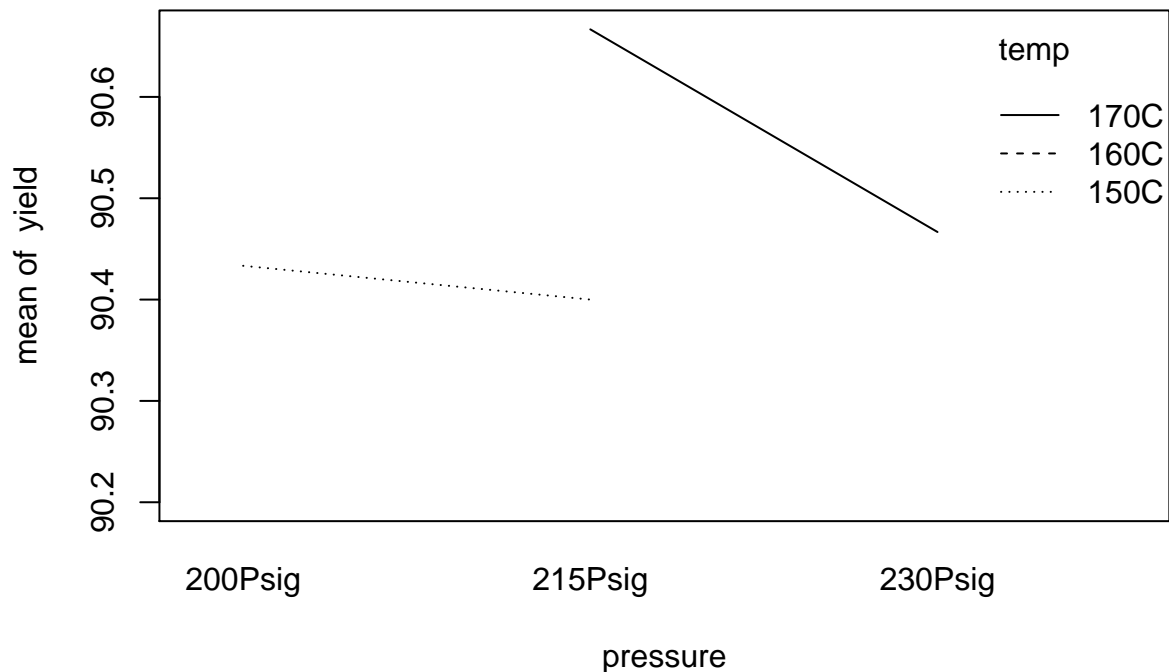
```
boxplot(yield~temp*pressure, main="yield vs temp*pressre")
```



```
interaction.plot(temp, pressure, yield)
```



```
interaction.plot(pressure, temp, yield)
```



Slopes are changing, so there is some kind of interaction

a2. Build a linear model using `aov()`. Print ANOVA output. Are main factors and interaction factor significant?

```
chem.process.mod <- aov(yield~temp*pressure)
summary.aov(chem.process.mod)
```

```
##              Df Sum Sq Mean Sq F value Pr(>F)
## temp          2  0.3011  0.15056    1.964  0.183
## pressure      2  0.0211  0.01056    0.138  0.873
## temp:pressure  1  0.0556  0.05556    0.725  0.411
## Residuals    12  0.9200  0.07667
```

```
summary.lm(chem.process.mod)
```

```
##
## Call:
## aov(formula = yield ~ temp * pressure)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.36667 -0.19167 -0.01667  0.18333  0.43333
##
## Coefficients: (3 not defined because of singularities)
##              Estimate Std. Error t value Pr(>|t|)
```

```
## (Intercept)          90.43333    0.15986 565.700   <2e-16 ***
## temp160C             -0.23333    0.22608  -1.032    0.322
## temp170C             -0.06667    0.31972  -0.209    0.838
## pressure215Psig      -0.03333    0.22608  -0.147    0.885
## pressure230Psig       0.10000    0.22608   0.442    0.666
## temp160C:pressure215Psig      NA          NA      NA      NA
## temp170C:pressure215Psig  0.33333    0.39158   0.851    0.411
## temp160C:pressure230Psig      NA          NA      NA      NA
## temp170C:pressure230Psig      NA          NA      NA      NA
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.2769 on 12 degrees of freedom
## Multiple R-squared:  0.2911, Adjusted R-squared:  -0.004281
## F-statistic: 0.9855 on 5 and 12 DF,  p-value: 0.4657
```

```
chem.process.nointeraction.mod <- aov(yield~temp+pressure)
anova(chem.process.mod, chem.process.nointeraction.mod)
```

```
## Analysis of Variance Table
##
## Model 1: yield ~ temp * pressure
## Model 2: yield ~ temp + pressure
##   Res.Df    RSS Df Sum of Sq    F Pr(>F)
## 1      12 0.92000
## 2      13 0.97556 -1 -0.055556 0.7246 0.4113
```

Since P-value >.05, we accept null and reject Alternate. The interaction term is in-significant, so we can discard the interaction term. We take the partial model instead of full model

a3. Print out regression model with coefficients

```
summary.lm(chem.process.nointeraction.mod)
```

```
##
## Call:
## aov(formula = yield ~ temp + pressure)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.42222 -0.15278 -0.01667  0.17778  0.37778
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   90.37778    0.14438  625.977   <2e-16 ***
## temp160C      -0.12222    0.18263   -0.669    0.515
## temp170C       0.15556    0.18263    0.852    0.410
## pressure215Psig 0.07778    0.18263    0.426    0.677
## pressure230Psig -0.01111    0.18263   -0.061    0.952
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.2739 on 13 degrees of freedom
```

```
## Multiple R-squared:  0.2483, Adjusted R-squared:  0.01699
## F-statistic: 1.073 on 4 and 13 DF,  p-value: 0.4089
```

Only the intercept is significant, so it means that the linear model can remove other terms while predicting the values.

## b. Prepare appropriate residuals plot and comment on the model's adequacy

```
summary.lm(chem.process.nointeraction.mod)
```

```
##
## Call:
## aov(formula = yield ~ temp + pressure)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.42222 -0.15278 -0.01667  0.17778  0.37778
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   90.37778    0.14438  625.977  <2e-16 ***
## temp160C      -0.12222    0.18263   -0.669    0.515
## temp170C       0.15556    0.18263    0.852    0.410
## pressure215Psig 0.07778    0.18263    0.426    0.677
## pressure230Psig -0.01111    0.18263   -0.061    0.952
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.2739 on 13 degrees of freedom
## Multiple R-squared:  0.2483, Adjusted R-squared:  0.01699
## F-statistic: 1.073 on 4 and 13 DF,  p-value: 0.4089
```

```
summary.aov(chem.process.nointeraction.mod)
```

```
##           Df Sum Sq Mean Sq F value Pr(>F)
## temp         2  0.3011  0.15056    2.006  0.174
## pressure     2  0.0211  0.01056    0.141  0.870
## Residuals   13  0.9756  0.07504
```

It looks like the difference of mean for both temperature and pressure is the same, so there is not much difference because of temperature or pressure.

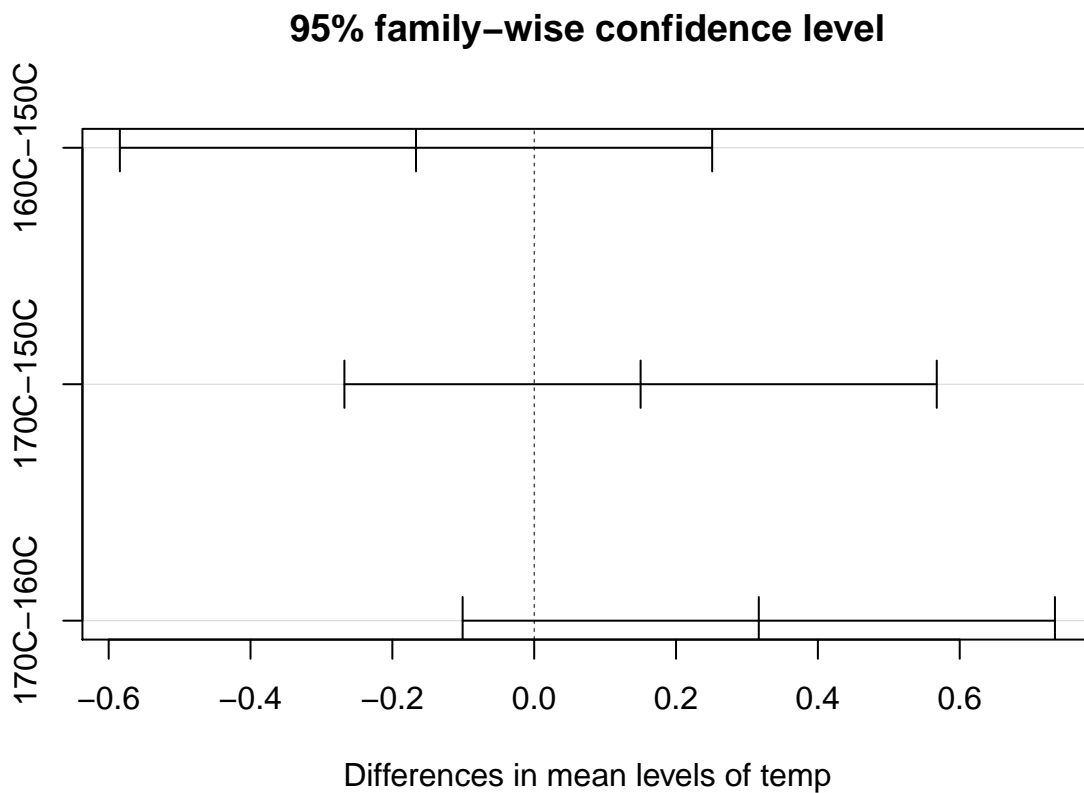
## c. Under what condition would you operate this process

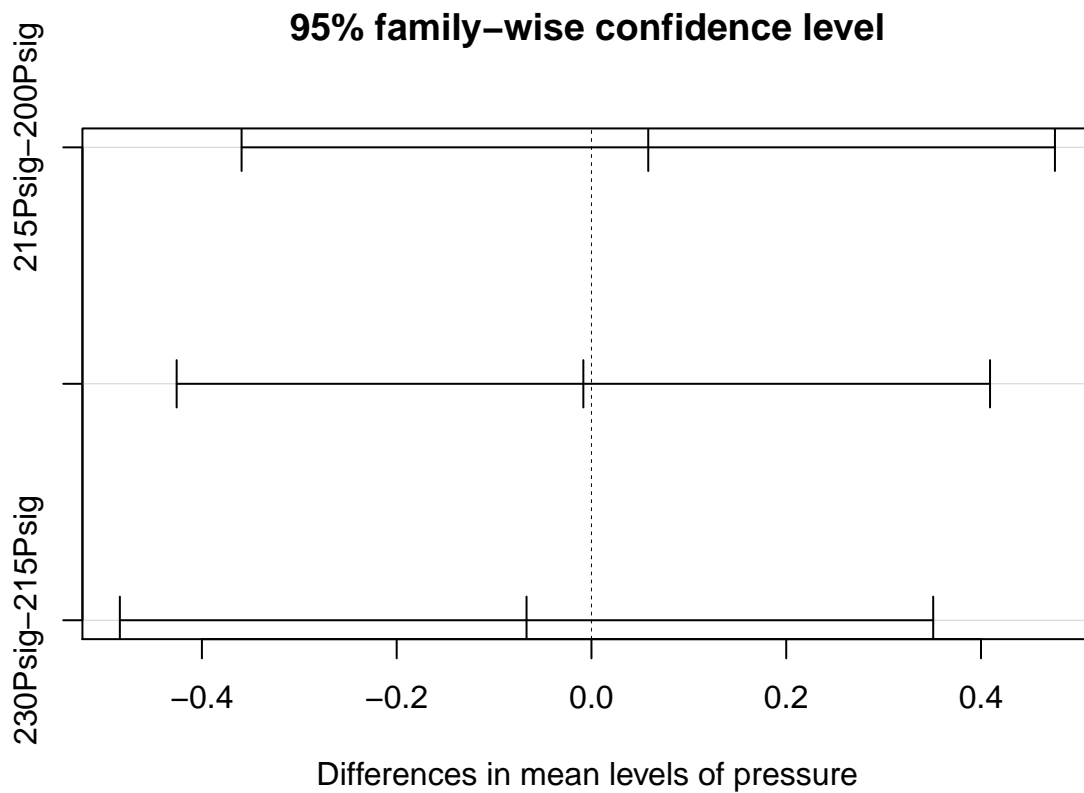
```
tukeys <- TukeyHSD(chem.process.nointeraction.mod)
tukeys
```



```
## Tukey multiple comparisons of means
## 95% family-wise confidence level
##
## Fit: aov(formula = yield ~ temp + pressure)
##
## $temp
##           diff          lwr          upr      p adj
## 160C-150C -0.1666667 -0.5842754 0.2509420 0.5578113
## 170C-150C  0.1500000 -0.2676087 0.5676087 0.6206552
## 170C-160C  0.3166667 -0.1009420 0.7342754 0.1509184
##
## $pressure
##           diff          lwr          upr      p adj
## 215Psig-200Psig  0.05833333 -0.3592754 0.4759420 0.9281651
## 230Psig-200Psig -0.00833333 -0.4259420 0.4092754 0.9984708
## 230Psig-215Psig -0.06666667 -0.4842754 0.3509420 0.9073869
```

```
plot(tukeys)
```





Pvalue is large for both pressure, and temperature at all conditions, so we accept null hypothesis that there is not much difference due to the changing conditions

```
library(agricolae)
```

```
## Warning: package 'agricolae' was built under R version 4.0.5
```

```
lsd <- LSD.test(chem.process.nointeraction.mod, c("temp", "pressure"), console=T)
```

```
##
## Study: chem.process.nointeraction.mod ~ c("temp", "pressure")
##
## LSD t Test for yield
##
## Mean Square Error: 0.07504274
##
## temp:pressure, means and individual ( 95 %) CI
##
##
```

	yield	std r		LCL	UCL	Min	Max
## 150C:200Psig	90.43333	0.2516611	3	90.09165	90.77501	90.2	90.7
## 150C:215Psig	90.40000	0.2000000	3	90.05832	90.74168	90.2	90.6
## 160C:200Psig	90.20000	0.3605551	3	89.85832	90.54168	89.9	90.6
## 160C:230Psig	90.30000	0.2000000	3	89.95832	90.64168	90.1	90.5
## 170C:215Psig	90.66667	0.1527525	3	90.32499	91.00835	90.5	90.8
## 170C:230Psig	90.46667	0.4041452	3	90.12499	90.80835	90.1	90.9

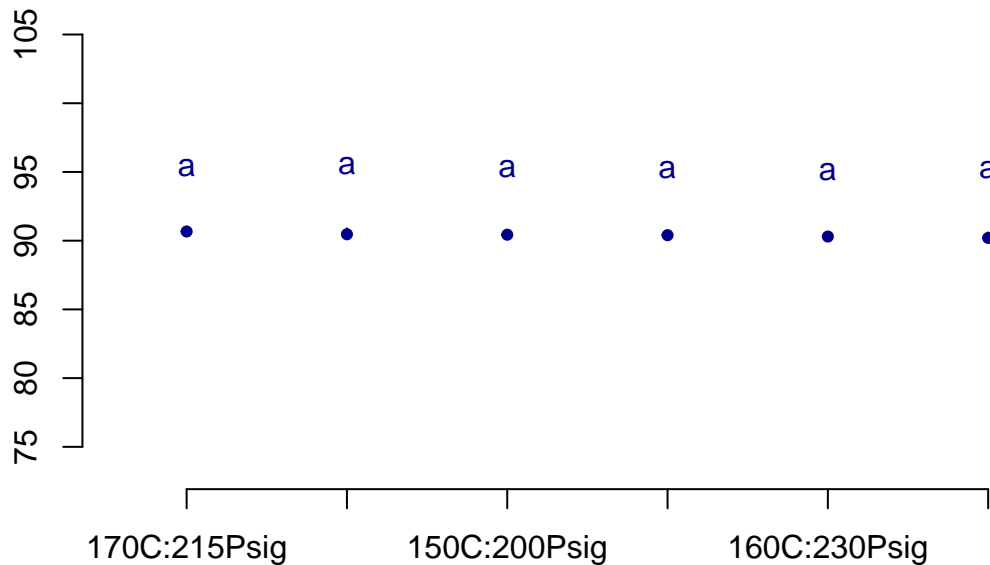
```
##
## Alpha: 0.05 ; DF Error: 13
## Critical Value of t: 2.160369
##
## least Significant Difference: 0.4832107
##
## Treatments with the same letter are not significantly different.
##
##          yield groups
## 170C:215Psig 90.66667      a
## 170C:230Psig 90.46667      a
## 150C:200Psig 90.43333      a
## 150C:215Psig 90.40000      a
## 160C:230Psig 90.30000      a
## 160C:200Psig 90.20000      a
```

```
lsd
```

```
## $statistics
##      MSerror Df      Mean      CV  t.value      LSD
## 0.07504274 13 90.41111 0.3029929 2.160369 0.4832107
##
## $parameters
##      test p.adjusted      name.t ntr alpha
## Fisher-LSD      none temp:pressure 6 0.05
##
## $means
##          yield      std r      LCL      UCL Min Max  Q25 Q50  Q75
## 150C:200Psig 90.43333 0.2516611 3 90.09165 90.77501 90.2 90.7 90.30 90.4 90.55
## 150C:215Psig 90.40000 0.2000000 3 90.05832 90.74168 90.2 90.6 90.30 90.4 90.50
## 160C:200Psig 90.20000 0.3605551 3 89.85832 90.54168 89.9 90.6 90.00 90.1 90.35
## 160C:230Psig 90.30000 0.2000000 3 89.95832 90.64168 90.1 90.5 90.20 90.3 90.40
## 170C:215Psig 90.66667 0.1527525 3 90.32499 91.00835 90.5 90.8 90.60 90.7 90.75
## 170C:230Psig 90.46667 0.4041452 3 90.12499 90.80835 90.1 90.9 90.25 90.4 90.65
##
## $comparison
## NULL
##
## $groups
##          yield groups
## 170C:215Psig 90.66667      a
## 170C:230Psig 90.46667      a
## 150C:200Psig 90.43333      a
## 150C:215Psig 90.40000      a
## 160C:230Psig 90.30000      a
## 160C:200Psig 90.20000      a
##
## attr(,"class")
## [1] "group"
```

```
plot(lsd)
```

## Groups and Range



```
detach()
```

All terms generate almost the same yield, so we should choose the one which can be operated at least cost. I would choose the one at 150C and 200Psig

## Question 2

setup data

```
operator<- rep(c(1,2,3), each=8)
machine<- rep(c(1,2,3,4), each=2, times=3)

strength <- c(109, 110,110,115,108,109,110,108,110,112,110,111,111,109,114,112,116,114,112,115,114,119,
110,111,112,113,114,115,116,117,118,119,120,121,122,123,124,125,126,127,128,129,130,131,132,133,134,135,136,137,138,139,140,141,142,143,144,145,146,147,148,149,150,151,152,153,154,155,156,157,158,159,160,161,162,163,164,165,166,167,168,169,170,171,172,173,174,175,176,177,178,179,180,181,182,183,184,185,186,187,188,189,190,191,192,193,194,195,196,197,198,199,200,201,202,203,204,205,206,207,208,209,210,211,212,213,214,215,216,217,218,219,220,221,222,223,224,225,226,227,228,229,230,231,232,233,234,235,236,237,238,239,240,241,242,243,244,245,246,247,248,249,250,251,252,253,254,255,256,257,258,259,260,261,262,263,264,265,266,267,268,269,270,271,272,273,274,275,276,277,278,279,280,281,282,283,284,285,286,287,288,289,290,291,292,293,294,295,296,297,298,299,300,301,302,303,304,305,306,307,308,309,310,311,312,313,314,315,316,317,318,319,320,321,322,323,324,325,326,327,328,329,330,331,332,333,334,335,336,337,338,339,340,341,342,343,344,345,346,347,348,349,350,351,352,353,354,355,356,357,358,359,360,361,362,363,364,365,366,367,368,369,370,371,372,373,374,375,376,377,378,379,380,381,382,383,384,385,386,387,388,389,390,391,392,393,394,395,396,397,398,399,400,401,402,403,404,405,406,407,408,409,410,411,412,413,414,415,416,417,418,419,420,421,422,423,424,425,426,427,428,429,430,431,432,433,434,435,436,437,438,439,440,441,442,443,444,445,446,447,448,449,450,451,452,453,454,455,456,457,458,459,460,461,462,463,464,465,466,467,468,469,470,471,472,473,474,475,476,477,478,479,480,481,482,483,484,485,486,487,488,489,490,491,492,493,494,495,496,497,498,499,500,501,502,503,504,505,506,507,508,509,510,511,512,513,514,515,516,517,518,519,520,521,522,523,524,525,526,527,528,529,530,531,532,533,534,535,536,537,538,539,540,541,542,543,544,545,546,547,548,549,550,551,552,553,554,555,556,557,558,559,560,561,562,563,564,565,566,567,568,569,570,571,572,573,574,575,576,577,578,579,580,581,582,583,584,585,586,587,588,589,590,591,592,593,594,595,596,597,598,599,600,601,602,603,604,605,606,607,608,609,610,611,612,613,614,615,616,617,618,619,620,621,622,623,624,625,626,627,628,629,630,631,632,633,634,635,636,637,638,639,640,641,642,643,644,645,646,647,648,649,650,651,652,653,654,655,656,657,658,659,660,661,662,663,664,665,666,667,668,669,670,671,672,673,674,675,676,677,678,679,680,681,682,683,684,685,686,687,688,689,690,691,692,693,694,695,696,697,698,699,700,701,702,703,704,705,706,707,708,709,710,711,712,713,714,715,716,717,718,719,720,721,722,723,724,725,726,727,728,729,730,731,732,733,734,735,736,737,738,739,740,741,742,743,744,745,746,747,748,749,750,751,752,753,754,755,756,757,758,759,760,761,762,763,764,765,766,767,768,769,770,771,772,773,774,775,776,777,778,779,780,781,782,783,784,785,786,787,788,789,790,791,792,793,794,795,796,797,798,799,800,801,802,803,804,805,806,807,808,809,810,811,812,813,814,815,816,817,818,819,820,821,822,823,824,825,826,827,828,829,830,831,832,833,834,835,836,837,838,839,840,841,842,843,844,845,846,847,848,849,850,851,852,853,854,855,856,857,858,859,860,861,862,863,864,865,866,867,868,869,870,871,872,873,874,875,876,877,878,879,880,881,882,883,884,885,886,887,888,889,890,891,892,893,894,895,896,897,898,899,900,901,902,903,904,905,906,907,908,909,910,911,912,913,914,915,916,917,918,919,920,921,922,923,924,925,926,927,928,929,930,931,932,933,934,935,936,937,938,939,940,941,942,943,944,945,946,947,948,949,950,951,952,953,954,955,956,957,958,959,960,961,962,963,964,965,966,967,968,969,970,971,972,973,974,975,976,977,978,979,980,981,982,983,984,985,986,987,988,989,990,991,992,993,994,995,996,997,998,999,1000,1001,1002,1003,1004,1005,1006,1007,1008,1009,1010,1011,1012,1013,1014,1015,1016,1017,1018,1019,1020,1021,1022,1023,1024,1025,1026,1027,1028,1029,1030,1031,1032,1033,1034,1035,1036,1037,1038,1039,1040,1041,1042,1043,1044,1045,1046,1047,1048,1049,1050,1051,1052,1053,1054,1055,1056,1057,1058,1059,1060,1061,1062,1063,1064,1065,1066,1067,1068,1069,1070,1071,1072,1073,1074,1075,1076,1077,1078,1079,1080,1081,1082,1083,1084,1085,1086,1087,1088,1089,1090,1091,1092,1093,1094,1095,1096,1097,1098,1099,1100,1101,1102,1103,1104,1105,1106,1107,1108,1109,1110,1111,1112,1113,1114,1115,1116,1117,1118,1119,1120,1121,1122,1123,1124,1125,1126,1127,1128,1129,1130,1131,1132,1133,1134,1135,1136,1137,1138,1139,1140,1141,1142,1143,1144,1145,1146,1147,1148,1149,1150,1151,1152,1153,1154,1155,1156,1157,1158,1159,1160,1161,1162,1163,1164,1165,1166,1167,1168,1169,1170,1171,1172,1173,1174,1175,1176,1177,1178,1179,1180,1181,1182,1183,1184,1185,1186,1187,1188,1189,1190,1191,1192,1193,1194,1195,1196,1197,1198,1199,1200,1201,1202,1203,1204,1205,1206,1207,1208,1209,1210,1211,1212,1213,1214,1215,1216,1217,1218,1219,1220,1221,1222,1223,1224,1225,1226,1227,1228,1229,1230,1231,1232,1233,1234,1235,1236,1237,1238,1239,1240,1241,1242,1243,1244,1245,1246,1247,1248,1249,1250,1251,1252,1253,1254,1255,1256,1257,1258,1259,1260,1261,1262,1263,1264,1265,1266,1267,1268,1269,1270,1271,1272,1273,1274,1275,1276,1277,1278,1279,1280,1281,1282,1283,1284,1285,1286,1287,1288,1289,1290,1291,1292,1293,1294,1295,1296,1297,1298,1299,1300,1301,1302,1303,1304,1305,1306,1307,1308,1309,1310,1311,1312,1313,1314,1315,1316,1317,1318,1319,1320,1321,1322,1323,1324,1325,1326,1327,1328,1329,1330,1331,1332,1333,1334,1335,1336,1337,1338,1339,1340,1341,1342,1343,1344,1345,1346,1347,1348,1349,1350,1351,1352,1353,1354,1355,1356,1357,1358,1359,1360,1361,1362,1363,1364,1365,1366,1367,1368,1369,1370,1371,1372,1373,1374,1375,1376,1377,1378,1379,1380,1381,1382,1383,1384,1385,1386,1387,1388,1389,1390,1391,1392,1393,1394,1395,1396,1397,1398,1399,1400,1401,1402,1403,1404,1405,1406,1407,1408,1409,1410,1411,1412,1413,1414,1415,1416,1417,1418,1419,1420,1421,1422,1423,1424,1425,1426,1427,1428,1429,1430,1431,1432,1433,1434,1435,1436,1437,1438,1439,1440,1441,1442,1443,1444,1445,1446,1447,1448,1449,1450,1451,1452,1453,1454,1455,1456,1457,1458,1459,1460,1461,1462,1463,1464,1465,1466,1467,1468,1469,1470,1471,1472,1473,1474,1475,1476,1477,1478,1479,1480,1481,1482,1483,1484,1485,1486,1487,1488,1489,1490,1491,1492,1493,1494,1495,1496,1497,1498,1499,1500,1501,1502,1503,1504,1505,1506,1507,1508,1509,1510,1511,1512,1513,1514,1515,1516,1517,1518,1519,1520,1521,1522,1523,1524,1525,1526,1527,1528,1529,1530,1531,1532,1533,1534,1535,1536,1537,1538,1539,1540,1541,1542,1543,1544,1545,1546,1547,1548,1549,1550,1551,1552,1553,1554,1555,1556,1557,1558,1559,1560,1561,1562,1563,1564,1565,1566,1567,1568,1569,1570,1571,1572,1573,1574,1575,1576,1577,1578,1579,1580,1581,1582,1583,1584,1585,1586,1587,1588,1589,1590,1591,1592,1593,1594,1595,1596,1597,1598,1599,1600,1601,1602,1603,1604,1605,1606,1607,1608,1609,1610,1611,1612,1613,1614,1615,1616,1617,1618,1619,1620,1621,1622,1623,1624,1625,1626,1627,1628,1629,1630,1631,1632,1633,1634,1635,1636,1637,1638,1639,1640,1641,1642,1643,1644,1645,1646,1647,1648,1649,1650,1651,1652,1653,1654,1655,1656,1657,1658,1659,1660,1661,1662,1663,1664,1665,1666,1667,1668,1669,1670,1671,1672,1673,1674,1675,1676,1677,1678,1679,1680,1681,1682,1683,1684,1685,1686,1687,1688,1689,1690,1691,1692,1693,1694,1695,1696,1697,1698,1699,1700,1701,1702,1703,1704,1705,1706,1707,1708,1709,1710,1711,1712,1713,1714,1715,1716,1717,1718,1719,1720,1721,1722,1723,1724,1725,1726,1727,1728,1729,1730,1731,1732,1733,1734,1735,1736,1737,1738,1739,1740,1741,1742,1743,1744,1745,1746,1747,1748,1749,1750,1751,1752,1753,1754,1755,1756,1757,1758,1759,1760,1761,1762,1763,1764,1765,1766,1767,1768,1769,1770,1771,1772,1773,1774,1775,1776,1777,1778,1779,1780,1781,1782,1783,1784,1785,1786,1787,1788,1789,1790,1791,1792,1793,1794,1795,1796,1797,1798,1799,1800,1801,1802,1803,1804,1805,1806,1807,1808,1809,1810,1811,1812,1813,1814,1815,1816,1817,1818,1819,1820,1821,1822,1823,1824,1825,1826,1827,1828,1829,1830,1831,1832,1833,1834,1835,1836,1837,1838,1839,1840,1841,1842,1843,1844,1845,1846,1847,1848,1849,1850,1851,1852,1853,1854,1855,1856,1857,1858,1859,1860,1861,1862,1863,1864,1865,1866,1867,1868,1869,1870,1871,1872,1873,1874,1875,1876,1877,1878,1879,1880,1881,1882,1883,1884,1885,1886,1887,1888,1889,1890,1891,1892,1893,1894,1895,1896,1897,1898,1899,1900,1901,1902,1903,1904,1905,1906,1907,1908,1909,1910,1911,1912,1913,1914,1915,1916,1917,1918,1919,1920,1921,1922,1923,1924,1925,1926,1927,1928,1929,1930,1931,1932,1933,1934,1935,1936,1937,1938,1939,1940,1941,1942,1943,1944,1945,1946,1947,1948,1949,1950,1951,1952,1953,1954,1955,1956,1957,1958,1959,1960,1961,1962,1963,1964,1965,1966,1967,1968,1969,1970,1971,1972,1973,1974,1975,1976,1977,1978,1979,1980,1981,1982,1983,1984,1985,1986,1987,1988,1989,1990,1991,1992,1993,1994,1995,1996,1997,1998,1999,2000,2001,2002,2003,2004,2005,2006,2007,2008,2009,2010,2011,2012,2013,2014,2015,2016,2017,2018,2019,2020,2021,2022,2023,2024,2025,2026,2027,2028,2029,2030,2031,2032,2033,2034,2035,2036,2037,2038,2039,2040,2041,2042,2043,2044,2045,2046,2047,2048,2049,2050,2051,2052,2053,2054,2055,2056,2057,2058,2059,2060,2061,2062,2063,2064,2065,2066,2067,2068,2069,2070,2071,2072,2073,2074,2075,2076,2077,2078,2079,2080,2081,2082,2083,2084,2085,2086,2087,2088,2089,2090,2091,2092,2093,2094,2095,2096,2097,2098,2099,2100,2101,2102,2103,2104,2105,2106,2107,2108,2109,2110,2111,2112,2113,2114,2115,2116,2117,2118,2119,2120,2121,2122,2123,2124,2125,2126,2127,2128,2129,2130,2131,2132,2133,2134,2135,2136,2137,2138,2139,2140,2141,2142,2143,2144,2145,2146,2147,2148,2149,2150,2151,2152,2153,2154,2155,2156,2157,2158,2159,2160,2161,2162,2163,2164,2165,2166,2167,2168,2169,2170,2171,2172,2173,2174,2175,2176,2177,2178,2179,2180,2181,2182,2183,2184,2185,2186,2187,2188,2189,2190,2191,2192,2193,2194,2195,2196,2197,2198,2199,2200,2201,2202,2203,2204,2205,2206,2207,2208,2209,2210,2211,2212,2213,2214,2215,2216,2217,2218,2219,2220,2221,2222,2223,2224,2225,2226,2227,2228,2229,2230,2231,2232,2233,2234,2235,2236,2237,2238,2239,2240,2241,2242,2243,2244,2245,2246,2247,2248,2249,2250,2251,2252,2253,2254,2255,2256,2257,2258,2259,2260,2261,2262,2263,2264,2265,2266,2267,2268,2269,2270,2271,2272,2273,2274,2275,2276,2277,2278,2279,2280,2281,2282,2283,2284,2285,2286,2287,2288,2289,2290,2291,2292,2293,2294,2295,2296,2297,2298,2299,2300,2301,2302,2303,2304,2305,2306,2307,2308,2309,2310,2311,2312,2313,2314,2315,2316,2317,2318,2319,2320,2321,2322,2323,2324,2325,2326,2327,2328,2329,2330,2331,2332,2333,2334,2335,2336,2337,2338,2339,2340,2341,2342,2343,2344,2345,2346,2347,2348,2349,2350,2351,2352,2353,2354,2355,2356,2357,2358,2359,2360,2361,2362,2363,2364,2365,2366,2367,2368,2369,2370,2371,2372,2373,2374,2375,2376,2377,2378,2379,2380,2381,2382,2383,2384,2385,2386,2387,2388,2389,2390,2391,2392,2393,2394,2395,2396,2397,2398,2399,2400,2401,2402,2403,2404,2405,2406,2407,2408,2409,2410,2411,2412,2413,2414,2415,2416,2417,2418,2419,2420,2421,2422,2423,2424,2425,2426,2427,2428,2429,2430,2431,2432,2433,2434,2435,2436,2437,2438,2439,2440,2441,2442,2443,2444,2445,2446,2447,2448,2449,2450,2451,2452,2453,2454,2455,2456,2457,2458,2459,2460,2461,2462,2463,2464,2465,2466,2467,2468,2469,2470,2471,2472,2473,2474,2475,2476,2477,2478,2479,2480,2481,2482,2483,2484,2485,2486,2487,2488,2489,2490,2491,2492,2493,2494,2495,2496,2497,2498,2499,2500,2501,2502,2503,2504,2505,2506,2507,2508,2509,2510,2511,2512,2513,2514,2515,2516,2517,2518,2519,2520,2521,2522,2523,2524,2525,2526,2527,2528,2529,2530,2531,2532,2533,2534,2535,2536,2537,2538,2539,2540,2541,2542,2543,2544,2545,2546,2547,2548,2549,2550,2551,2552,2553,2554,2555,2556,2557,2558,2559,2560,2561,2562,2563,2564,2565,2566,2567,2568,2569,2570,2571,2572,2573,2574,2575,2576,2577,2578,2579,2580,2581,2582,2583,2584,2585,2586,2587,2588,2589,2590,25
```

```
## 1      Op1  Mach1    109
## 2      Op1  Mach1    110
## 3      Op1  Mach2    110
## 4      Op1  Mach2    115
## 5      Op1  Mach3    108
## 6      Op1  Mach3    109
```

```
str(fiber)
```

```
## 'data.frame':  24 obs. of  3 variables:
## $ operator: Factor w/ 3 levels "Op1","Op2","Op3": 1 1 1 1 1 1 1 2 2 ...
## $ machine  : Factor w/ 4 levels "Mach1","Mach2",..: 1 1 2 2 3 3 4 4 1 1 ...
## $ strength: num  109 110 110 115 108 109 110 108 110 112 ...
```

```
attach(fiber)
```

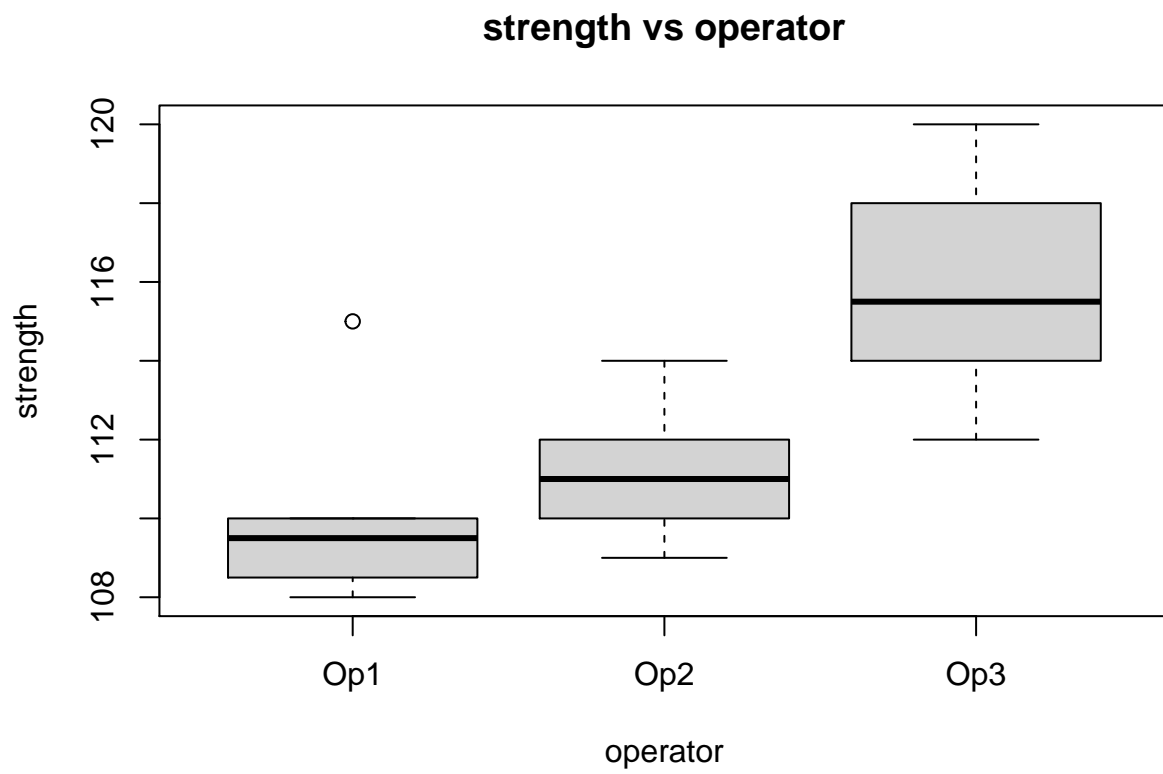
```
## The following objects are masked _by_ .GlobalEnv:
##
## machine, operator, strength
```

a1. Plotting: boxplot of strength vs operator, strength vs machine, strength vs operator and machine, interaction plot

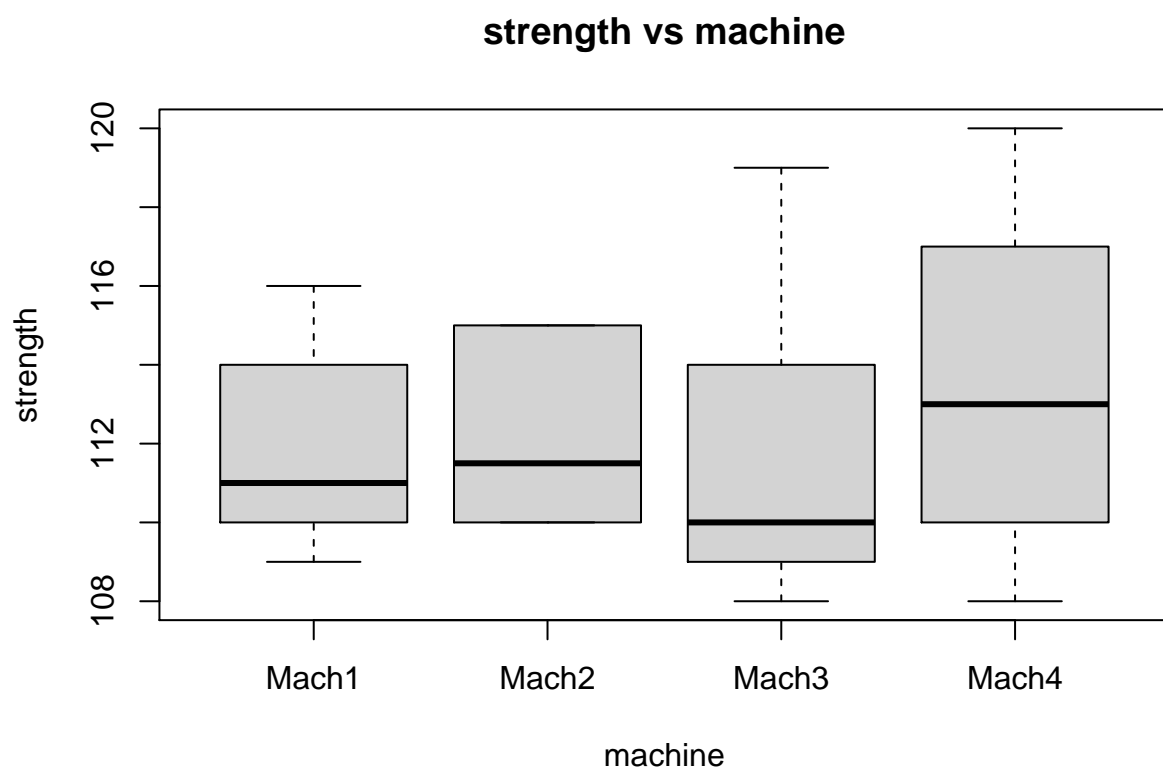
```
tapply(strength, list(operator,machine), mean)
```

```
##      Mach1 Mach2 Mach3 Mach4
## Op1 109.5 112.5 108.5 109.0
## Op2 111.0 110.5 110.0 113.0
## Op3 115.0 113.5 116.5 118.5
```

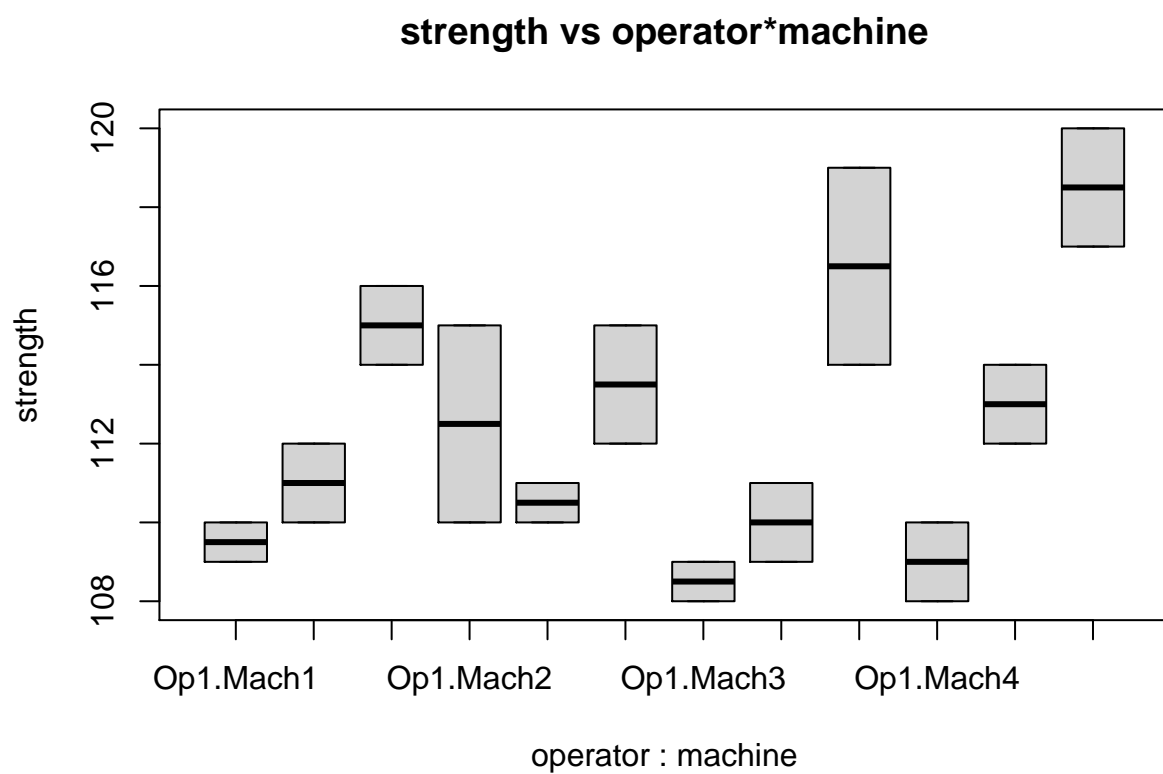
```
boxplot(strength~operator, main="strength vs operator")
```



```
boxplot(strength~machine, main="strength vs machine")
```

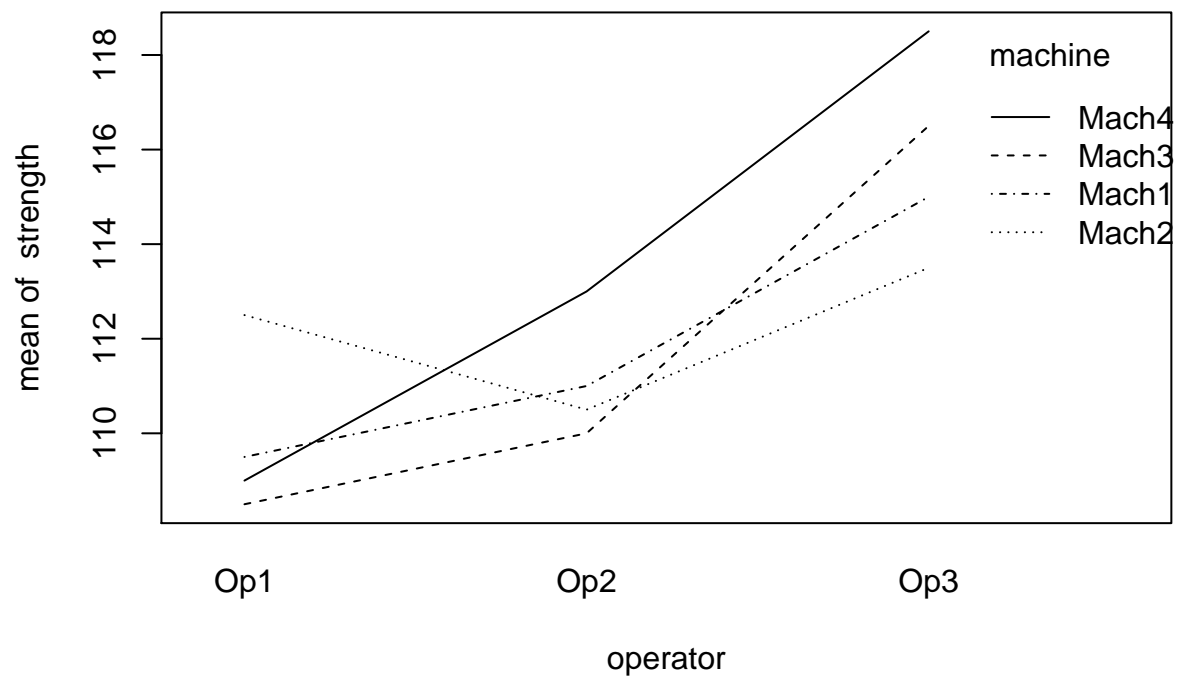


```
boxplot(strength~operator*machine, main="strength vs operator*machine")
```

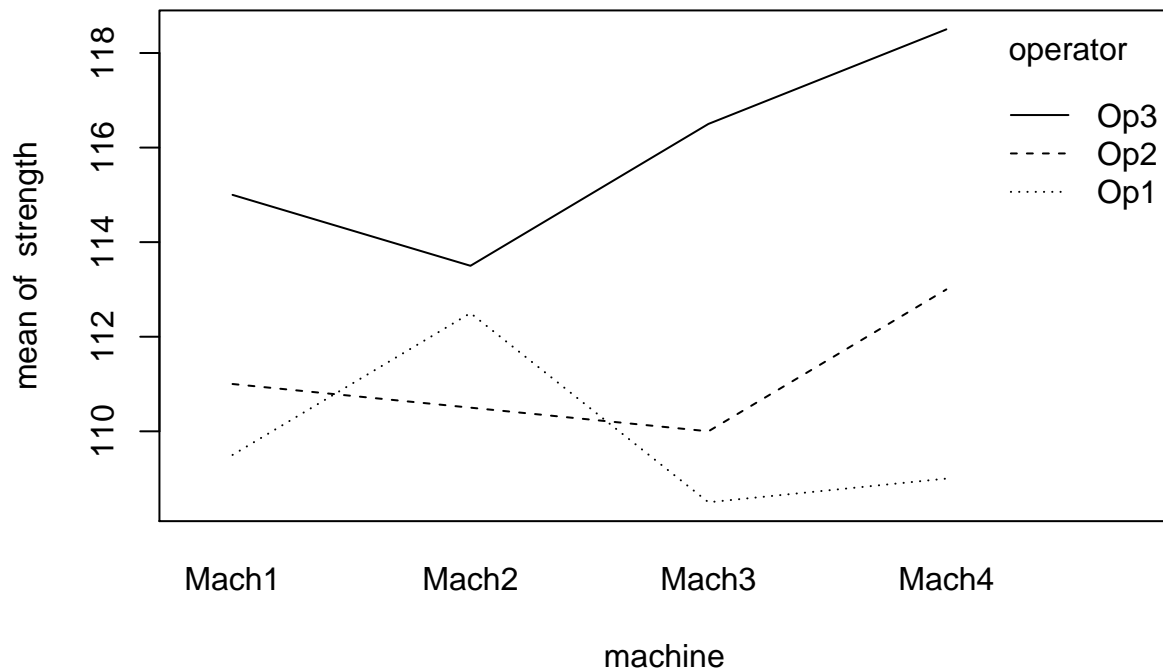


```
interaction.plot(operator, machine, strength)
```





```
interaction.plot(machine, operator, strength)
```



Interaction plots are intersecting, so there is a indication of strong interaction

a2. Build a linear model using `aov()`. Print ANOVA output. Are main factors and interaction factor significant?

```
fiber.mod <- aov(strength~operator*machine)
summary.aov(fiber.mod)
```

```
##              Df Sum Sq Mean Sq F value    Pr(>F)
## operator      2  160.33    80.17   21.143 0.000117 ***
## machine       3   12.46     4.15    1.095 0.388753
## operator:machine 6   44.67     7.44    1.963 0.150681
## Residuals    12   45.50     3.79
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
summary.lm(fiber.mod)
```

```
##
## Call:
## aov(formula = strength ~ operator * machine)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
##    -2.5    -1.0     0.0     1.0     2.5
##
```

```
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)    1.095e+02  1.377e+00  79.527  <2e-16 ***
## operatorOp2     1.500e+00  1.947e+00   0.770   0.4560
## operatorOp3     5.500e+00  1.947e+00   2.825   0.0153 *
## machineMach2     3.000e+00  1.947e+00   1.541   0.1493
## machineMach3    -1.000e+00  1.947e+00  -0.514   0.6169
## machineMach4    -5.000e-01  1.947e+00  -0.257   0.8017
## operatorOp2:machineMach2 -3.500e+00  2.754e+00  -1.271   0.2278
## operatorOp3:machineMach2 -4.500e+00  2.754e+00  -1.634   0.1282
## operatorOp2:machineMach3  8.573e-14  2.754e+00   0.000   1.0000
## operatorOp3:machineMach3  2.500e+00  2.754e+00   0.908   0.3818
## operatorOp2:machineMach4  2.500e+00  2.754e+00   0.908   0.3818
## operatorOp3:machineMach4  4.000e+00  2.754e+00   1.453   0.1720
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 1.947 on 12 degrees of freedom
## Multiple R-squared:  0.827, Adjusted R-squared:  0.6684
## F-statistic: 5.214 on 11 and 12 DF, p-value: 0.004136
```

```
operator
```

```
## [1] Op1 Op1 Op1 Op1 Op1 Op1 Op1 Op1 Op1 Op2 Op2 Op2 Op2 Op2 Op2 Op2 Op2 Op3 Op3 Op3
## [20] Op3 Op3 Op3 Op3 Op3
## Levels: Op1 Op2 Op3
```

```
fiber.nointeraction.mod <- aov(strength~operator+machine)
anova(fiber.mod, fiber.nointeraction.mod)
```

```
## Analysis of Variance Table
##
## Model 1: strength ~ operator * machine
## Model 2: strength ~ operator + machine
##   Res.Df    RSS Df Sum of Sq    F Pr(>F)
## 1      12 45.500
## 2      18 90.167 -6   -44.667 1.9634 0.1507
```

Since P-value >.05, we accept null and reject Alternate. The interaction term is in-significant, so we can discard the interaction term. We take the partial model instead of full model

a3. Print out regression model with coefficients

```
summary.lm(fiber.nointeraction.mod)
```

```
##
## Call:
## aov(formula = strength ~ operator + machine)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -3.7500 -1.1250 -0.2917  0.5833  5.2500
```

```
##
## Coefficients:
##           Estimate Std. Error t value Pr(>|t|)
## (Intercept)  109.4167      1.1191  97.775 < 2e-16 ***
## operatorOp2    1.2500      1.1191   1.117  0.279
## operatorOp3    6.0000      1.1191   5.362 4.27e-05 ***
## machineMach2   0.3333      1.2922   0.258  0.799
## machineMach3  -0.1667      1.2922  -0.129  0.899
## machineMach4   1.6667      1.2922   1.290  0.213
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 2.238 on 18 degrees of freedom
## Multiple R-squared:  0.6571, Adjusted R-squared:  0.5619
## F-statistic: 6.899 on 5 and 18 DF,  p-value: 0.00093
```

Intercept and Operator are both significant

## b. Prepare appropriate residuals plot and comment on the model's adequacy

```
summary.lm(fiber.nointeraction.mod)
```

```
##
## Call:
## aov(formula = strength ~ operator + machine)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -3.7500 -1.1250 -0.2917  0.5833  5.2500
##
## Coefficients:
##           Estimate Std. Error t value Pr(>|t|)
## (Intercept)  109.4167      1.1191  97.775 < 2e-16 ***
## operatorOp2    1.2500      1.1191   1.117  0.279
## operatorOp3    6.0000      1.1191   5.362 4.27e-05 ***
## machineMach2   0.3333      1.2922   0.258  0.799
## machineMach3  -0.1667      1.2922  -0.129  0.899
## machineMach4   1.6667      1.2922   1.290  0.213
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 2.238 on 18 degrees of freedom
## Multiple R-squared:  0.6571, Adjusted R-squared:  0.5619
## F-statistic: 6.899 on 5 and 18 DF,  p-value: 0.00093
```

```
summary.aov(fiber.nointeraction.mod)
```

```
##           Df Sum Sq Mean Sq F value    Pr(>F)
## operator    2  160.33   80.17   16.004 0.000101 ***
## machine     3   12.46    4.15    0.829 0.495098
## Residuals   18   90.17    5.01
```

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

It looks like the difference of mean is same for machine while it's different for operator. We need to run Tukey's test to see which one are different

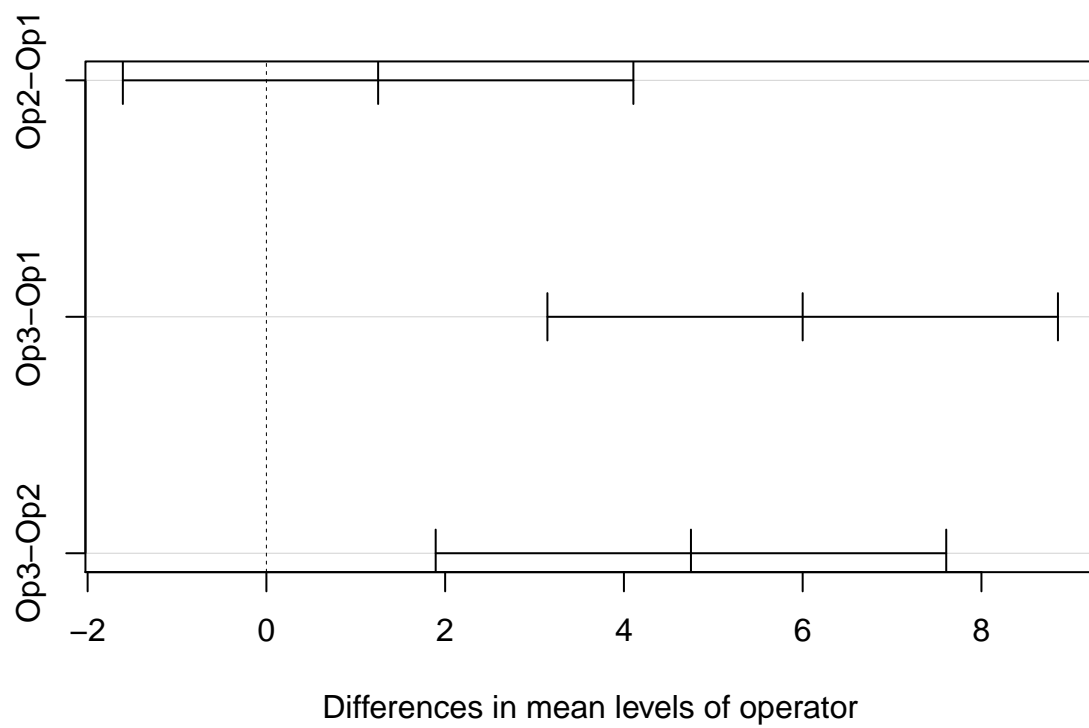
### c. Under what condition would you operate this process

```
tukeys <- TukeyHSD(fiber.nointeraction.mod)
tukeys
```

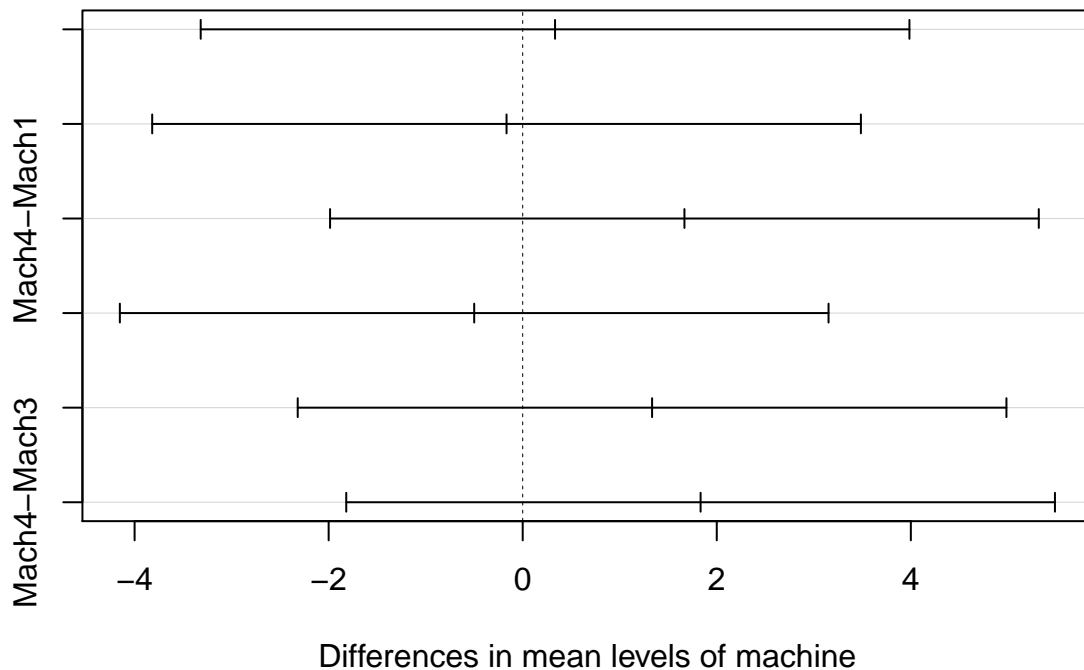
```
## Tukey multiple comparisons of means
## 95% family-wise confidence level
##
## Fit: aov(formula = strength ~ operator + machine)
##
## $operator
##      diff      lwr      upr      p adj
## Op2-Op1 1.25 -1.606046 4.106046 0.5162537
## Op3-Op1 6.00  3.143954 8.856046 0.0001210
## Op3-Op2 4.75  1.893954 7.606046 0.0013473
##
## $machine
##      diff      lwr      upr      p adj
## Mach2-Mach1 0.3333333 -3.318768 3.985435 0.9937651
## Mach3-Mach1 -0.1666667 -3.818768 3.485435 0.9992035
## Mach4-Mach1 1.6666667 -1.985435 5.318768 0.5807291
## Mach3-Mach2 -0.5000000 -4.152102 3.152102 0.9796977
## Mach4-Mach2 1.3333333 -2.318768 4.985435 0.7334070
## Mach4-Mach3 1.8333333 -1.818768 5.485435 0.5043547
```

```
plot(tukeys)
```

### 95% family-wise confidence level



## 95% family-wise confidence level



Pvalue is large for both pressure, and temperature at all conditions, so we accept null hypothesis that there is not much difference due to the changing conditions

```
library(agricolae)
```

```
## Warning: package 'agricolae' was built under R version 4.0.5
```

```
lsd <- LSD.test(fiber.nointeraction.mod, c("operator", "machine"), console=T)
```

```
##
## Study: fiber.nointeraction.mod ~ c("operator", "machine")
##
## LSD t Test for strength
##
## Mean Square Error: 5.009259
##
## operator:machine, means and individual ( 95 %) CI
##
##      strength      std r      LCL      UCL Min Max
## Op1:Mach1    109.5 0.7071068 2 106.1751 112.8249 109 110
## Op1:Mach2    112.5 3.5355339 2 109.1751 115.8249 110 115
## Op1:Mach3    108.5 0.7071068 2 105.1751 111.8249 108 109
## Op1:Mach4    109.0 1.4142136 2 105.6751 112.3249 108 110
## Op2:Mach1    111.0 1.4142136 2 107.6751 114.3249 110 112
## Op2:Mach2    110.5 0.7071068 2 107.1751 113.8249 110 111
```

```

## Op2:Mach3      110.0 1.4142136 2 106.6751 113.3249 109 111
## Op2:Mach4      113.0 1.4142136 2 109.6751 116.3249 112 114
## Op3:Mach1      115.0 1.4142136 2 111.6751 118.3249 114 116
## Op3:Mach2      113.5 2.1213203 2 110.1751 116.8249 112 115
## Op3:Mach3      116.5 3.5355339 2 113.1751 119.8249 114 119
## Op3:Mach4      118.5 2.1213203 2 115.1751 121.8249 117 120
##
## Alpha: 0.05 ; DF Error: 18
## Critical Value of t: 2.100922
##
## least Significant Difference: 4.702152
##
## Treatments with the same letter are not significantly different.
##
##          strength groups
## Op3:Mach4      118.5      a
## Op3:Mach3      116.5      ab
## Op3:Mach1      115.0      abc
## Op3:Mach2      113.5      bcd
## Op2:Mach4      113.0      bcde
## Op1:Mach2      112.5      bcde
## Op2:Mach1      111.0      cde
## Op2:Mach2      110.5      cde
## Op2:Mach3      110.0      de
## Op1:Mach1      109.5      de
## Op1:Mach4      109.0      de
## Op1:Mach3      108.5      e

```

```
lsd
```

```

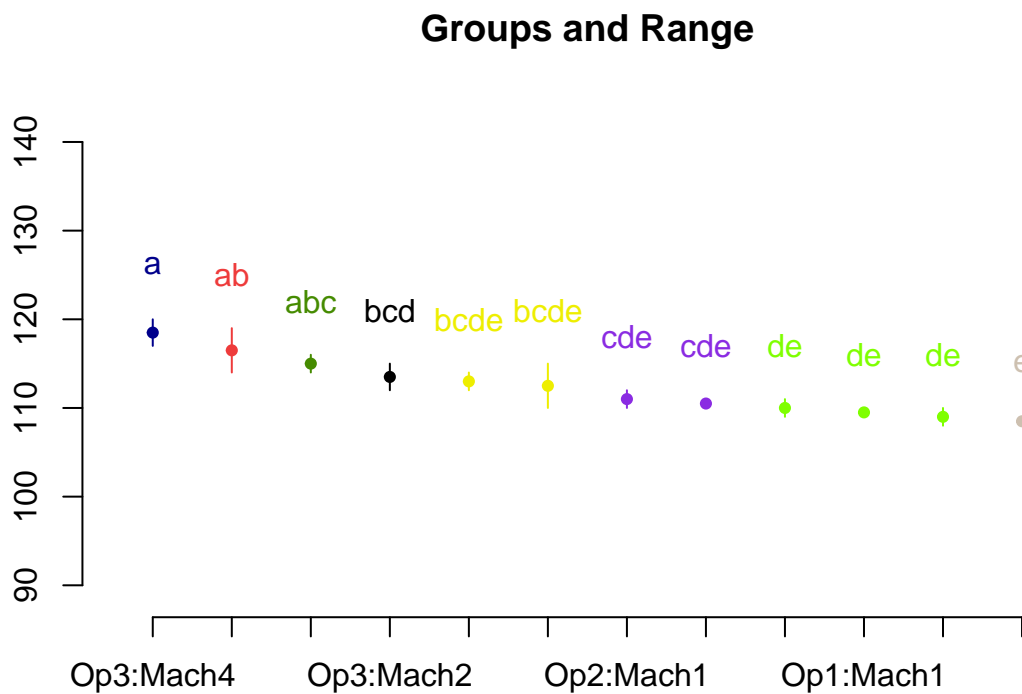
## $statistics
##      MSError Df      Mean      CV  t.value      LSD
##      5.009259 18 112.2917 1.993147 2.100922 4.702152
##
## $parameters
##      test p.adjusted      name.t ntr alpha
##      Fisher-LSD      none operator:machine 12 0.05
##
## $means
##      strength      std r      LCL      UCL Min Max      Q25      Q50      Q75
## Op1:Mach1      109.5 0.7071068 2 106.1751 112.8249 109 110 109.25 109.5 109.75
## Op1:Mach2      112.5 3.5355339 2 109.1751 115.8249 110 115 111.25 112.5 113.75
## Op1:Mach3      108.5 0.7071068 2 105.1751 111.8249 108 109 108.25 108.5 108.75
## Op1:Mach4      109.0 1.4142136 2 105.6751 112.3249 108 110 108.50 109.0 109.50
## Op2:Mach1      111.0 1.4142136 2 107.6751 114.3249 110 112 110.50 111.0 111.50
## Op2:Mach2      110.5 0.7071068 2 107.1751 113.8249 110 111 110.25 110.5 110.75
## Op2:Mach3      110.0 1.4142136 2 106.6751 113.3249 109 111 109.50 110.0 110.50
## Op2:Mach4      113.0 1.4142136 2 109.6751 116.3249 112 114 112.50 113.0 113.50
## Op3:Mach1      115.0 1.4142136 2 111.6751 118.3249 114 116 114.50 115.0 115.50
## Op3:Mach2      113.5 2.1213203 2 110.1751 116.8249 112 115 112.75 113.5 114.25
## Op3:Mach3      116.5 3.5355339 2 113.1751 119.8249 114 119 115.25 116.5 117.75
## Op3:Mach4      118.5 2.1213203 2 115.1751 121.8249 117 120 117.75 118.5 119.25
##
## $comparison

```



```
## NULL
##
## $groups
##      strength groups
## Op3:Mach4    118.5     a
## Op3:Mach3    116.5    ab
## Op3:Mach1    115.0   abc
## Op3:Mach2    113.5   bcd
## Op2:Mach4    113.0  bcde
## Op1:Mach2    112.5  bcde
## Op2:Mach1    111.0   cde
## Op2:Mach2    110.5   cde
## Op2:Mach3    110.0    de
## Op1:Mach1    109.5    de
## Op1:Mach4    109.0    de
## Op1:Mach3    108.5     e
##
## attr(,"class")
## [1] "group"
```

```
plot(lsd)
```



Operator3 and machine 4 appears to give the best strength

### Question 3.

a. create data frame with days and solution and growth as response variable

```
solution <- rep(c(1,2,3), each=4)
days <- rep(c(1,2,3,4), each=3)
solution <- factor(solution, levels=c(1,2,3), labels = c("Sol1", "Sol2", "Sol3"))
days <- factor(days, levels = c(1,2,3,4), labels = c("Day1", "Day2", "Day3", "Day4"))

growth<-c(13,22,18,39,16,24,17,44,5,4,1,22)

powder <- data.frame(solution, days, growth)

head(powder)
```

```
##   solution days growth
## 1      Sol1 Day1     13
## 2      Sol1 Day1     22
## 3      Sol1 Day1     18
## 4      Sol1 Day2     39
## 5      Sol2 Day2     16
## 6      Sol2 Day2     24
```

```
str(powder)
```

```
## 'data.frame':   12 obs. of  3 variables:
## $ solution: Factor w/ 3 levels "Sol1","Sol2",...: 1 1 1 1 2 2 2 2 3 3 ...
## $ days    : Factor w/ 4 levels "Day1","Day2",...: 1 1 1 2 2 2 3 3 3 4 ...
## $ growth  : num  13 22 18 39 16 24 17 44 5 4 ...
```

```
attach(powder)
```

```
## The following objects are masked _by_ .GlobalEnv:
##
##   days, growth, solution
```

Any evidence that the solution affect bacteria growth

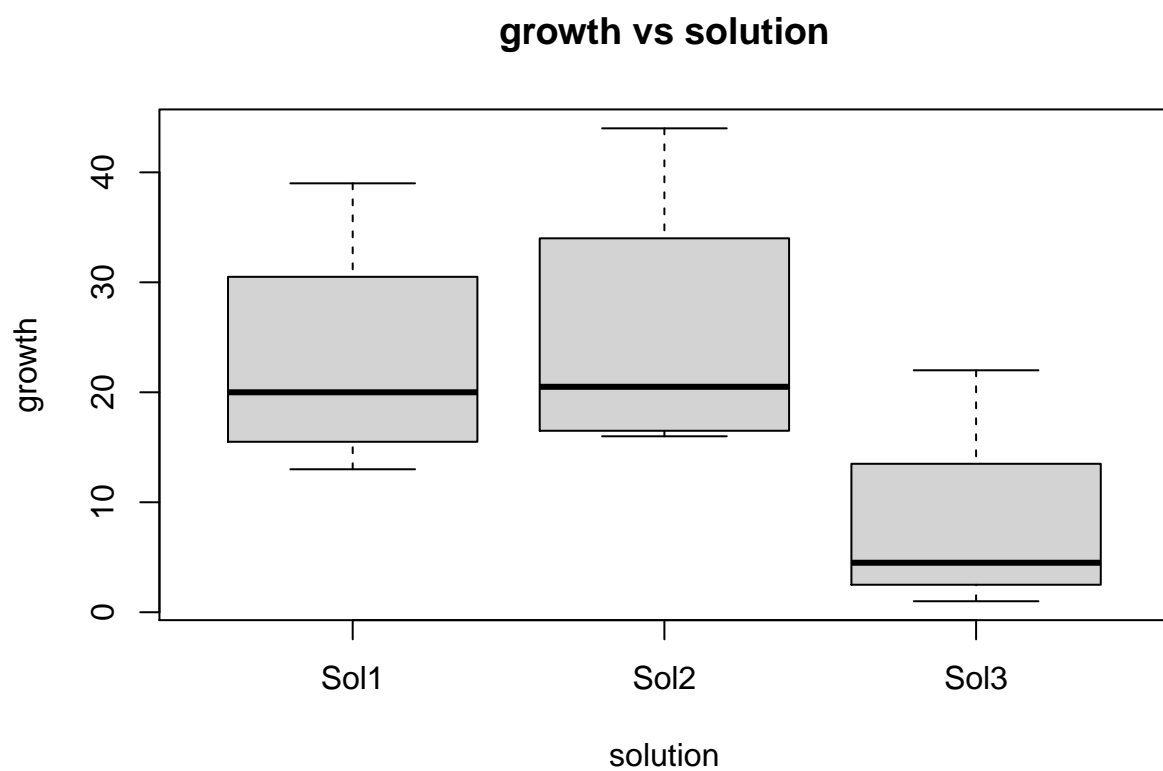
```
length(growth)
```

```
## [1] 12
```

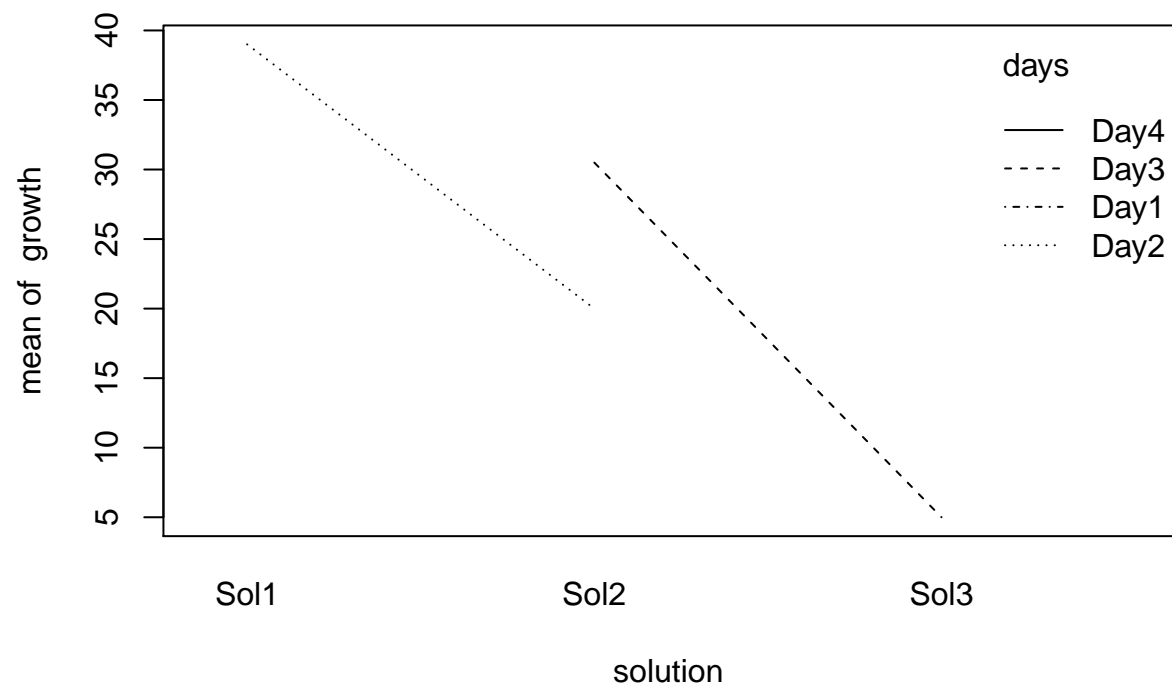
```
length(solution)
```

```
## [1] 12
```

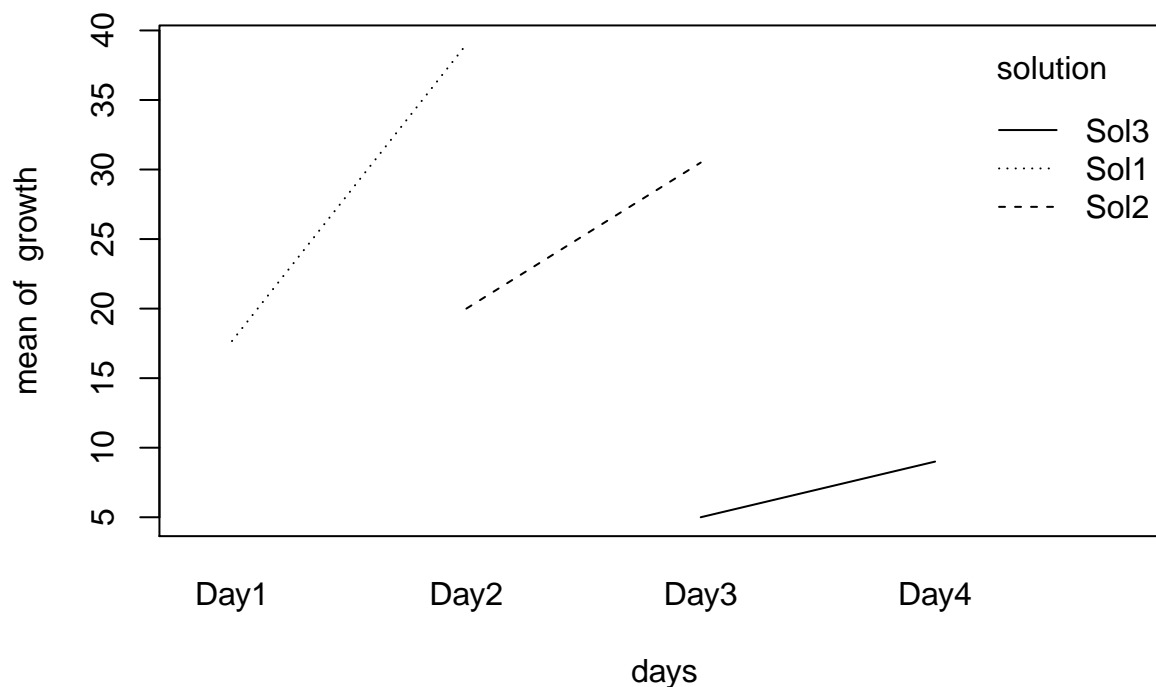
```
boxplot(growth~solution, main="growth vs solution")
```



```
interaction.plot(solution, days, growth)
```



```
interaction.plot(days, solution, growth)
```



The interaction appears to be weak cause these interaction plots are intersecting.

```
powder.mod <- aov(growth~solution*days)
summary.aov(powder.mod)
```

```
##           Df Sum Sq Mean Sq F value Pr(>F)
## solution    2  703.5   351.8    3.036  0.123
## days        3  463.6   154.5    1.334  0.348
## Residuals   6  695.2   115.9
```

```
summary.lm(powder.mod)
```

```
##
## Call:
## aov(formula = growth ~ solution * days)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -13.500  -4.750   0.000   4.083  13.500
##
## Coefficients: (6 not defined because of singularities)
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)    17.667     6.215   2.843  0.0295 *
## solutionSol2   -19.000    13.183  -1.441  0.1996
## solutionSol3   -44.500    18.644  -2.387  0.0543 .
##
```

```
## daysDay2          21.333      12.429      1.716      0.1369
## daysDay3          31.833      16.442      1.936      0.1010
## daysDay4          35.833      20.611      1.739      0.1328
## solutionSol2:daysDay2      NA          NA          NA          NA
## solutionSol3:daysDay2      NA          NA          NA          NA
## solutionSol2:daysDay3      NA          NA          NA          NA
## solutionSol3:daysDay3      NA          NA          NA          NA
## solutionSol2:daysDay4      NA          NA          NA          NA
## solutionSol3:daysDay4      NA          NA          NA          NA
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.76 on 6 degrees of freedom
## Multiple R-squared:  0.6267, Adjusted R-squared:  0.3156
## F-statistic: 2.015 on 5 and 6 DF,  p-value: 0.2093
```

```
powder.nointeraction.mod <- aov(growth~solution+days)
anova(powder.mod, powder.nointeraction.mod)
```

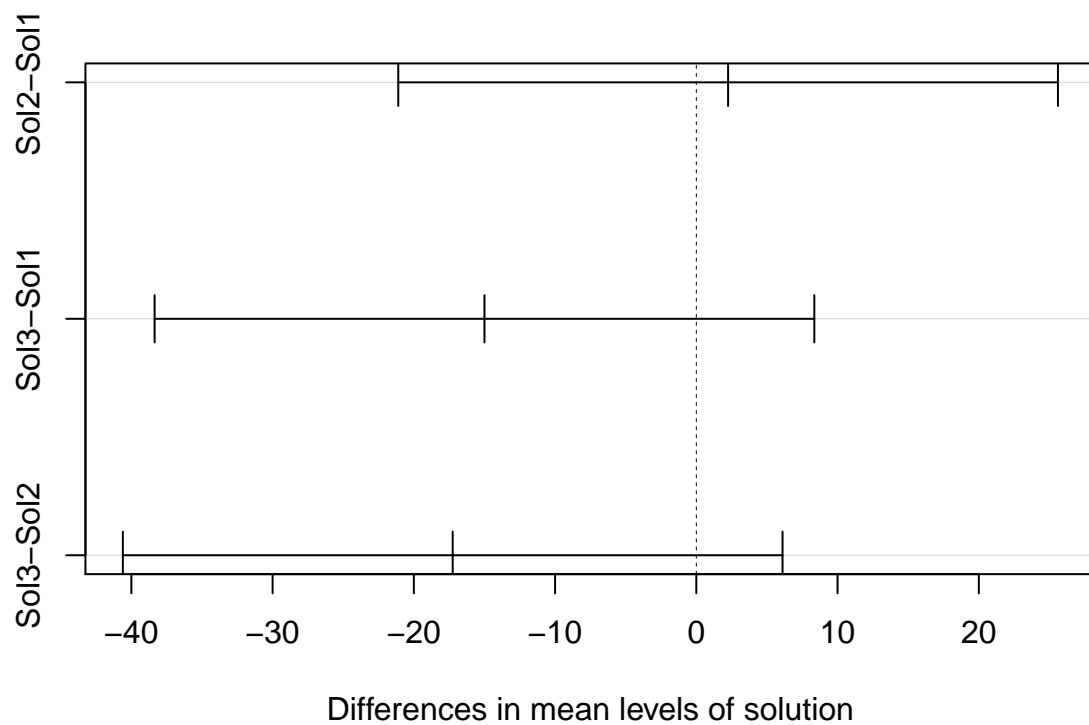
```
## Analysis of Variance Table
##
## Model 1: growth ~ solution * days
## Model 2: growth ~ solution + days
##   Res.Df    RSS Df Sum of Sq F Pr(>F)
## 1      6 695.17
## 2      6 695.17  0          0
```

Pvalue is 0, so there appears to be no interaction, so we chose non-interactive model.

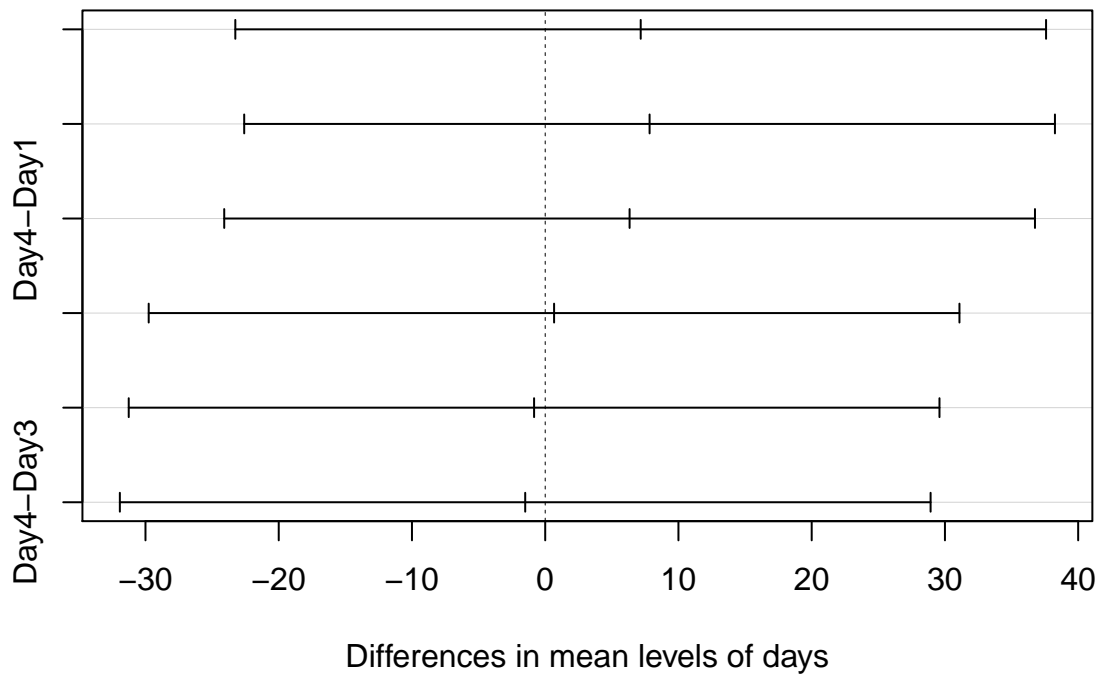
#### b. Perform a TukeyHSD to compare solution treatment means

```
tukeys <- TukeyHSD(powder.nointeraction.mod)
plot(tukeys)
```

### 95% family-wise confidence level



## 95% family-wise confidence level



Difference of mean is the same so the solution or days doesn't affect much of the bacterial growth

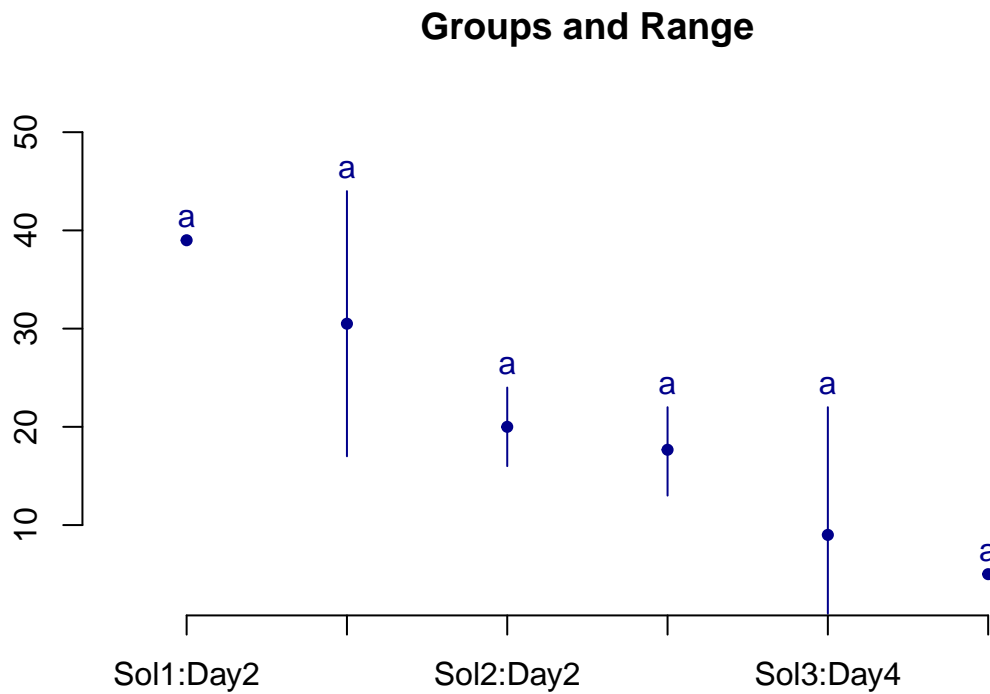
```
lsd <- LSD.test(powder.nointeraction.mod, c("solution", "days"), console = T)
```

```
##
## Study: powder.nointeraction.mod ~ c("solution", "days")
##
## LSD t Test for growth
##
## Mean Square Error: 115.8611
##
## solution:days, means and individual ( 95 %) CI
##
##      growth      std r      LCL      UCL Min Max
## Sol1:Day1 17.66667  4.509250 3  2.460262 32.87307 13 22
## Sol1:Day2 39.00000      NA 1 12.661735 65.33827 39 39
## Sol2:Day2 20.00000  5.656854 2  1.376034 38.62397 16 24
## Sol2:Day3 30.50000 19.091883 2 11.876034 49.12397 17 44
## Sol3:Day3  5.00000      NA 1 -21.338265 31.33827  5  5
## Sol3:Day4  9.00000 11.357817 3 -6.206405 24.20640  1 22
##
## Alpha: 0.05 ; DF Error: 6
## Critical Value of t: 2.446912
##
## Groups according to probability of means differences and alpha level( 0.05 )
##
```



```
## Treatments with the same letter are not significantly different.
##
##           growth groups
## Sol1:Day2 39.00000      a
## Sol2:Day3 30.50000      a
## Sol2:Day2 20.00000      a
## Sol1:Day1 17.66667      a
## Sol3:Day4  9.00000      a
## Sol3:Day3  5.00000      a
```

```
plot(lsd)
```

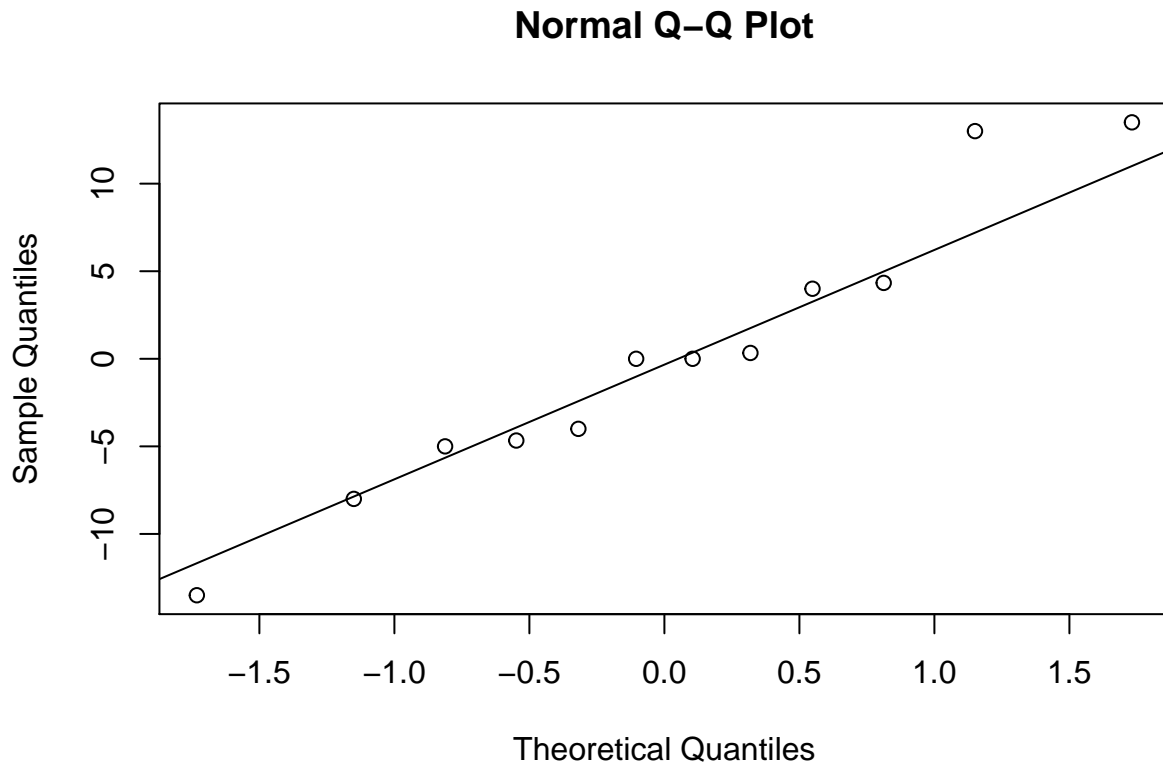


The solution and days doesn't appear to have much affect on growth.

#### c. Check assumptions of the residuals

```
res <- residuals(powder.nointeraction.mod)

qqnorm(res)
qqline(res)
```



```
shapiro.test(res)
```

```
##
##  Shapiro-Wilk normality test
##
## data:  res
## W = 0.95242, p-value = 0.6726
```

```
#check variance
```

```
bartlett.test(res~solution)
```

```
##
##  Bartlett test of homogeneity of variances
##
## data:  res by solution
## Bartlett's K-squared = 2.8626, df = 2, p-value = 0.239
```

```
bartlett.test(res~days)
```

```
##
##  Bartlett test of homogeneity of variances
##
## data:  res by days
## Bartlett's K-squared = 3.3249, df = 3, p-value = 0.3442
```

The data is normal and variance is equal.