Tutorial Problems

Question 1

A split-plot experiment used three varieties of alfalfa (lucerne) on the whole plots in six blocks. Each whole plot was divided into four subplots, to which four cutting schemes were applied. In the summer, the alfalfa on all subplots was cut twice, the second cut taking place on 27 July. The cutting schemes were: no further cut (A), or a third cut on 1 September (S1), 20 September (S20) or 7 October (O7). The table below gives the yields for the following year in tons per acre. They have been rearranged from field order to make the arithmetic easier.

Variety	Date of third cutting	Block I	II	III	IV	V	VI
Ladak	A	2.17	1.88	1.62	2.34	1.58	1.66
	S1	1.58	1.26	1.22	1.59	1.25	0.94
	S20	2.29	1.60	1.67	1.91	1.39	1.12
	O7	2.23	2.01	1.82	2.10	1.66	1.10
Cossack	A	2.33	2.01	1.70	1.78	1.42	1.35
	S1	1.38	1.30	1.85	1.09	1.13	1.06
	S20	1.86	1.70	1.81	1.54	1.67	0.88
	O7	2.27	1.81	2.01	1.40	1.31	1.06
Ranger	A	1.75	1.95	2.13	1.78	1.31	1.30
	S1	1.52	1.47	1.80	1.37	1.01	1.31
	S20	1.55	1.61	1.82	1.56	1.23	1.13
	O7	1.56	1.72	1.99	1.55	1.51	1.33

```r
dat <- data.frame(
  Yield=c(2.17, 1.88, 1.62, 2.34, 1.58, 1.66, 1.58, 1.26, 1.22, 1.59,
  1.25, 0.94, 2.29, 1.60, 1.67, 1.91, 1.39, 1.12, 2.23, 2.01, 1.82,
  2.10, 1.66, 1.10, 2.33, 2.01, 1.70, 1.78, 1.42, 1.35, 1.38, 1.30,
  1.85, 1.09, 1.13, 1.06, 1.86, 1.70, 1.81, 1.54, 1.67, 0.88, 2.27,
  1.81, 2.01, 1.40, 1.31, 1.06, 1.75, 1.95, 2.13, 1.78, 1.31, 1.30,
  1.52, 1.47, 1.80, 1.37, 1.01, 1.31, 1.55, 1.61, 1.82, 1.56, 1.23,
  1.13, 1.56, 1.72, 1.99, 1.55, 1.51, 1.33),
  Block = rep(c("I", "II", "III", "IV", "V", "VI"), times=4*3),
  Wholeplot = factor(rep(1:3, each=4*6)),
  Subplot = factor(rep(rep(1:4, each=6), times=3)),
  Variety = rep(c("Ladak", "Cossack", "Ranger"), each=4*6),
  Cut = rep(rep(c("A", "S1", "S20", "O7"), each=6), times=3)
  ) %>%
  mutate(Trt = paste(Variety, Cut))

dat %>% group_by(Block) %>% summarise(sum(Yield)) %>% deframe()
```

```
##     I    II   III    IV     V    VI
## 22.49 20.32 21.44 20.01 16.47 14.24
```



```r
dat %>% group_by(Variety) %>% summarise(sum(Yield)) %>% deframe()
```

```
## Cossack   Ladak  Ranger
##   37.72   39.99   37.26
```

```r
dat %>% group_by(Cut) %>% summarise(sum(Yield)) %>% deframe()
```

```
##     A    07    S1   S20
## 32.06 30.44 24.13 28.34
```

```r
dat %>% group_by(Trt) %>% summarise(sum(Yield)) %>% deframe()
```

```
##   Cossack A  Cossack 07  Cossack S1 Cossack S20     Ladak A    Ladak 07
##       10.59        9.86        7.81        9.46       11.25       10.92
##    Ladak S1   Ladak S20    Ranger A   Ranger 07   Ranger S1  Ranger S20
##        7.84        9.98       10.22        9.66        8.48        8.90
```

```r
sum(dat$Yield)
```

```
## [1] 114.97
```

```r
anova(lm(Yield ~ Trt, data=dat))
```

```
## Analysis of Variance Table
##
## Response: Yield
##           Df Sum Sq Mean Sq F value  Pr(>F)
## Trt       11 2.3510 0.21373   1.894 0.05813 .
## Residuals 60 6.7707 0.11285
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
anova(lm(Yield ~ Block/Wholeplot, data=dat))
```

```
## Analysis of Variance Table
##
## Response: Yield
##                 Df Sum Sq Mean Sq F value    Pr(>F)
## Block            5 4.1498 0.82996   13.06 2.424e-08 ***
## Block:Wholeplot 12 1.5404 0.12836    2.02   0.04003 *
## Residuals       54 3.4316 0.06355
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

(a) Describe the experimental design employed, clearly identifying the treatment structure, experimental units and observational units, including how many there are of each.

(b) Write the expected output from the following command. You can omit the mean square, F-value and p-value from the output.

```r
anova(lm(Yield ~ Variety:Cut))
```

(c) Using the R output above, show the sum of the squares for Variety, Cut, Variety-Cut interaction and the residual for the fitted model below.

```
##             Df Sum Sq Mean Sq F value  Pr(>F)
## Variety     ##  0.178  ###      ###     ###
## Cut         ##  1.962  ###      ###     ###
## Variety:Cut ##  0.211  ###      ###     ###
## Residuals   ##  6.771  ###
```

(d) Using the R output above, complete the ANOVA table below by filling out ??s.

```
##
## Error: Block
##           Df Sum Sq Mean Sq F value Pr(>F)
## Residuals ??   ??     ??
##
## Error: Block:Wholeplot
##           Df Sum Sq Mean Sq F value Pr(>F)
## Variety   ??   ??      ??         ??   ###
## Residuals ??   ??      ??
##
## Error: Block:Wholeplot:Subplot
##             Df Sum Sq Mean Sq F value   Pr(>F)
## Cut          ??   ??    ??         ??     ###
## Variety:Cut  ??   ??    ??         ??     ###
## Residuals    ??   ??    ??
```

(e) What is the difference between the analysis in (b), (c) and (d)? Which analysis is the most appropriate for this data?

Question 2

In a biotechnology experiment, plants were grown in 90 pots. Five different quantities of potassium were randomized to the pots, so that each quantity was applied to the soil in 18 pots. After each of 15, 30 and 45 days, one plant was randomly chosen from each pot and removed; nine small pieces were cut from it to be used for tissue culture. Three different levels of nutrition were each applied to three of the pieces of each plant removed at each time. After a certain further length of time, the number of plantlets growing in each piece of tissue was counted.

(a) What are the treatments, and how many are there?
(b) What are the observational units, and how many are there?
(c) What are the experimental units, and how many are there?
(d) Construct the skeleton analysis-of-variance table.

Question 3

This example is based from Martin et al. (1996) Effects of grasshopper-control insecticides on survival and brain acetylcholinesterase of pheasant (Phasianus colchicus) chicks. *Environmental Toxicology and Chemistry* **15**(4) 518–524.

- An experiment was conducted on a prairie in Western Canada to find out if insecticides used to control grasshoppers affected the weight of young chicks of ring-necked pheasants, either by affecting the grass around the chicks or by affecting the grasshoppers eaten by the chicks.
- Three insecticides were used, at low and high doses.
- The low dose was the highest dose recommended by the department of agriculture; the high dose was four times as much as the recommended dose, to assess the effects of mistakes.
- The experimental procedure took place in each of three consecutive weeks.
- On the first day of each week a number of newly-hatched female pheasant chicks were placed in a brooder pen.
- On the third day, the chicks were randomly divided into twelve groups of six chicks each.
- Each chick was given an identification tape and weighed.
- On the fourth day, a portion of the field was divided into three strips, each of which was divided into two swathes.
- The two swathes within each strip were sprayed with the two doses of the same insecticide.
- Two pens were erected on each swathe, and one group of pheasant chicks was put into each pen.
- For the next 48 hours, the chicks were fed with grasshoppers which had been collected locally.
- Half the grasshoppers were anaesthetized and sprayed with insecticide; the other half were also anaesthetized and handled in every way like the first half except that they were not sprayed.
- All grasshoppers were frozen.
- The experimenters maintained a supply of frozen grasshoppers to each pen, putting them on small platforms so that they would not absorb further insecticide from the grass.
- In each swathe, one pen had unsprayed grasshoppers while the other had grasshoppers sprayed by the insecticide which had been applied to that swathe.
- At the end of the 48 hours, the chicks were weighed again individually.

(a) What is the aim of the experiment?
(b) Identify the treatment structure and the structural factors within the experiment. What are the experimental and observational units are and how many of each there are?
(c) Complete the skeleton analysis of variance below.

Stratum	Source	Degrees of freedom
Weeks	Weeks	
Strips	Insecticide	
	Residual	
Swathes	Dose	
	Insecticide:Dose	
	Residual	
Pens	Food	
	Insecticide : Food	
	Dose : Food	
	Insecticide : Dose : Food	
	Residual	
Chicks	OU Residual	
	Total	

Computer Problems

Question 1

In an experiment on eight varieties of guayule (a Mexican plant yielding rubber), four different treatments were applied to the seeds.

	T1	T2	T3	T4	Totals
1.V1	66	12	13	6	97
2.V1	63	10	13	12	98
3.V1	70	13	11	7	101
1.V2	77	26	27	15	145
2.V2	47	11	5	4	67
3.V2	66	18	11	15	110
1.V3	51	8	20	10	89
2.V3	81	16	30	14	141
3.V3	63	14	29	10	116
1.V4	52	4	19	13	88
2.V4	40	15	16	9	80
3.V4	59	11	7	7	84
1.V5	45	20	9	12	86
2.V5	51	13	10	12	86
3.V5	52	16	12	11	91
1.V6	59	8	28	14	109
2.V6	66	8	32	21	127
3.V6	49	8	29	16	102
1.V7	56	12	26	15	109
2.V7	38	16	16	8	78
3.V7	45	16	24	7	92
1.V8	49	14	30	9	102
2.V8	41	20	28	15	104
3.V8	54	25	36	12	127
Totals	1340	334	481	274	2429

A split-plot type design was used, whereby

- a variety was randomly assigned to each of 24 greenhouse flats (3 flats per variety),
- each flat (wholeplot) was divided into 4 subplots, each of which was randomly assigned a different treatment and 100 seeds of the appropriate variety received the appropriate treatment and were planted in each subplot.
- The response was the number of seeds germinating in each subplot.
- So we have two crossed factors (variety and treatment), with a further factor flats nested within variety.

The data is stored in `rubber.txt`.
There exist various ways of modeling such data:

(a) Create a data set `dat` using `read.table()` and provide `skimr::skim(dat)`.
(b) Compute the two-way (with replications) ANOVA table based on the two crossed factors `treatment` and `variety`; that is, ignoring `flats` completely.
(c) Provide an interaction plot for the interaction term.
(d) Compute the ANOVA table based on the two nested factors `variety` and then `flats`-within-`variety`; that is, the nested classification we obtain by ignoring `treatment` completely.
(e) Compute the ANOVA table for the complete block design we obtain by completely ignoring `variety`.
(f) Combine all these sources of variation together to form a single ANOVA table.

