Mixed models in R using the lme4 package
Part 2: R Graphics with lattice and ggplot2

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Outline

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Exploring and presenting data

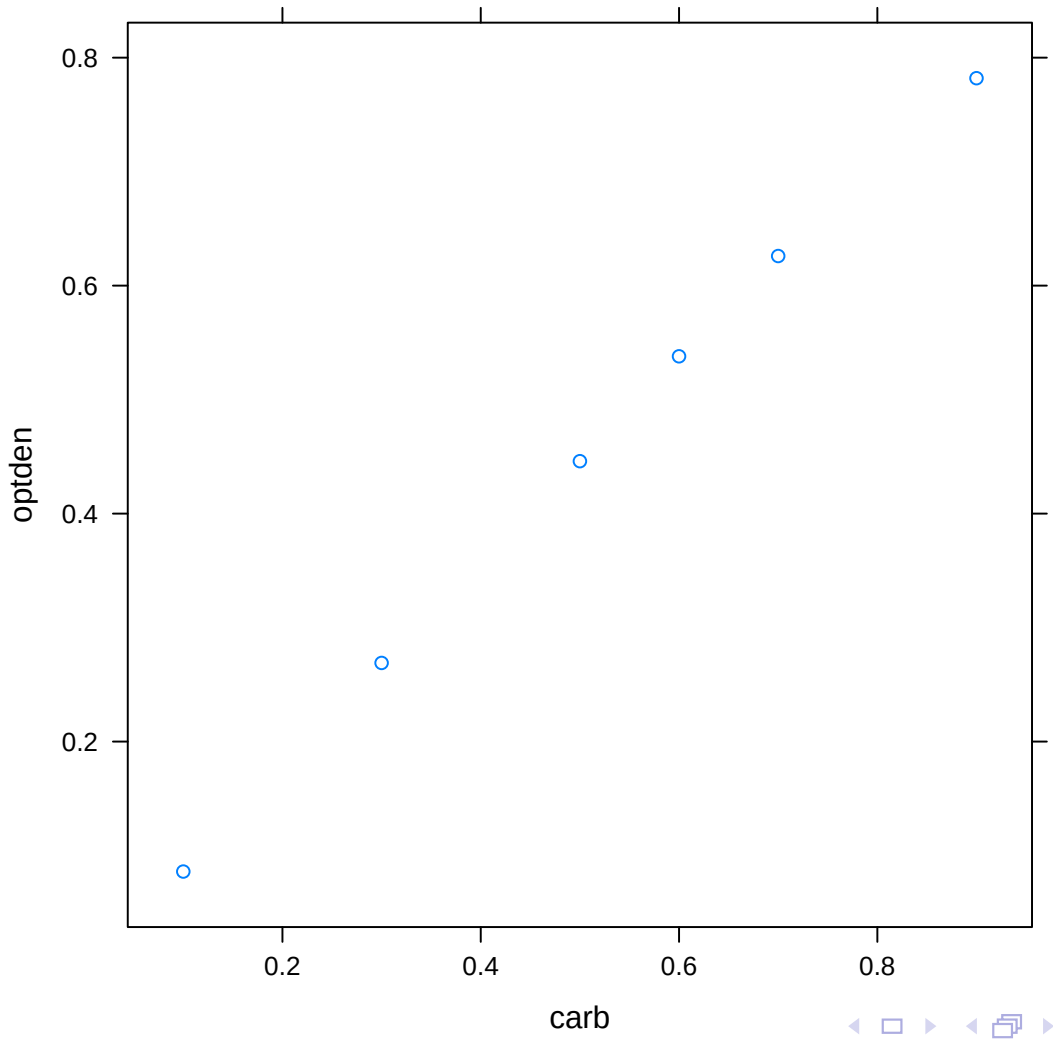
- When possible, use graphical presentations of data. Time spend creating informative graphical displays is well invested.
- Ron Snee, a friend who spent his career as a statistical consultant for DuPont, once said, *"Whenever I am writing a report, the most important conclusion I want to communicate is always presented as a graphic and shown early in the report. On the other hand, if there is a conclusion I feel obligated to include but would prefer people not notice, I include it as a table."*
- One of the strengths of R is its graphics capabilities.
- There are several styles of graphics in R. The style in Deepayan Sarkar's *lattice* package is well-suited to the type of data we will be discussing.
- Deepayan's book, *Lattice: Multivariate Data Visualization with R* (Springer, 2008) provides in-depth documentation and explanations of lattice graphics.

The formula/data method of specifying graphics

- The first two arguments to lattice graphics functions are usually `formula` and `data`.
- This specification is also used in model-fitting functions (`lm`, `aov`, `lmer`, ...) and in other functions such as `xtabs`.
- The formula incorporates a tilde, ($\sim$), character. A one-sided formula specifies the value on the x-axis. A two-sided formula specifies the x and y axes.
- The second argument, `data`, is usually the name of a data frame.
- Many optional arguments are available. Ones that we will use frequently allow for labeling axes (`xlab`, `ylab`), and controlling the type of information displayed, `type`.
- The `lattice` package is not attached by default. You must enter `library(lattice)` before you can use lattice functions.

A simple scatterplot in lattice

```
> xyplot(optden ~ carb, Formaldehyde)
```



Scatterplots in lattice

- A scatter plot is the most versatile plot in applied statistics. It is simply a plot of a numeric response, `y`, versus a numeric covariate, `x`.
- The lattice function `xyplot` produces scatter plots. I typically specify `type = c("g","p")` requesting a background grid in addition to the plotted points.
- The `type` argument takes a selection from

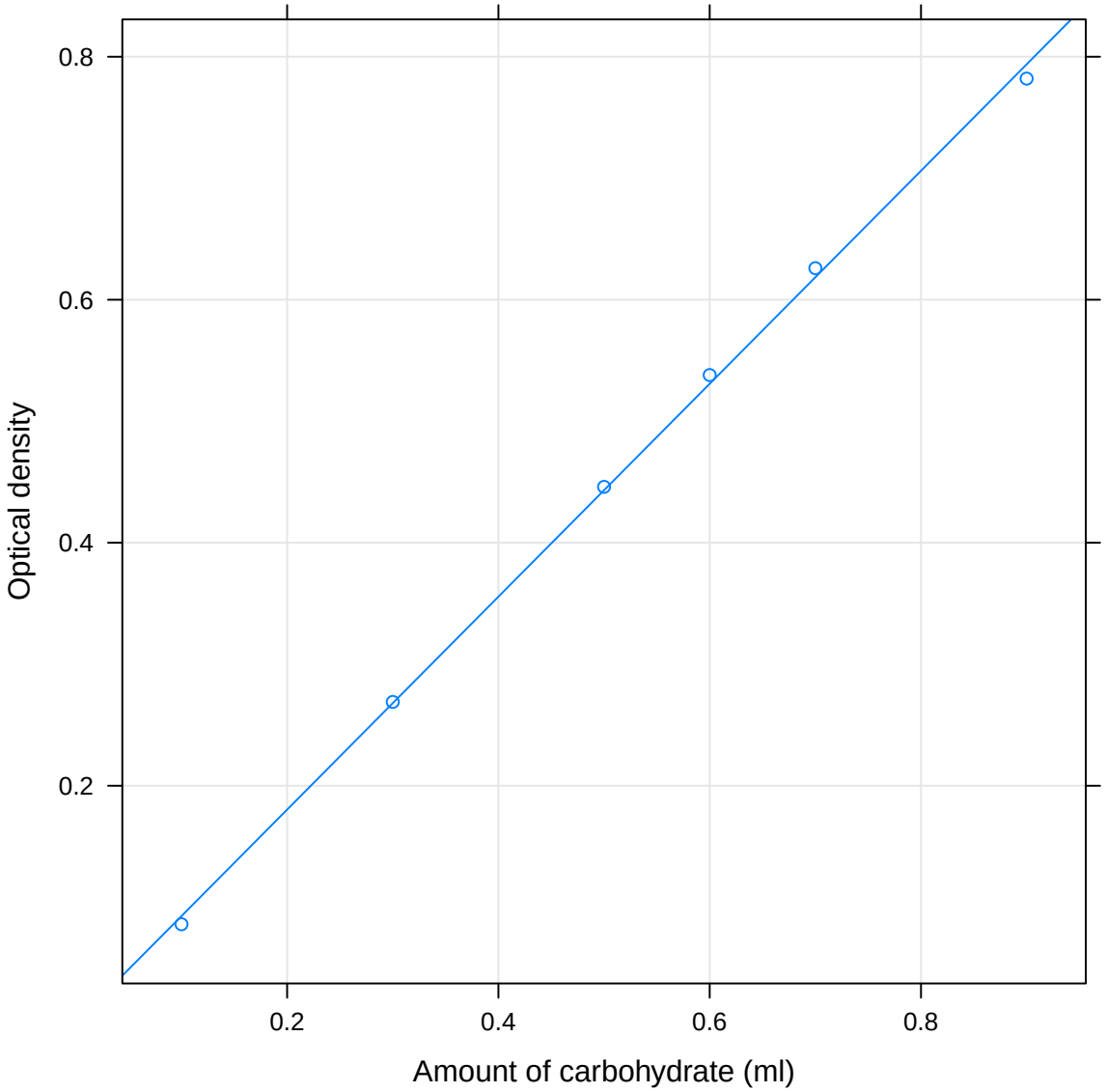
"p"	points
"g"	background grid
"l"	lines
"b"	both points and lines
"r"	reference (or "regression") straight line
"smooth"	scatter-plot smoother lines

- In evaluating a scatterplot the aspect ratio (ratio of vertical size to horizontal size) can be important. In particular, differences in slopes are most apparent near 45^o.

General principles of lattice graphics

- The formula is of the form `~x` or `y~x` or `y~x | f` where `x` is the variable on the x axis (usually continuous), `y` is the variable on the y axis and `f` is a factor that determines the panels.
- Titles can be added with `xlab`, `ylab`, `main` and `sub`. Titles can be character strings or, more generally, expressions that allow for special characters, subscripts, superscripts, etc. See `help(plotmath)` for details.
- The `groups` argument, if used, specifies different point styles and different line styles for each level of the group. If lines are calculated, each group has separate lines.
- If `groups` is used, we usually also use `auto.key` to add a key relating the line or point styles to the groups.
- The `layout` specifies the number of columns and rows of panels.

An enhanced scatterplot of the Formaldehyde data



Saving plots

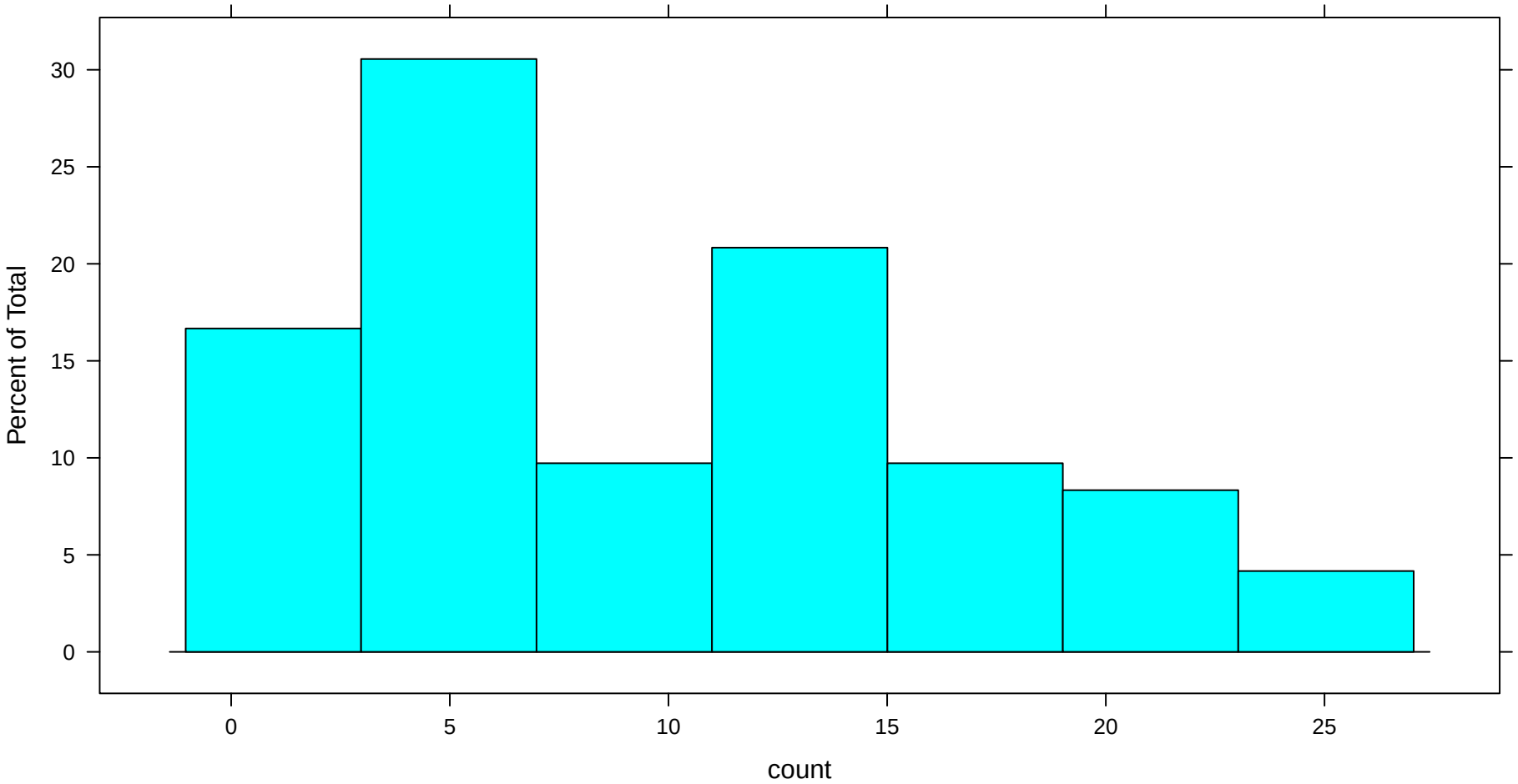
- I recommend using the facilities in the R application to save plots and transcripts.
- To save a plot, ensure that the graphics window is active and use the menu item `File`→`Save To Clipboard`→`Windows Metafile`. (On a Mac, save as PDF.) Then switch to a word processor and paste the figure.
- Adjust the aspect ratio of the graphics window to suit the pasted version of the plot before you copy the graphic.
- Those who want more control (and less cutting and pasting) could consider the Sweave system or the odfWeave package.

Histograms and density plots

- A histogram is a type of bar plot created from dividing numeric data into adjacent bins (typically having equal width).
- The purpose of a histogram is to show the distribution or density of the observations. It is almost never a good way of doing this.
- A `densityplot` is a better way of showing the density or, even better, comparing the densities of observations associated with different groups. Also, densityplots for different groups can be overlaid.
- If you have only a few observations you may want to use a comparative box-and-whisker plot (`bwplot`) or a comparative `dotplot` instead. Density plots based on a small number of observations tend to be rather "lumpy".
- If the data are bounded, perhaps because the data must be positive, a density plot can blur the boundary. However, this may indicate that the data are more meaningfully represented on another scale.

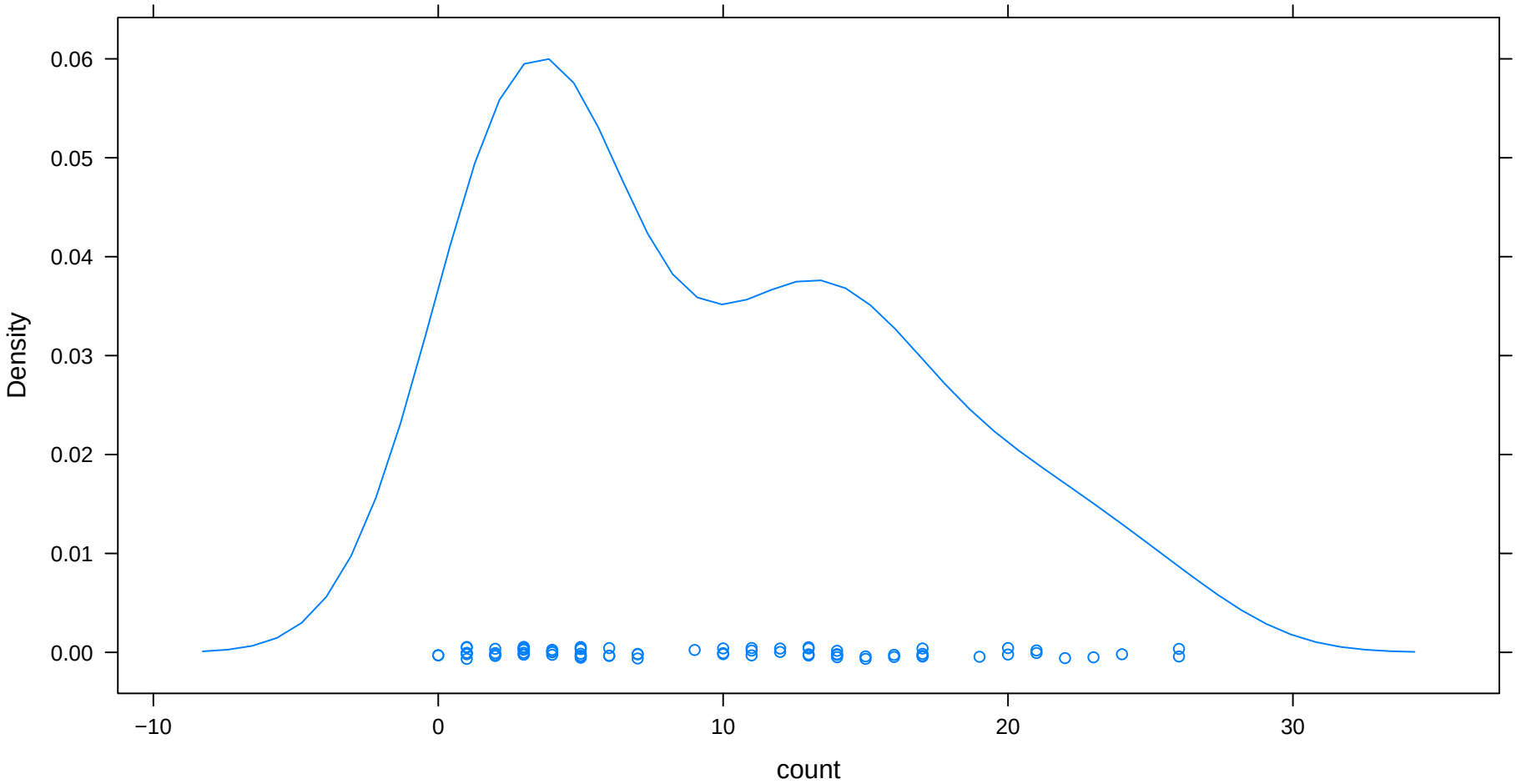
Histogram of the InsectSprays data

```
> histogram(~ count, InsectSprays)
```



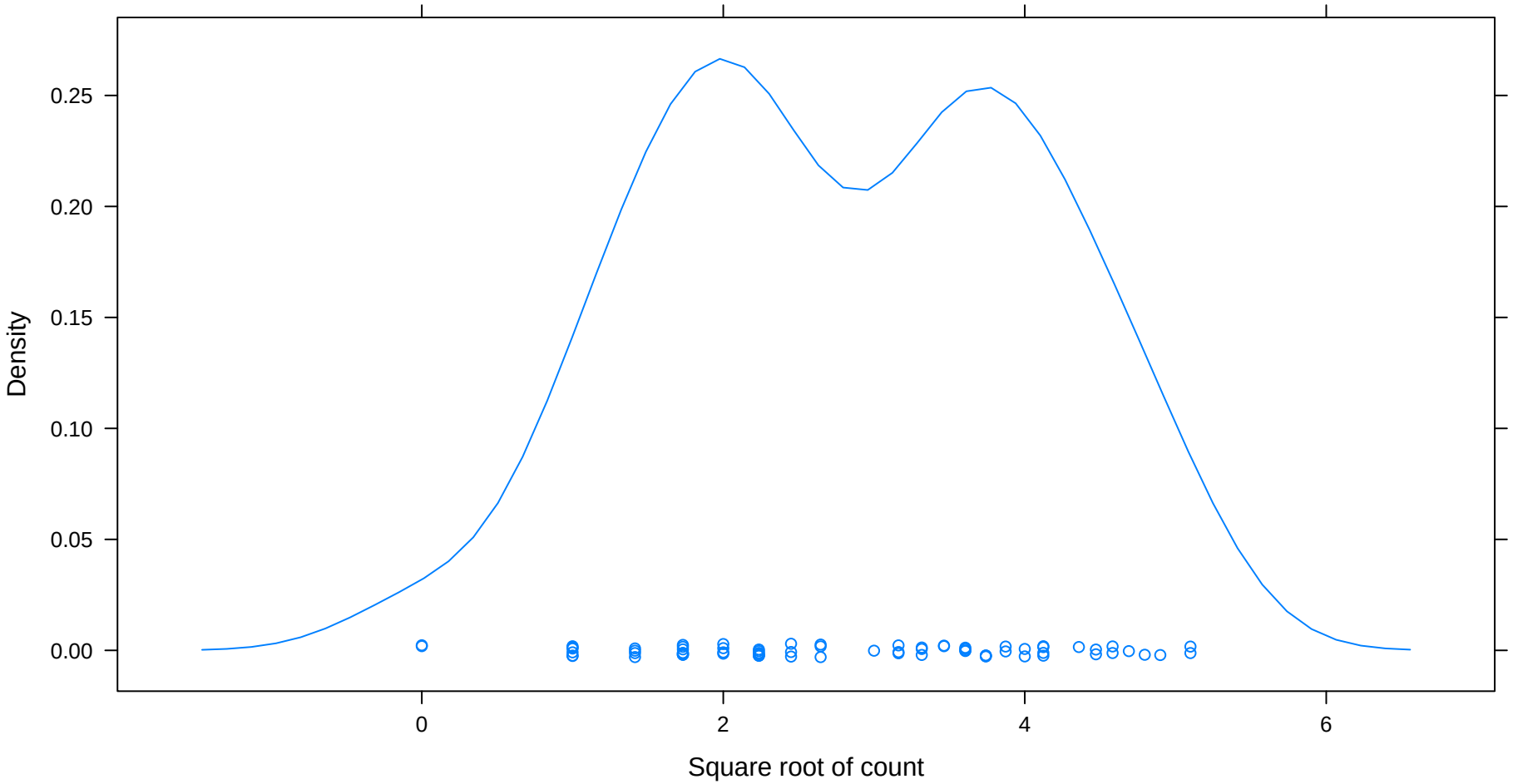
Density plot of the InsectSprays data

```
> densityplot(~ count, InsectSprays)
```



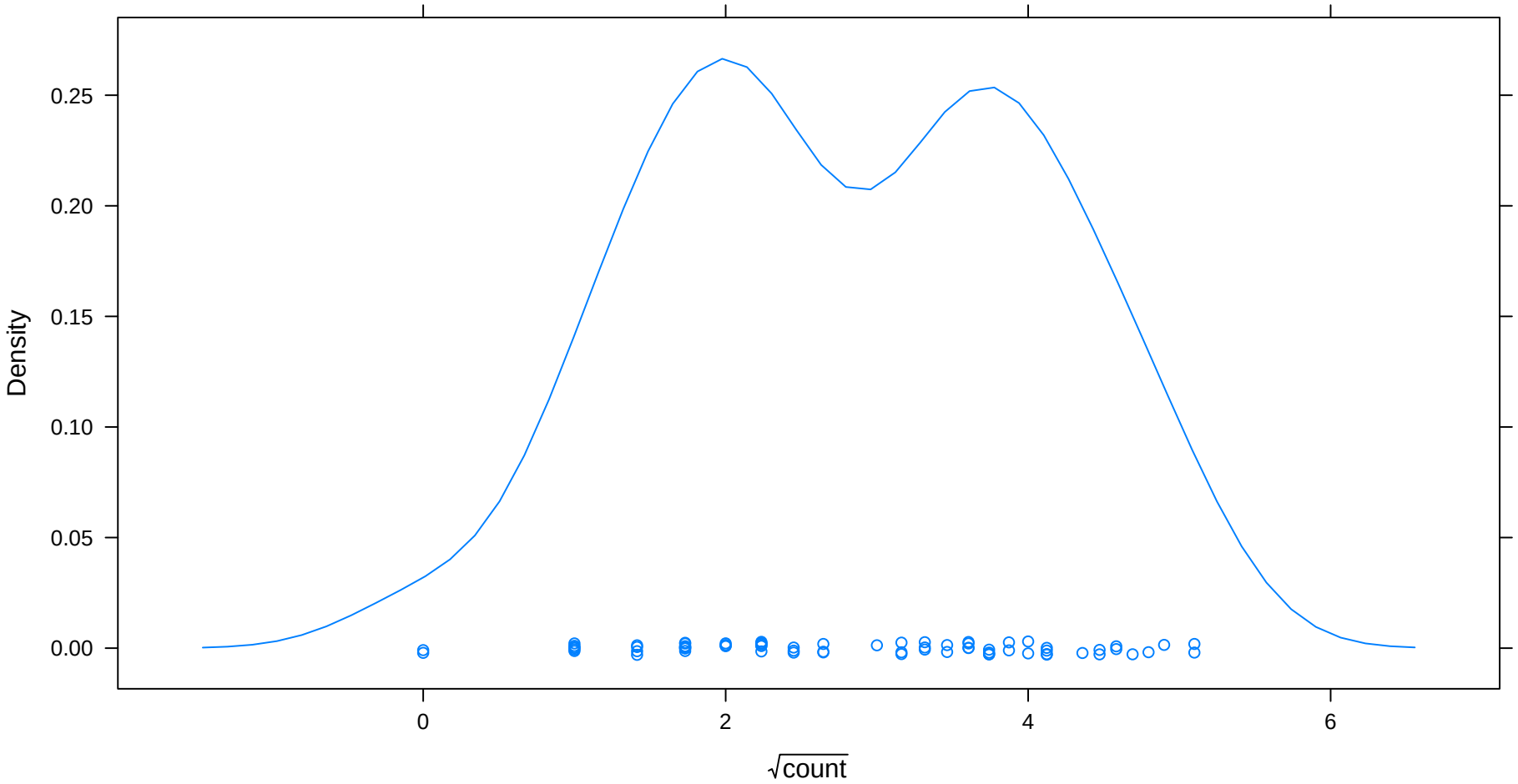
Density plot of the square root of the count

```
> densityplot(~ sqrt(count), InsectSprays,  xlab = "Square root
```



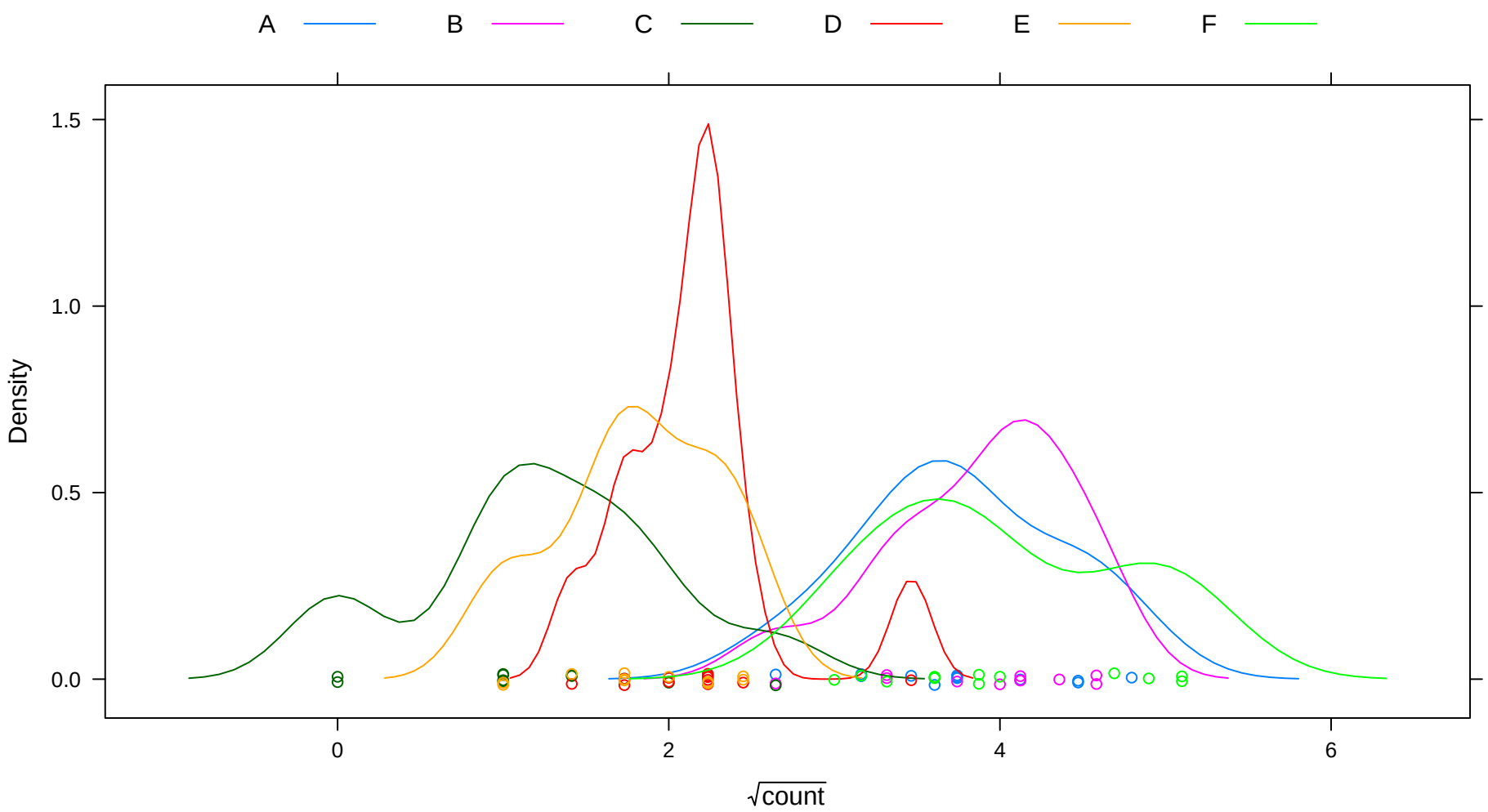
Density plot of the square root with fancy label

```
> densityplot(~ sqrt(count), InsectSprays, xlab = expression(sq
```



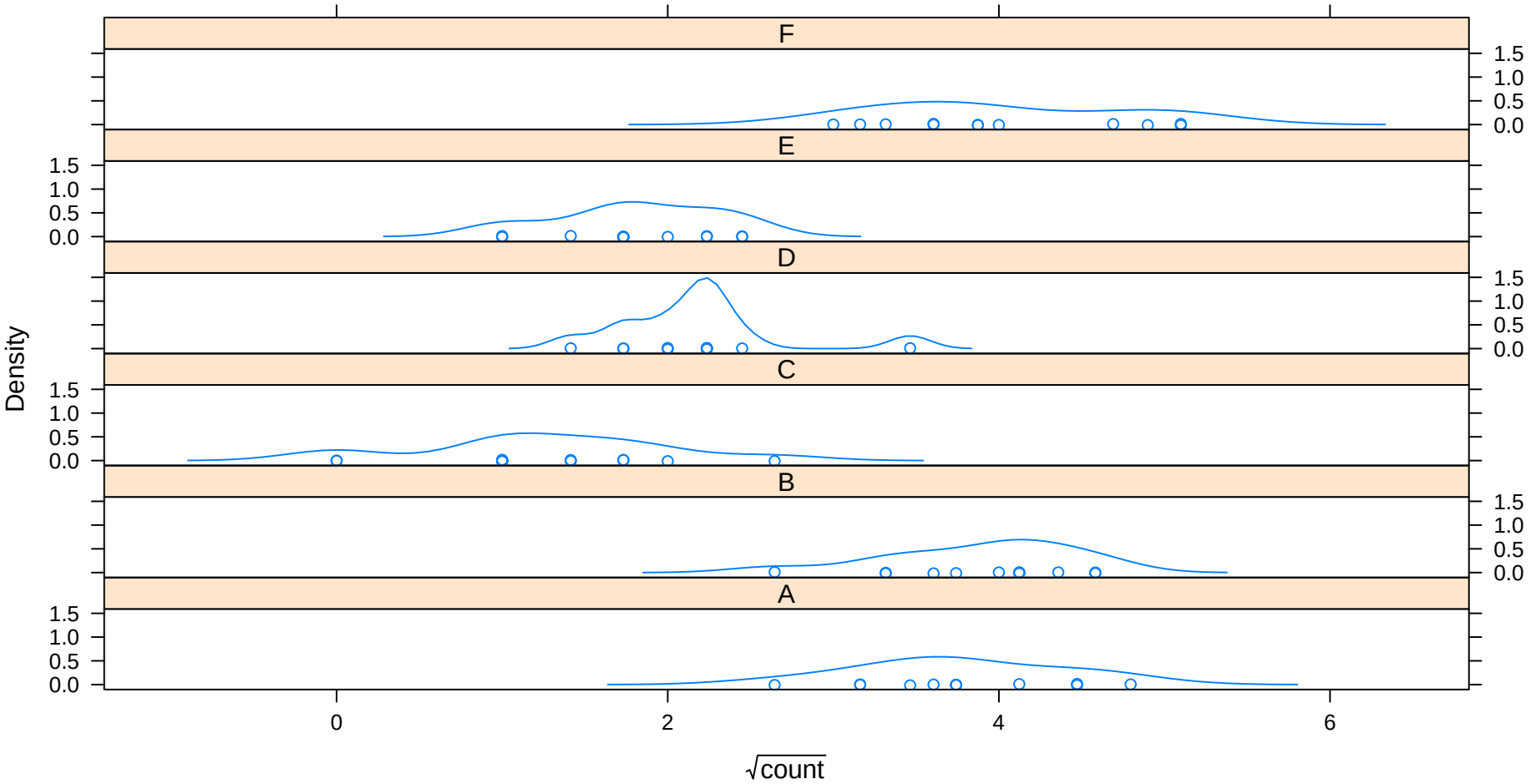
Comparative density plot of square root

```
> densityplot(~ sqrt(count), InsectSprays, groups = spray,
+             auto.key = list(columns = 6))
```



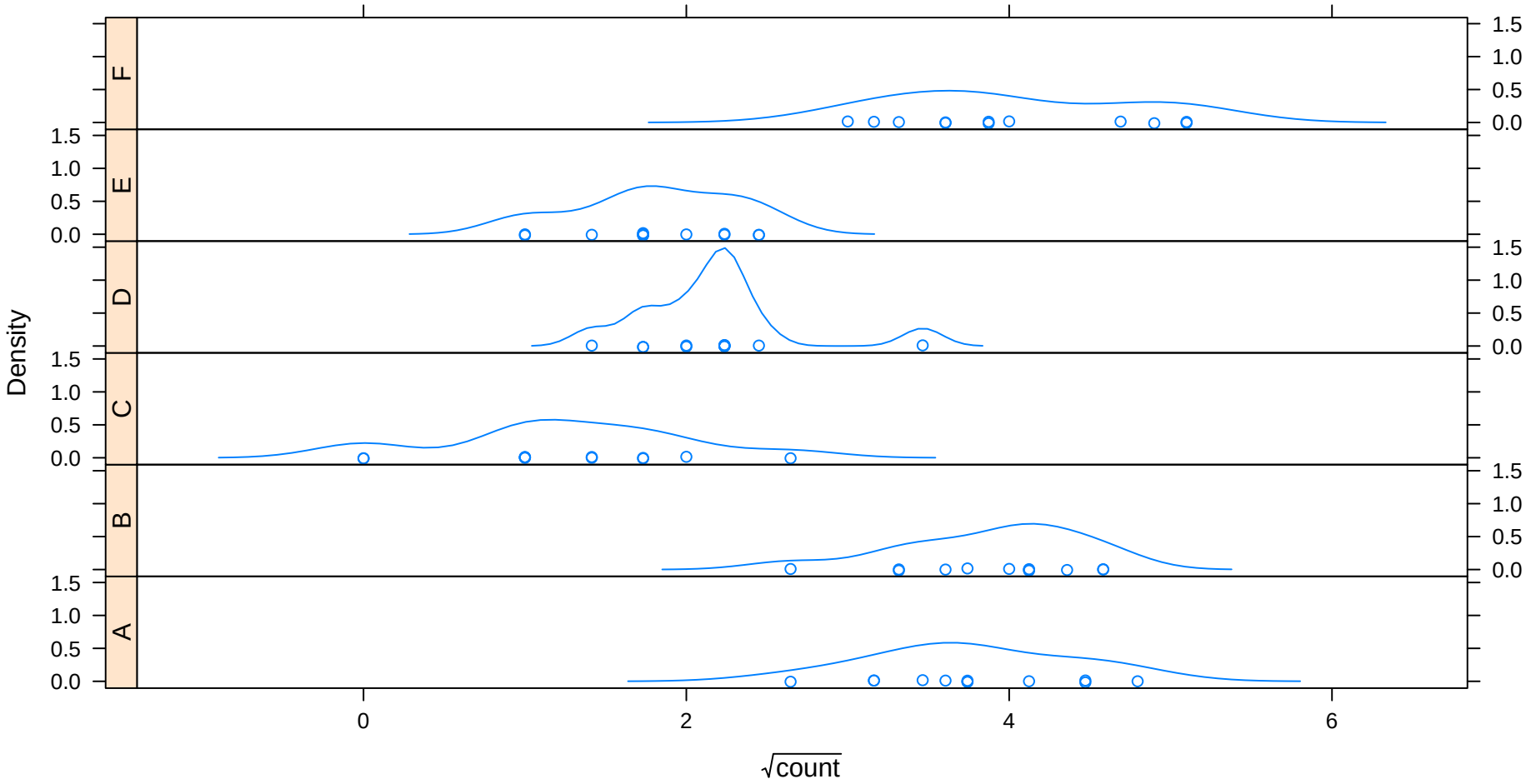
Comparative density plot, separate panels

```
> densityplot(~ sqrt(count)|spray, InsectSprays, layout = c(1,6
```



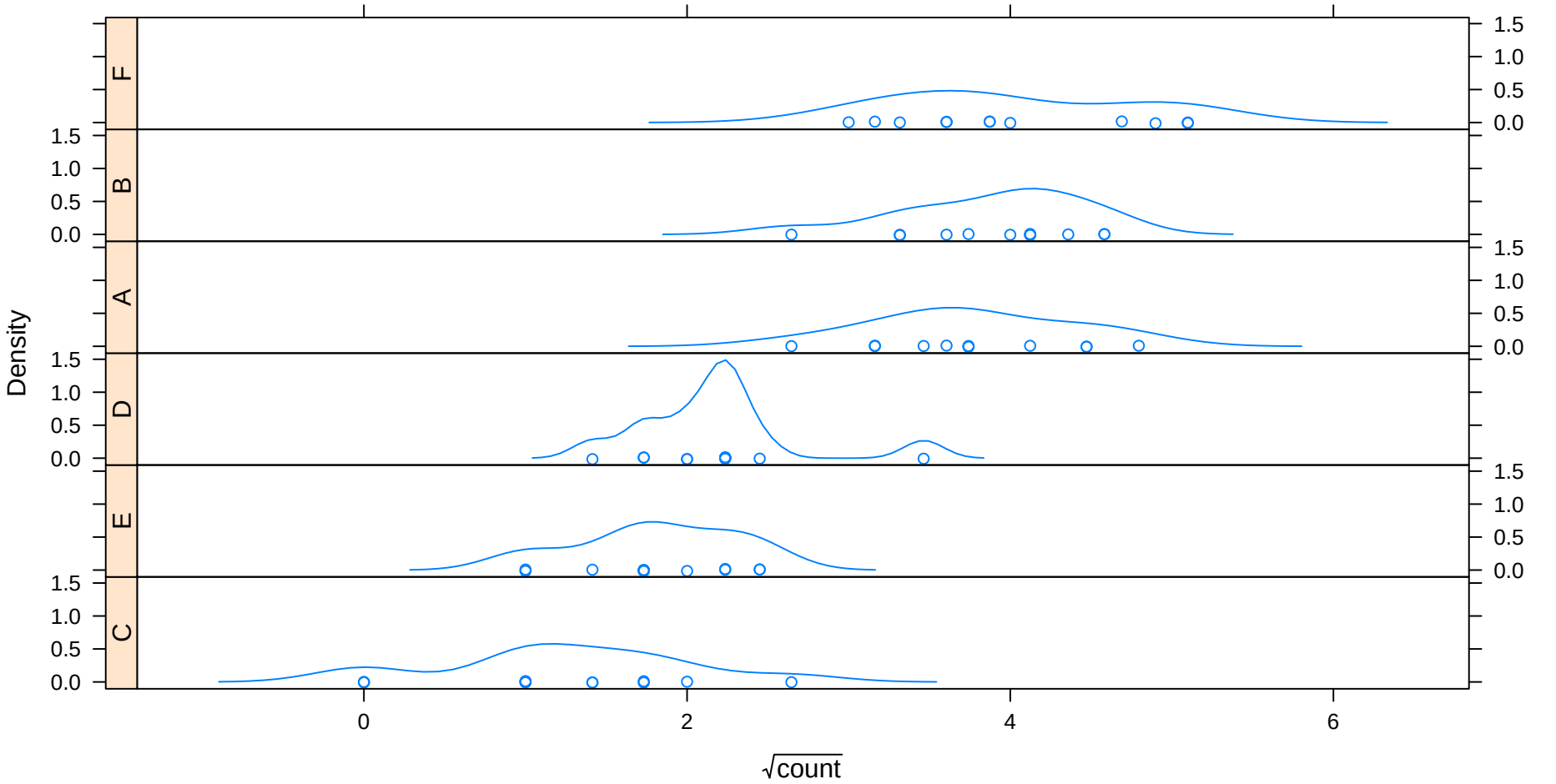
Comparative density plot, separate panels, strip at left

```
> densityplot(~ sqrt(count)|spray, InsectSprays, layout = c(1,6
+             strip.left = TRUE)
```



Comparative density plot, separate panels, reordered

```
> densityplot(~ sqrt(count)|reorder(spray,count), InsectSprays)
```

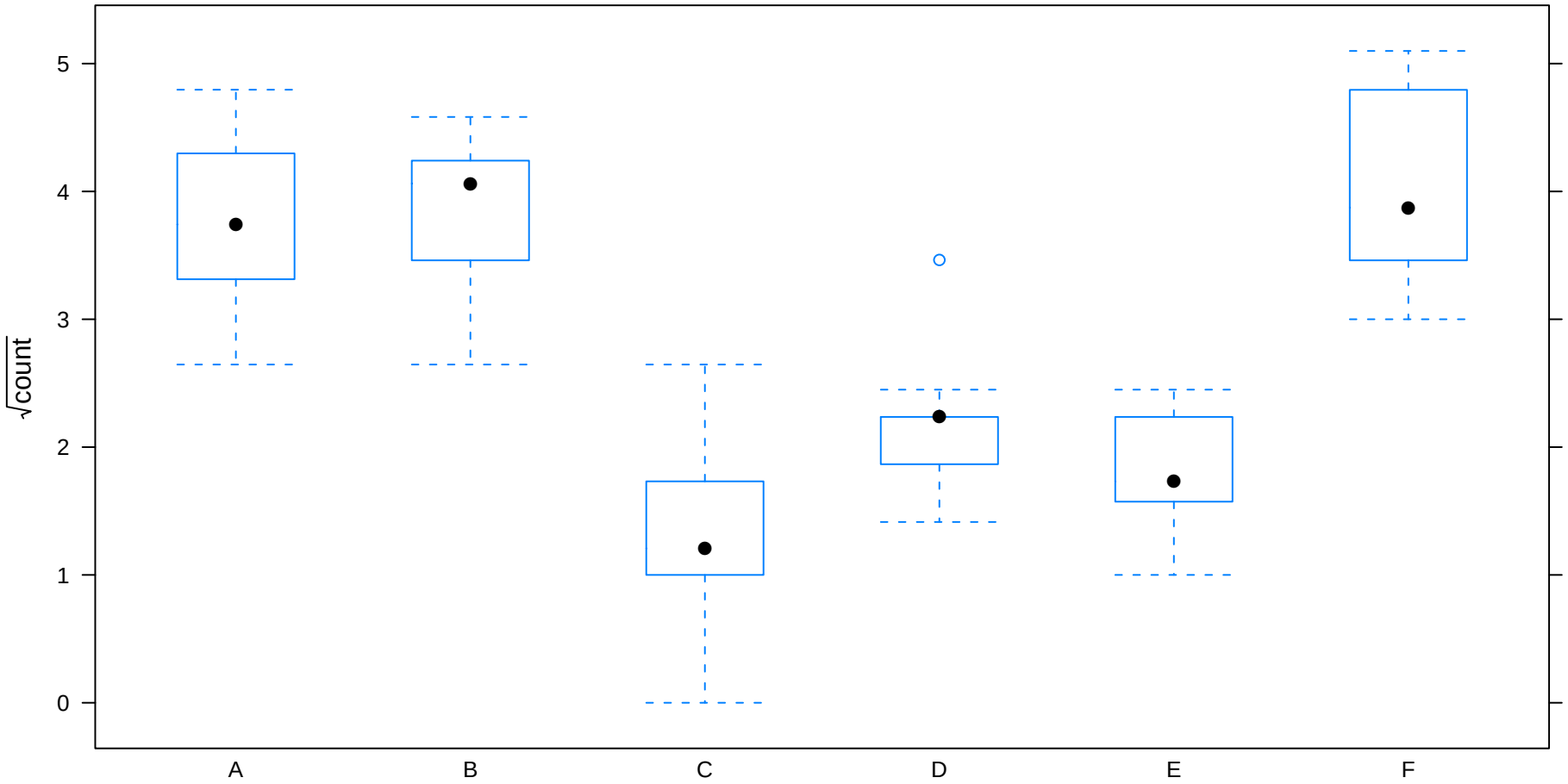


Box-and-whisker plot and dotplot

- A box-and-whisker plot gives a rough summary (based on the five-number summary - min, 1st quartile, median, 3rd quartile, max) of the distribution.
- A dotplot consists of points on a number line. For a large number of data values we jitter the y values to avoid overplotting. By default a density plot also shows a dotplot.
- Box-and-whisker plots or dotplots are often used for comparison of groups.
- It is widely believed that a comparative boxplot should have the response on the vertical axis. Most of the time it is more effective to put the response on the horizontal axis.
- If the default ordering of the groups is arbitrary reorder them according to the level of the response (mean response, by default).
- Reordering makes it easier to see if the variability increases with the level of the response.

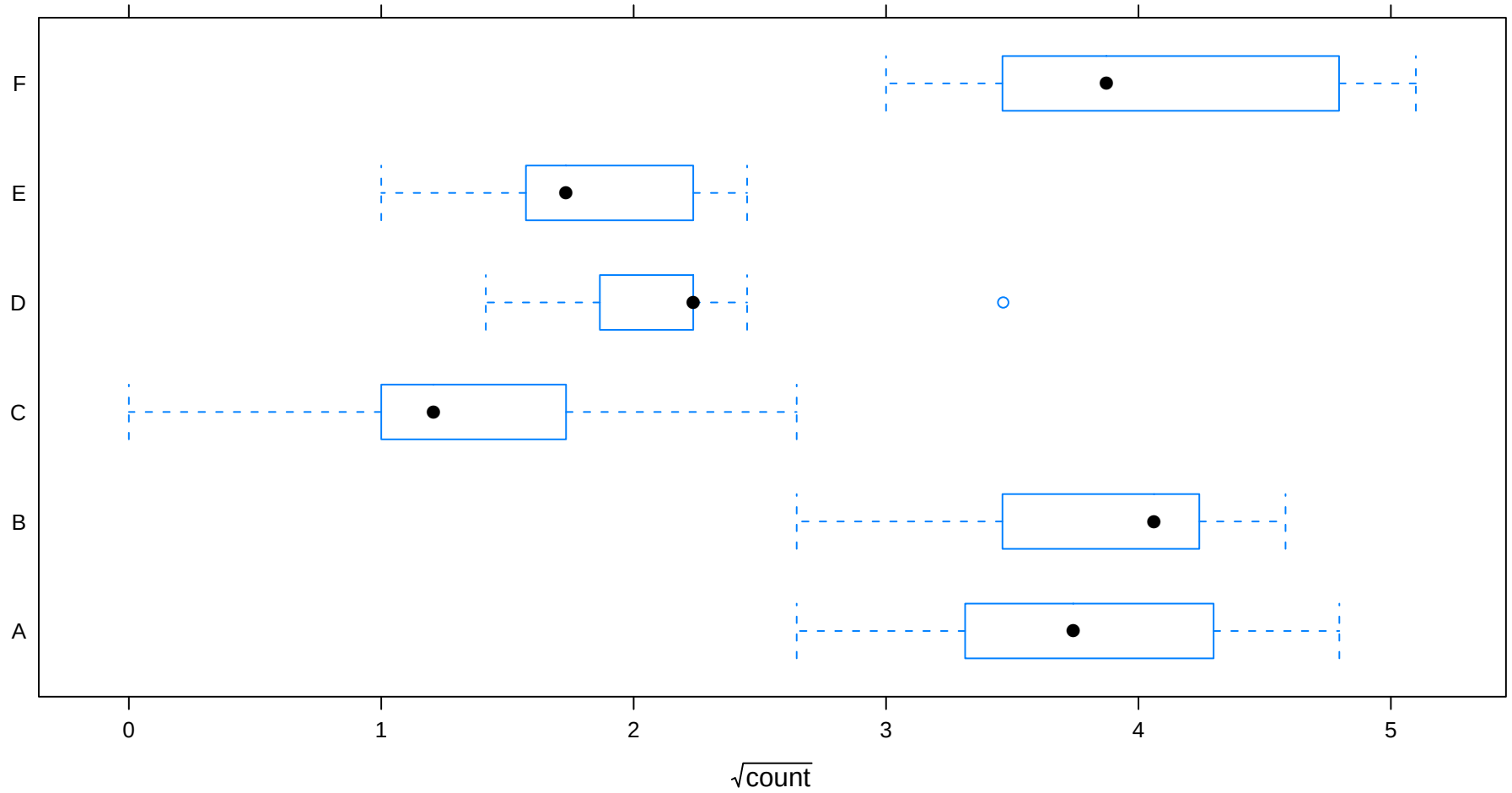
Vertical comparative box-and-whisker plot

```
> bwplot(sqrt(count) ~ spray, InsectSprays)
```



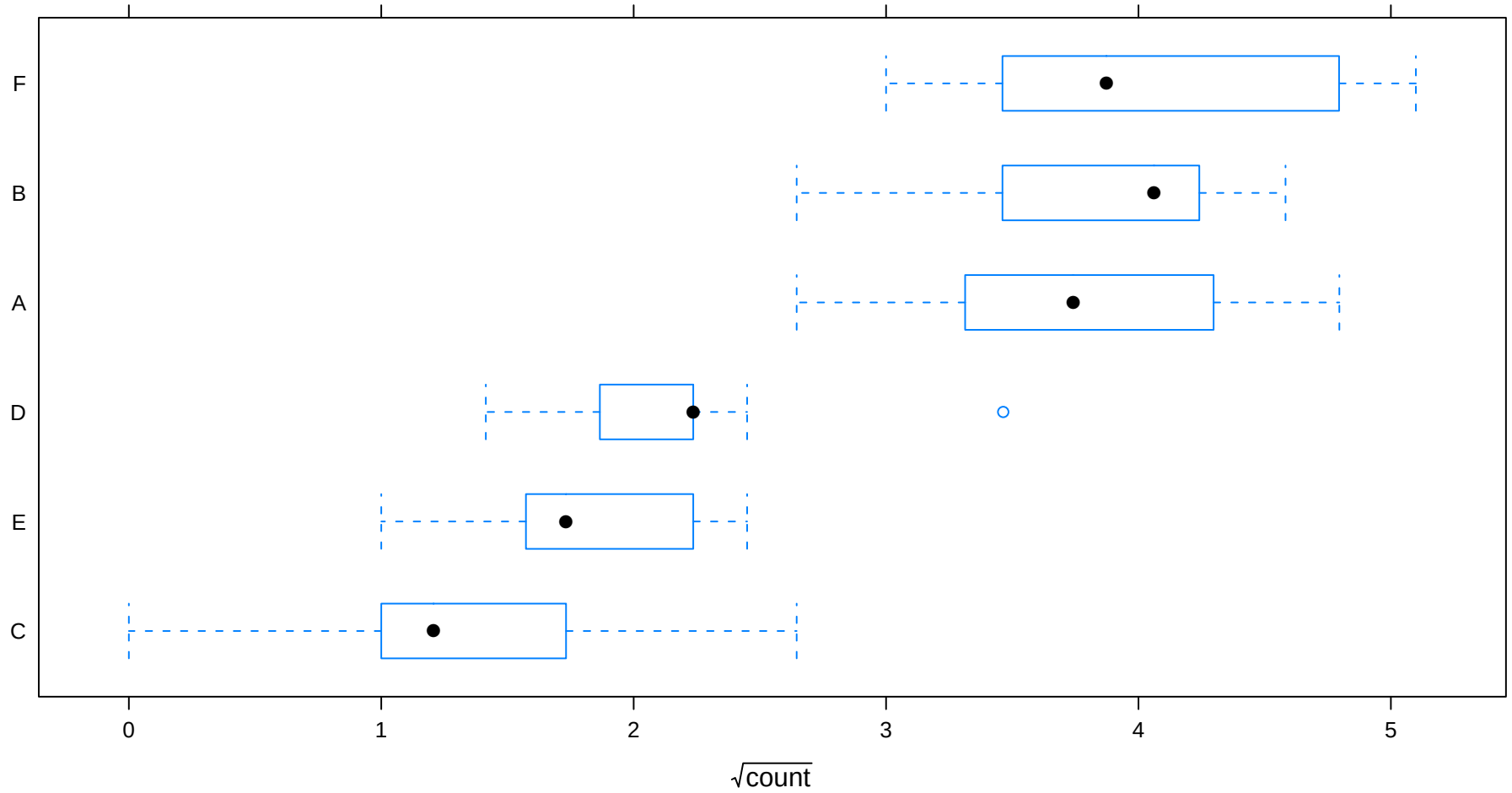
Horizontal comparative box-and-whisker plot

```
> bwplot(spray ~ sqrt(count), InsectSprays)
```



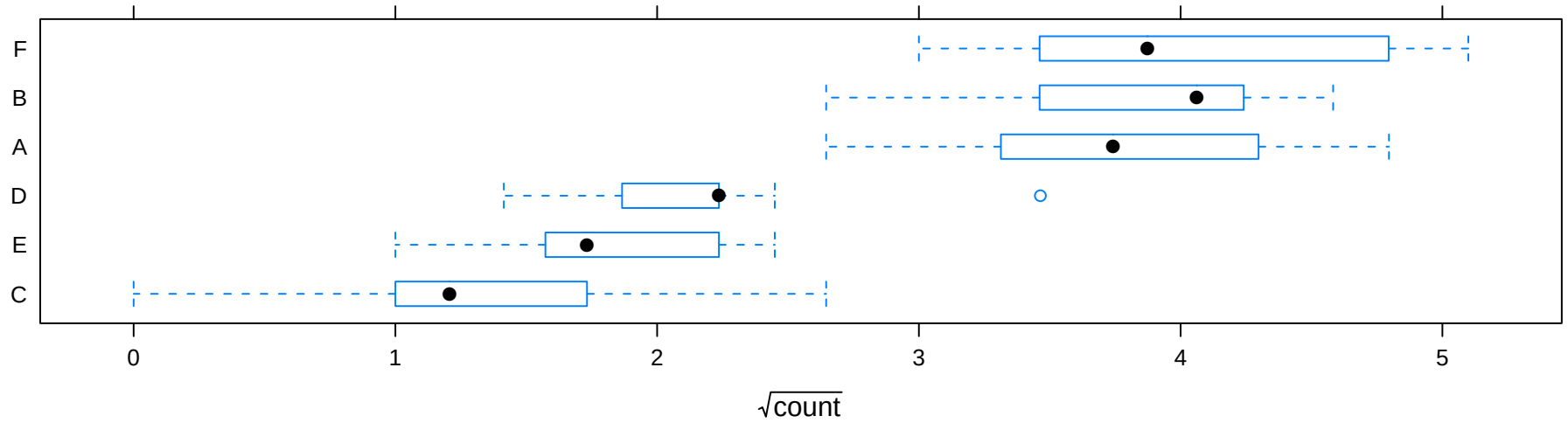
Reordered horizontal comparative box-and-whisker plot

```
> bwplot(reorder(spray,count) ~ sqrt(count), InsectSprays)
```



Compressed horizontal comparative box-and-whisker plot

```
> bwplot(reorder(spray,count) ~ sqrt(count), InsectSprays, aspe
```



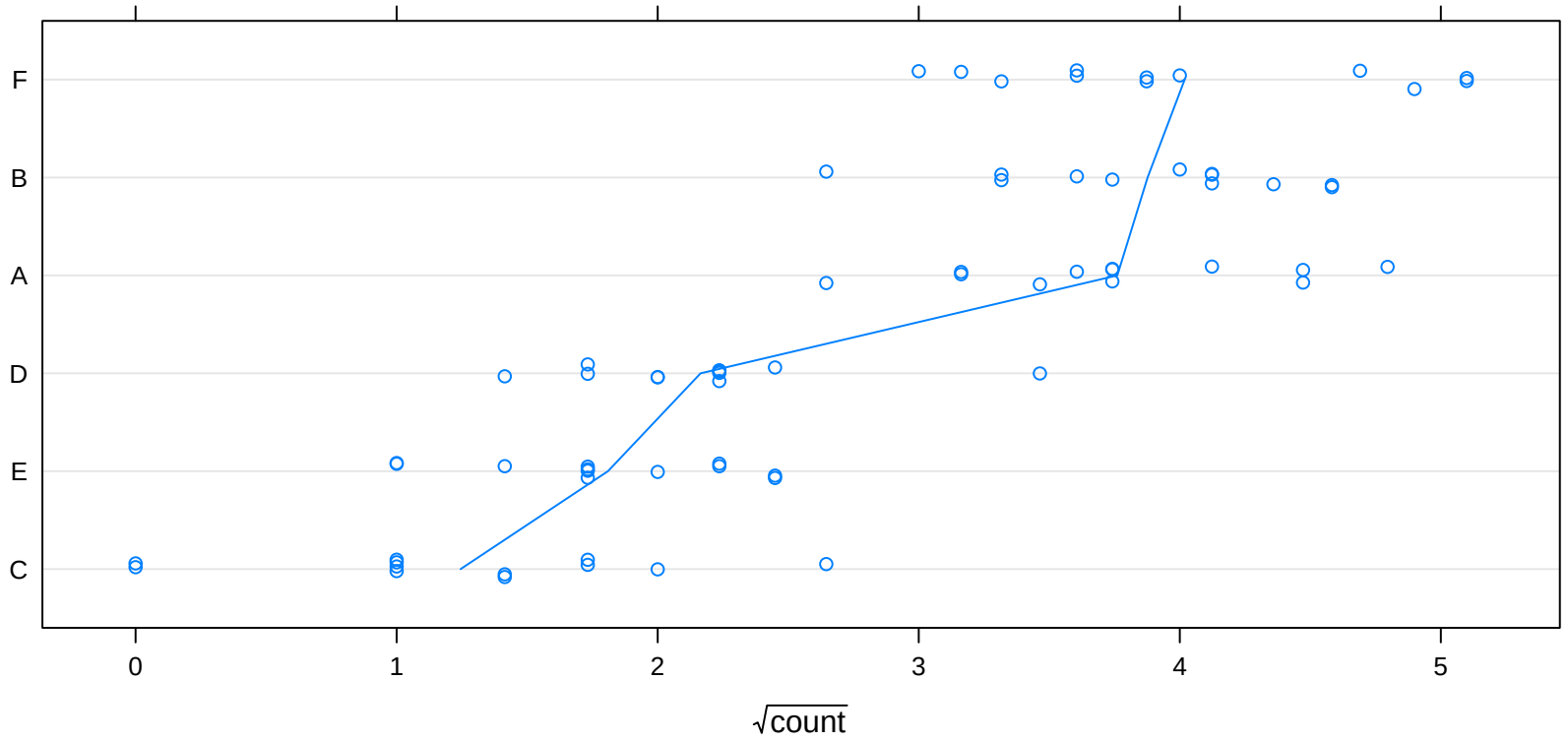
- You can extract much more information from this, compressed plot than from the original vertical box-and-whisker plot.
- In Edward Tufte's phrase, this plot has a greater "information/ink ratio".

Comparative dotplots

- When the number of observations per group is small, a box-and-whisker plot can obscure the structure of the data, rather than illuminating it.
- By default, the density plot provides a dotplot on the "rug".
- A comparative dotplot displays all of the data. The principles described for a comparative boxplot (factor on vertical axis, reorder levels if no natural order, choose an appropriate scale) apply here too.
- By default, the character in the dotplot is filled. I often use optional arguments `pch = 21` and `jitter.y = TRUE` to avoid overplotting.
- Setting `type = c("p","a")` provides a line joining the group averages.
- Interaction plots can be produced as a comparative dotplot with `groups`

Comparative dotplot of InsectSprays

```
> dotplot(reorder(spray,count) ~ sqrt(count), InsectSprays,
+         type = c("p","a"), pch = 21, jitter.y = TRUE)
```



Summary

- In order of importance the graphic displays I consider are scatter plots, density plots, box-and-whisker plots, dot plots and histograms.
- Pay careful attention to layout and axis labels. Include units in the axis labels, if known.
- For mixed models we always have at least one unordered categorical covariate and often have a numeric response. Comparative dot plots and box-and-whisker plots will be important data presentation techniques for us.
- Plots of a continuous response by levels of a categorical variable work best with the category on the vertical axis. Consider reordering the levels of the category if they do not have a natural order.