VERTICAL BLOCKING IN CULTIVAR PERFORMANCE TRIALS: A NORTH CAROLINA EXPERIENCE

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ABSTRACT
Field trials should be designed so that blocks aid the researcher in controlling variability. Spatial variability varies with weather, soil, crops, and other factors. The one variable the researcher can control is direction of operation. Several papers have advocated blocking trials so that operations can be conducted and stopped within a block and in most cases this means vertical blocking. The objective of this study was to compare precision between three years of horizontal blocking with three years of vertical blocking in corn, soybean, and wheat in North Carolina Official Variety Trials. Field trials with vertical blocking were as precise as those with horizontal blocking when using spatial analysis even when yields were higher and the number of entries increased. However, errors tended to increase with vertical blocking when the standard analysis of variance was followed thus spatial analysis are recommended. Examples are given showing the advantage of vertical blocking over horizontal blocking in planting and harvesting trials.

INTRODUCTION
Field plot design for cultivar performance trials has not changed significantly over the preceding decades. Design principles of randomization, replication, and blocking are routinely followed in the conduct of the majority of field research, especially crop performance trials. Some aspects of field plot design have been examined in several studies such as plot configuration (Bowman, 1989, 1991) and restricted randomization (Bowman 2000 and Multize 1990). Both Bowman (2000) and Multize (1990) addressed the issue of back-to-back placement of the same entry. Multize (1990) also addressed the issue of the same entry occupying multiple outside plots, which complicates adjustments in the nearest neighbor analysis because outside plots do not have the same number of adjoining plots. This was not addressed by Bowman (2000) who considered unequal placement of entries in the field as more important.

Some aspects of field plot design including estimating errors in different designs and row and column designs have been addressed by Martin (1982) and Pearce (1975). As mentioned by Stroup et al. (1994) large experiments present problems with complicated designs like row-column designs.

Most field agronomists and breeders design their trial based on row direction that the farmer or research station has established and block horizontally. Blocking is not based on soil variability, although some may consider the slope of the field. Soil at the top of the slope is generally less fertile than at the bottom of the slope (Pearce 1995). Field variation may not always follow the direction of the field slope, and actual field variation may not be known. Bowman (1990) demonstrated in a flue-cured (Nicotinana tobaccum L.) tobacco trial that blocking perpendicular to the slope was effective in removing variability for yield but not effective for another trait-grade index.

Several factors influence field variability including weather patterns (Ping and Green, 2000), crops (Vieira and Gonzalez, 2003), and years (Harris and Scofield, 1920). Knowing soil variability may not prove helpful in designing field experiments. Erghbhall and Varvel (1997) concluded that variability changed with time more so than space.

Given the potential uncertainty of the direction of variability in field experiments, the researcher is left with the task of arranging blocks to remove the variability that can be controlled. Pearce (1995) mentioned “…blocks are often chosen so casually that they correspond to nothing in the field …”. Earlier, Mulla et al. (1990) admitted that blocking might not be effective due to patterns of variability.

Blocking should result in compact areas that are uniform, meeting the assumption that all experimental units within a block are the same (Patterson et al., 1978). These authors also make the point that field operations should be completed within each block. This point was also stressed by Pearce (1995) “It is helpful to have block boundaries where it is safe to stop without damage to the experiment. If the break in operations does lead to a differential effect, it will be absorbed by the blocking system.” Warren and Mendez (1982) emphasized the need to block sources of variation that the researcher has
some control over such as planting and harvesting. Thus one would need to block vertically or in the direction of field operations. This latter point is seldom followed where field experiments are typically blocked horizontally and are perpendicular to the direction of field operations. However, there are concerns regarding vertical blocking and the shape of the resulting blocks. Vertical blocks tend to have longer diagonals than horizontal blocks due in part to the rectangular shape of the plots and therefore blocks are less compact. With longer diagonals some researchers believe that the blocks will contain more variability.

Bowman and Kuraparthi (2015) compared precision of cotton (Gossypium hirsutum L.) trials blocked horizontally with those blocked vertically. Vertical blocking produced higher s.e. than horizontal blocking when the standard analysis of variance was performed but showed no difference when spatial analysis was performed. Patterns of variability changed from year to year as illustrated with 12 residual charts and those charts indicated blocking would not have been effective in any direction in most years. Stroup et al. (1994) also found that blocking did not control field variability in wheat trials. Gusmão (1986) demonstrated the lack of efficiency in blocking field trials.

The objective of this study was to compare precision of three years of horizontal blocking with three years of vertical blocking in corn (Zea mays L.), soybean (Glycine max (L.), and wheat (Triticum aestivum L.) crops of the North Carolina Official Variety Trials.

MATERIALS AND METHODS

To compare precision between horizontal blocking and vertical blocking, data were obtained from the North Carolina Official Variety Trials (OVT). Details on plot sizes, dates of planting, soil types, dates of harvest, and general agronomic practices can be found in the Crop Science Research Reports for the three crops (Bowman 2007-2012, Weisz 2013). Corn, and soybean data from 2007-2009 were from trials that were blocked horizontally while data from 2010-2012 were from trials blocked vertically. Wheat data from 2008-2010 came from horizontally blocked trials while data from 2011-2013 came from vertically blocked trials. The only change was the direction of blocking; most all other field plot decisions were the same across years. Differences between locations included dates of planting and harvesting and row width for corn. There were no differences in row width for soybean and wheat trials. Many of the trials were in the same field for both horizontal and vertical blocking.

Entries did change from year to year with nearly half of the corn entries changing each year and a third of the soybean and wheat entries changing (Bowman 1998).

The number of entries changed as well with average number of entries shown in Table 1.

In order to make fair comparisons between the data sets we first determined any relationship between error variance and productivity level. The natural log of the error variance was regressed on the natural log of the mean yield for each crop in previous studies (Bowman and Watson, 1997). Regression values significantly (P<0.05) different from zero indicate a relationship; i.e., error variances tend to increase with increased mean yields.

Average standard errors were compared between the blocking methods to determine changes in precision (Brownie et al., 1993). The data were analyzed with the standard ANOVA and with Proc Trend (Kirk et al., 1980); the latter is a spatial analysis using a polynomial regression and routinely followed in the NCOVT program. To prevent overfitting, the model in Proc Trend terms were limited to eight and used a significance level of 0.05. The data was also analyzed using standard ANOVA to see if spatial distance, which knowing would increase with vertical blocking, would lower precision.

The author acknowledges that this is not a balanced data set in that the direction of blocking occurred in different years, the entries were different, and the fields were not always the same. However, this is a very robust data set. There are 12 direct comparisons between average s.e. by crop/maturity. Within the 12 comparisons there are 197 locations of horizontal-blocking data and 185 locations of vertical-blocking data. There are 5,342 location by entry data points for horizontal blocking and 5,575 location by entry data points for vertical blocking. There were a total of 26,710 plots of data in the horizontal blocks and 27,610 plots of data in the vertical blocks. Because this robust data set can show general trends and it addresses the concept of alternative blocking designs, it is worthy for discussion.

RESULTS

Error variance is related to productivity level for one group of soybean, and for wheat as previously reported by Bowman and Watson (1997); therefore, fair comparisons for those crops must take into account the average yield. Table 1 lists the groups with a significant relationship by indicating their ‘b’ values.

For all three maturity groups of corn, there were no significant relationships between error and mean yield, thus one can compare standard errors without regard to mean yield (Table 1). In each maturity group, vertical blocks were just as precise as the horizontal blocks when using spatial analyses. A different story appears when one uses the standard ANOVA analyses. In every maturity group using vertical blocks resulted in a larger
s.e. when compared to the s.e. associated with horizontal blocking (average 639 versus 522 kg/ha). This lends credence to those who advocate creating blocks as square as possible such as Patterson et al. 1978. However, most agronomic plots are rectangular and do not lend themselves to forming square blocks.

Only one maturity group of soybean had a relationship between error and yield — group V conventional. The three years of horizontal blocking averaged 141 kg/ha compared to 134 kg/ha for three years of vertical blocking using spatial analyses (Table 1). For all other maturity groups, the standard error for vertical blocking was the same or slightly smaller (not significantly) than that for horizontal blocking. Examination of s.e. when the standard analysis (ANOVA) was performed indicated slightly larger but not significant values for vertical blocking over horizontal blocking (numbers in parenthesis in Table 1) in three of eight groups, similar numbers in four of eight groups and slightly smaller s.e. in one group (IV RR). The larger values for vertical blocking would suggest that more variation is found in vertical blocks compared to horizontal blocks and spatial distance is a factor. The diagonal of a vertical block is longer than the diagonal of a horizontal block since individual plots are rectangular in shape and not square (typically more than three times as long as wide). The use of spatial analysis as demonstrated in these data sets is generally not impacted by the shape or direction of blocks.

In wheat, the average yield for vertical blocking was larger than horizontal blocking (5.1 vs. 4.0 mg/ha) and the standard error was smaller although not significant (163 vs. 175). One would have expected the s.e. to have been larger for vertical blocking data with the higher yields due to 0.6 b value (Table 1). The 0.6 b value says that the error tends to increase with increased mean yield. If spatial analyses were not used, vertical blocking enlarged the s.e. slightly (average 215 vs. 200) over horizontal blocking; however, this should be expected given higher yields under vertical blocking (5.1 vs 4.0 Mg/Ha) and larger blocks (76 vs. 66 entries). As mentioned below some of the wheat trials blocked vertically had fewer replicates due to issues in the field and a natural result should have been a larger s.e.

Since the North Carolina Official Variety Testing Program began using vertical blocking in 2010 in all its trials the following incidents occurred in just three years:

- Rowan 2010 – during harvest operations of the wheat OVT rain began to fall after harvesting of the fourth replicate, vertical blocking allowed the test to be salvaged using the four replicates.
- Perquimans 2011 – the farmer did not leave enough room (width) to plant all five replicates of the wheat OVT so the fifth replicate was dropped in order to plant it. Had it been blocked horizontally, then it would have required a complete re-randomization of the test and rearrangement of the seed packets in the planting trays, significantly delaying planting.
- Kinston 2012- the research station did not leave enough rows to plant the corn OVT so the fifth replicate was dropped immediately before planting the test.
- Plymouth 2012- while harvesting a group V soybean trial rain began to fall after the harvest of the fourth replicate and the fifth replicate was not harvested; again vertical blocking allowed the test to be salvaged.
- Plymouth 2012 – the research station reassigned fields placing the test in too narrow of a field with a wet spot on one side. Vertical blocking allowed a replicate to be easily dropped without compromising the test.

You could argue that if the fields were not long enough then vertical blocking would have been at a disadvantage at the time of planting and that is true. On the other hand, in the incidents occurring during harvest, the tests would have been lost entirely or use of the data would have been questionable.

Vertical blocking in the North Carolina wheat OVT allows the use of two combines to harvest one test. The wheat OVT in North Carolina had gotten so large (>90 entries) by 2012 that it takes two combines to finish one test in one day; the typical NC wheat OVT has five replicates. Horizontal blocking would make it difficult for two combines to harvest one test. Again, this confirms the emphasis Pearce (1995), Patterson et al. (1978), and Warren and Mendez (1982) placed on blocking to aid in operations.

One other observation that is worth noting is that there appears to be a general trend of the spatial analyses reducing error greater with vertical blocking compared to horizontal blocking. Averaged over all data sets Proc Trend reduced the s.e. 34 kg/ha when blocks were horizontally blocked and 89 kg/ha when blocked vertically; this is highly significant (prob= 0.001) (Table 1). The largest reduction came in the corn plots where the spatial analysis lowered s.e. by 208 kg/ha when blocked vertically. Corn plots were 6.7 m by 1.83 or 1.52 m while soybean and wheat plots were 6.7m by 1.52 m. So plot size may not be a factor. This would need further confirmation and there is no clear explanation for this trend.

**SUMMARY**

Vertical blocking did not reduce precision in any crop or maturity group while using spatial analysis. The number of entries in each of these trials actually increased in the years of vertical blocking compared to the previous three years in 9 of the 12 data sets. A natural consequence of these larger tests should have
Table 1. Comparison of standard error (S.E.) between 3 years with horizontal blocking and vertical blocking for various maturity groups of three crops in North Carolina.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Maturity</th>
<th>Blocking Direction</th>
<th>Points*</th>
<th>Average S.E. (Kg/Ha)*</th>
<th>b†</th>
<th>Average Yield (Mg/Ha)</th>
<th>Average Number of Entries</th>
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<tbody>
<tr>
<td>Corn</td>
<td>Early</td>
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<td>457(522)</td>
<td>NS</td>
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<td></td>
<td></td>
<td>Vertical</td>
<td>17</td>
<td>376(562)</td>
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<td></td>
<td>Medium</td>
<td>Horizontal</td>
<td>18</td>
<td>504(537)</td>
<td>NS</td>
<td>9.5</td>
<td>37</td>
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<tr>
<td></td>
<td></td>
<td>Vertical</td>
<td>17</td>
<td>459(662)</td>
<td></td>
<td>8.3</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Late</td>
<td>Horizontal</td>
<td>15</td>
<td>470(507)</td>
<td>NS</td>
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<td>25</td>
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<tr>
<td></td>
<td></td>
<td>Vertical</td>
<td>17</td>
<td>457(692)</td>
<td></td>
<td>8.3</td>
<td>37</td>
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<tr>
<td>Soybean</td>
<td>V Conv.</td>
<td>Horizontal</td>
<td>10</td>
<td>141(179)</td>
<td>0.73</td>
<td>3.4</td>
<td>22</td>
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<tr>
<td></td>
<td></td>
<td>Vertical</td>
<td>16</td>
<td>134(183)</td>
<td></td>
<td>3.0</td>
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<tr>
<td></td>
<td>VI Conv.</td>
<td>Horizontal</td>
<td>11</td>
<td>148(187)</td>
<td>NS</td>
<td>2.9</td>
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<tr>
<td></td>
<td></td>
<td>Vertical</td>
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<td>134(195)</td>
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<td>3.1</td>
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</tr>
<tr>
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<td>VII Conv.</td>
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<td>134(179)</td>
<td>NS</td>
<td>3.0</td>
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<tr>
<td></td>
<td></td>
<td>Vertical</td>
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<td>134(176)</td>
<td></td>
<td>3.0</td>
<td>15</td>
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<tr>
<td></td>
<td>IV RR</td>
<td>Horizontal</td>
<td>20</td>
<td>148(179)</td>
<td>NS</td>
<td>3.1</td>
<td>39</td>
</tr>
<tr>
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<td>141(171)</td>
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<td></td>
<td>3.0</td>
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<tr>
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<td>141(187)</td>
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<td>19</td>
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<tr>
<td></td>
<td>VII RR</td>
<td>Horizontal</td>
<td>9</td>
<td>155(175)</td>
<td>NS</td>
<td>3.3</td>
<td>21</td>
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<td></td>
<td>Vertical</td>
<td>7</td>
<td>134(212)</td>
<td></td>
<td>3.2</td>
<td>18</td>
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<tr>
<td>Wheat</td>
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<td>Horizontal</td>
<td>12</td>
<td>175(200)</td>
<td>0.6</td>
<td>4.0</td>
<td>66</td>
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<tr>
<td></td>
<td></td>
<td>Vertical</td>
<td>12</td>
<td>163(215)</td>
<td></td>
<td>5.1</td>
<td>76</td>
</tr>
</tbody>
</table>

*Number of environments, i.e. locations x years.
† Regression of the natural log of the error variance on productivity level.
NS = not significantly different from 0.
RR = Roundup Ready

*Numbers in parenthesis are s.e. using the standard ANOVA while the other numbers (outside the parenthesis) are from Proc Trend (spatial analyses).
been less precision, but precision did not decline with vertical blocking. Also, when one drops a replicate for various reasons the standard error will actually go up since the square root of the number of replicates is in the denominator. Again, precision was not compromised by vertical blocking. Several examples of the advantages of vertical blocking have been given from the North Carolina program. Errors tend to increase when using the standard analysis of variance with vertical blocks especially with corn and soybean suggesting that spatial distance is more critical with those two crops than with wheat.

Blocking should be designed to control variation within the power of the researcher. This study shows that blocking with the direction of operations, e.g., the row direction where planting and harvesting can be started and stopped, does not compromise the data. Data from this study show that for some crops vertical blocking is best accompanied by use of spatial analyses, such as Nearest Neighbor Analysis or Trend Analysis because no direction of blocking is going to be effective all the time. Row-column designs can be used if there is a concern about variation in the horizontal direction and these can be found at John and Mitchell (1977) and Whitaker et al. (2006). In this context, it is proposed that the use of vertical blocking can prove beneficial.

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REFERENCES


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