The design of agronomic field and greenhouse experiments requires consideration of spatial variability. Blocking is often used to remove large-scale field trends, and randomized plot allocation is presumed to ensure that a treatment is not continually favored or handicapped in successive replications by some extraneous source of variation. Although the randomization process is widely accepted and intuitively appealing, it has been shown to cause biases and imprecision under many experimental conditions (van Es and van Es, 1993). This is the result of possible non-random variability patterns in fields or greenhouses, including trends (higher and lower responses in different parts of the field), spatial correlation (nearby locations showing similar response), or periodicity (repetitive patterns across the field; van Es, 2002). The randomization process does not explicitly account for such patterns, and certain designs may be undesirable, such as one treatment being in the same location in multiple blocks or two treatments always being located nearby. Also, concerns exist about possible manipulation of experimental designs in the testing of agricultural products, especially when executed by the manufacturers themselves, because a layout that favors a certain product may in theory be the result of a preselected randomized design outcome.

These concerns can be addressed through advanced experimental design and analysis, or both. In reality, however, agronomists rarely use advanced designs in field experiments. A review of 537 experiments discussed in three volumes of the Agronomy Journal (2001-2003) revealed that 57% of controlled field experiments were implemented as conventional Randomized Complete Block Designs.

Spatially-Balanced Complete Block Designs

In an earlier WCU article (Vol. 12, No. 2, 2003; Robust Designs for Simple Agronomic Experiments), we presented some preliminary designs that are spatially balanced. In the past year, we further developed Spatially-Balanced Complete Block Designs (SBCBD) that are based on standard, spatially optimized layouts (Tables 1 and 2; van Es et al., 2004). They guarantee that the design is insensitive to trends, spatial correlation, and periodicity in the research domain (field, greenhouse, etc.). Random assignment of treatments ensures against user bias and allows for a large number of possible design outcomes, explicitly excluding those that are undesirable. SBCBD designs were developed using the computational method of simulated annealing (Gomes et al., 2004) for which two simultaneous objectives were applied: (i) promoting spatial balance among treatment contrasts, and (ii) disallowing treatments to occur in the same position in different blocks. Simulations were performed for up to 15 treatments and 15 replications (blocks). Designs will be developed in the future.
SBCB designs are listed in Table 1 for up to 10 treatments, and in Table 2 for 12 to 15 treatments. These layouts can be used in experimental design by randomly allocating treatments to the outer indicators. Blocks in the layout may also be interchanged as this does not affect spatial balance. Although spatial balance in the designs was developed for treatments that are laid out adjacent, the results also provide good designs when the treatments are implemented in other arrangements (e.g., blocks of 8 treatments laid out as 2x4). Split-plot designs based on SBCBDs can be obtained through a two-stage procedure where the main plots are first identified and the split plots are subsequently defined within the main plots.

A Proposed Design Standard

SBCB designs provide protection against the effects of nonrandom variability patterns in fields and greenhouses, while the randomized allocation of treatments to the indicators insures against user bias. This approach allows for straightforward design of agronomic experiments, requires no change in statistical analysis, and prevents undesirable design outcomes that can result from the traditional randomized approach. SBCB designs also provide a useful standard for field testing of agricultural products by university, industry, and consultants, because designs based on the traditional randomization approach can be subject to manipulation of plot layout, while SBCB-based research allows for verification of the unbiasedness of the design.

Acknowledgement

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References


Table 2. Spatially-Balanced Complete Block Designs for experiments with 11 to 15 treatments (a-o) and up to eight blocks.

<table>
<thead>
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<th>Blocks</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<td>11</td>
<td>a</td>
<td>b</td>
<td>c</td>
<td>d</td>
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<td>i</td>
<td>j</td>
<td>k</td>
<td>l</td>
<td>m</td>
<td>n</td>
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<td>o</td>
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<td>q</td>
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<td>s</td>
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<td>x</td>
<td>y</td>
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</tbody>
</table>
Phosphorus Removal by BMR Sorghum Sudangrass
Olurin A. Ketterings*, Tom F. Klicer**, Paul Correale*, and Jerry H. Cherry**
*Department of Crop & Soil Sciences, Cornell University
**CCE Rensselaer County, CCE Delaware County

Introduction

The December 2002 release of the Final Concentrated Animal Feeding Operation (CAFO) ruling from the US Environmental Protection Agency made animal agriculture fully accountable to the Clean Water Act. In New York, all CAFOs are required to develop and implement a Comprehensive Nutrient Management Plan (CNMP) which meets USDA-NRCS standards and specifications by January 2009. Nutrient management planning is guided by NRCS Standard NY590 which requires that all fields be assessed for their P runoff potential using the New York Phosphorus Index (NY Ph). If the NY Ph is classified as high (between 75 and 100), P applications through manure and/or fertilizer should not exceed P removal by the crop. For many forage crops, average nutrient concentration data are available through commercial forage testing laboratories. However, because BMR SxS is a relatively new crop for the region, accurate P removal rates have yet to be determined.

Our objectives were to determine P concentrations and P removal by BMR sorghum sudangrass as impacted by N and K application rates, stand height at harvest, dry matter yield, and soil test P. The BMR SxS was grown in three different New York soil and climatic regions and over two very different years including the 2002 drought year and a very good 2003 growing season.

Materials and Methods

Seven field trials were conducted in New York at three different locations, Delaware County, Columbia County, and Tompkins County in 2002 and 2003 (Table 1).

The trials were part of a larger, multi-year effort to determine stand height optimum for yield and nutrient and N and K requirements of the crop. The Delaware trials were stand height studies conducted on Chenango gravelly silt loam. The Tompkins County trials were N and K rate studies conducted on a Mardin silt loam. The three trials in Columbia County were conducted on Hoosic gravelly silt loam. Two of the three studies were N rate studies. The third study was a stand height study. At each location, trials were conducted as complete randomized block designs with K rate (0, 50, 100, 155, 200 and 250 lbs P2O5 per acre) and/or stand height at harvest (30 to 80 inches) as the treatments and four replications per treatment. At the Tompkins County site, the main plots (N rates) were split to include a K rate (0, 100, or 200 lbs K2O per acre) as well. The BMR SxS was planted with a seed density of 60-70 lbs seed/acre using conventional grain drills in the first two weeks of June with harvests at the end of July and the end of September. The subplots were 6 feet wide and 10 feet long of which an area of 3 x 5 feet was harvested. The Delaware County trials and the N rate studies in Columbia County were conducted on soils that had not received any manure in recent years.

All trials were managed as a 2-cut system. Harvest took

| Table 1: Soil types, pH, organic matter and soil test P for each of the seven BMR sorghum-sudangrass nitrogen, potassium and harvest stand-height studies conducted in New York. |

<table>
<thead>
<tr>
<th>Trial</th>
<th>County</th>
<th>Year</th>
<th>Study</th>
<th>Soil pH</th>
<th>Morgan soil test P lbs/acre</th>
<th>Classification</th>
<th>Addition P, O2 acre</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Tompkins</td>
<td>2002</td>
<td>N, K rates</td>
<td>6.2</td>
<td>5 Medium</td>
<td>45</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2 Tompkins</td>
<td>2003</td>
<td>N, K rates</td>
<td>6.0</td>
<td>5 Medium</td>
<td>45</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Columbia</td>
<td>2002</td>
<td>N rate</td>
<td>6.2</td>
<td>10 High</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Columbia</td>
<td>2002</td>
<td>Height</td>
<td>6.2</td>
<td>10 High</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Delaware</td>
<td>2002</td>
<td>Height</td>
<td>5.6†</td>
<td>20 High</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Delaware</td>
<td>2002</td>
<td>Height</td>
<td>6.7</td>
<td>47 Very high</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Lime was applied to achieve a pH of 6.4.

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Results and Discussion

The original treatment (stand height at harvest, N or K rate) or harvest number (first or second cut harvest) did not impact P concentrations in the forage with the exception of plots which did not receive fertilizer N. In the trials in Tompkins County the average P concentration was 0.33% without N addition versus 0.28-0.30% P with N application. Although values can vary considerably depending on plant species, plant age, and concentration of other mineral elements, a P concentration of 0.20% or greater is considered sufficient for adequate production. In the Columbia County trials where manure had been applied, the average P concentrations were 0.30% (2002) and 0.37% (2003) versus 0.25-0.27% (2002) and 0.27-0.34% (2003) when N had been applied. This decrease in P concentration of the forage with N application is most likely a dilution effect caused by the substantial (1.3 to 2.0 fold) yield increase upon the addition of just 50 lbs N/acre per cut.

There were no consistent trends in P concentration of the forage when N had been applied. Average P concentrations over the two cuts in each location ranged from 0.24% at one of the 2002 Delaware County sites where the soil tested very high in P but where no additional P fertilizer was used, to 0.31% for the 2003 trials (Table 2). Phosphorus concentrations from individual plots ranged 0.15% to 0.53% with an overall average of 0.29% P (dry matter basis) if the plots without N application were included and 0.28% when N limited plots were excluded. Differences in P concentration among trial sites in New York in 2002 and 2003 were not explained by soil test P level. The forage P concentration...
was less than 0.20%. In two instances (Delaware County stand height trials) only. In both cases, harvest took place at stand heights of 54 and 55 inches and dry matter yields of 2.9 to 3.3 tons/acre.

Phosphorus removal was linearly related to dry matter yield in both cuts. Across all sites and trial years, P removal by the crop was estimated as:

\[ P \text{ removal (lbs P}_2\text{O}_5/\text{acre}) = 4.8 + 11.6 \times \text{yield (tons dry matter/acre)} \]  
\( (r^2 = 0.65) \)

Thus, 85% of the variability in P removal rates across all trials was explained by yield alone (Fig. 1). According to this equation, a BMR SxS crop with 5.8 tons of dry matter (16 tons at 35% dry matter) would remove about 70 lbs P\(_2\)O\(_5\)/acre. This is 6 lbs P\(_2\)O\(_5\)/acre more than the 62 lbs of P\(_2\)O\(_5\)/acre estimated for a similar corn silage yield using an average corn silage P concentration of 0.24% of dry matter. However, actual P removal rates for BMR SxS ranged from 50 to 90 lbs P\(_2\)O\(_5\)/acre. The additional variability in P concentrations and removal for the individual trials shown in Fig. 1 was not explained by N (beyond a 50 lbs N/acre application) or K application rate, stand height at harvest, 1st or 2nd cut, or soil test P, although at one of two Delaware County sites (site 6), P concentrations tended to decrease slightly with stand-height at harvest \((r^2 = 0.53)\). Additional research is needed to identify location differences that may have resulted in varying P concentrations in harvest.

**Summary and Conclusions**

Differences in yields across 3 locations and two years of field trials explained 85% of the variability in P removal rates. The average P concentration across all sites was 0.28% P. A crop of 5.6 tons of dry matter would remove 70 lbs P\(_2\)O\(_5\)/acre. This is the P\(_2\)O\(_5\)_equivalent of 5500 gallons of liquid manure assuming an average P\(_2\)O\(_5\)_concentration in the manure of 13.6 lbs P\(_2\)O\(_5\) per 1000 gallons the average manure composition of 503 samples analyzed in 2003 by Dailey One (Paul Sirois, personal communication). However, SxS P concentrations of individual pots ranged from 0.15% to 0.53% indicating that producers need to analyze their forage P concentration and determine yields to obtain accurate values for P removal by this crop in addition to sample manure to determine manure application rates for environmentally sound nutrient management planning.

**Additional Articles on BMR Sorghum Sudangrass in NY**


**Acknowledgments**

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**For Further Information**

For further information on BMR sorghum sudangrass in NY contact Thomas Klicer at the Rensselaer Cooperative Extension Office at tklicer@cornell.edu or 518-272-4210 or visit the Rensselaer County website at: http://www.cce.cornell.edu/rensselear/Agriculture/new%20bmr_sorghum.htm. All above mentioned articles are downloadable from the BMR sorghum sudangrass website at http://nmssp.css.cornell.edu/projects/bmr.asp.
Calendar of Events

Jan. 3-6, 2005  Northwestern Weed Science Society, Washington, D.C.
Jan. 19, 2005  Western NY Corn Congress, Holiday Inn, Batavia
Jan. 20, 2005  Finger Lakes Corn Congress, Holiday Inn, Waterloo
Jan. 27, 2005  Winter Crop Meeting, Clarion, Iowa
Feb. 7-10, 2005  Weed Science Society of America, Honolulu, HI
Feb. 9, 2005  Western NY Soybean/Small Grains Congress, Batavia Party House, Leroy
Feb. 10, 2005  Finger Lakes Soybean/Small Grains Congress, Holiday Inn, Waterloo
Feb. 22-23, 2005  NYSAPA Annual Meeting, Holiday Inn, Auburn
Mar. 1, 2005  Northern NY Crop Congress, Elkridge Lodge, Carthage
Mar. 2, 2005  Northern NY Crop Congress, St. Lawrence County
Mar. 3, 2005  North Country Corn Congress, Miner Institute, Chazy
Mar. 3, 2005  Quality Forage Forum, North Java Fire Hall, North Java
Mar. 4, 2005  Quality Forage Forum, Randolph Fire Hall, Randolph
Mar. 8, 2005  Field Crop Industry Day, Holiday Inn, Waterloo, NY

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