SOYBEAN YIELD VARIABILITY OF DRAINAGE AND SUBIRRIGATION SYSTEMS IN A CLAYPAN SOIL

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ABSTRACT. Claypan soils with less than 1% slope are poorly drained because of an argillic claypan layer 45 to 60 cm below the soil surface. Field research was conducted near Bethel, Missouri, to evaluate soybean (Glycine max [L.] Merr.) grain yields and plant populations above subsurface drain tile lines and 3.1 m distances from the tile lines of laterals installed at 6.1 and 12.2 m wide spacings for drainage (DO) or drainage plus subirrigation (DSI). The site was arranged as a split-plot design with four replications. In some years, sub-sub-plots included multiple cultivars or fungicide/insecticide management systems. This resulted in 30 year-cultivar-management (YCM) treatments from 2002 to 2015. Averaged over all of the 30 YCM systems, the highest yields (4,050 kg/ha) were observed above the 6.1 m DSI drainage tile line. Subsurface drainage tile spacings (6.1 and 12.2 m) and distances from the tile lines for DO or DSI yielded 11% to 21% greater than the ND control. Due to extreme weather events among YCM systems, data were separated into low (LYE, <3,360 kg/ha) and high (HYE, >3,360 kg/ha) yield environments. In LYE, yields were more variable above the tile line and generally decreased as the distance from the subsurface tile lines increased for DSI, but yields were greater and more variable between the tile lines for DO. In HYE, yields were greatest and more variable between the 6.1 or 12.2 m spaced DO treatments, while yields were greatest above the drain tiles with lower variability compared to between the tile lines with DSI. A narrower drain tile spacing may be needed to reduce yield variability in LYE, but this was less evident in HYE.

Keywords. Claypan, Drain tile spacing, Drainage, Subirrigation, Water management.

Over 4 million ha of claypan soils are in the Midwestern United States. These soils typically have a perched water table from November to May that is caused by an argillic clay layer in the soil that is normally 45 to 60 cm below the soil surface on soils with less than 1% slope (Anderson et al., 1990). Soybean (Glycine max [L.] Merr.) grain yields can be reduced in these soils by cool, wet soil conditions in the spring and/or drought during the summer months. Poorly drained soils can affect soil conditions that result in compaction, delayed soybean planting dates, and an increase in the severity of diseases (Lim, 1980; Helsel and Minor, 1993; Scherm and Yang, 1996; Rousseau et al., 2006; Sweeney et al., 2006). Water management is one of the major factors affecting soybean production on claypan soils with grain yields of soybean being more sensitive to excess water in the soil than corn (Zea mays L.) (Thompson et al., 1991); however, soybean grain yield response to irrigation was generally less than corn (Sipp et al., 1984).

Subsurface tile drainage systems (DO) installed in claypan soils have been evaluated for their effect on soybean production (Walker et al., 1982). A synergistic increase (4.8 Mg ha⁻¹) in corn grain yields was reported when overhead irrigation was used in conjunction with subsurface tile drainage in southern Illinois (Walker et al., 1982; Sipp et al., 1986). However, other research has recently evaluated the impact of subsurface drainage systems used in conjunction with subirrigation (DSI) in claypan soils (Nelson et al., 2011, 2012; Nelson and Meinhardt 2011). A DSI system utilizes subsurface tile drainage to remove water in the soil profile during spring and fall to allow aeration of the soil and timely field operations, regulate water flow during winter (controlled drainage) (Frankenberger et al., 2006) and improve water quality (Nash et al., 2015a, b), and provide irrigation water to the crop during dry periods of the growing season (Belcher and D’Itri, 1995; Skaggs, 1999).

High yield soybean production systems in the 1980’s utilized DSI on 6.1 m spacings on fragipan soils in Ohio to produce yields that were over 5,300 kg ha⁻¹ (Cooper et al., 1990; 1991). Controlled drainage systems on claypan soils have reduced nitrate-N loading up to 85% and P loading up to 80% (Nash et al., 2015a, b), while controlled drainage as part of a DSI system has been important in conserving and reducing the amount of water applied compared to overhead irrigation in corn (Nelson et al., 2009). Water table depth is an important consideration for maximizing soybean grain yields using DSI where a shallow depth (45 cm) had the...
a drainage coefficient of 1.3 cm 24 h⁻¹. Subsurface tile drains and DSI 6.1 m or 12.2 m). The DSI or DO main plot was subsurface drainage tile spacing (ND, DO 6.1 m or 12.2 m, infections. The main plots were DO or DSI and sub-plots were cultivars or management systems were evaluated and concerns about grain yield variability could affect recommended drain tile spacings in claypan soils. However, no research has reported the spatial yield variability of soybean from DO or DSI systems on a claypan soil. The objective of this research was to evaluate soybean grain yields, plant populations, and heights above subsurface drainage tile lines (0 m) and 3.1 m distances from the tile lines for subsurface drainage tile laterals installed at 6.1 and 12.2 m spacings.

MATERIALS AND METHODS

Field research was conducted at the MU Drainage and Subirrigation (MUDS) site near Bethel, Missouri (39°56´ N, 92°3´ W) from 2002 to 2015 on a Putnam silt loam (fine, smectitic, mesic Vertic Albaqufs). Subsurface tile drainage treatments included drainage only (DO) and drainage plus subirrigation (DSI) drain tile spacings (6.1 and 12.2 m) compared to non-drained (ND) and non-drained, delayed planting (NDDP) controls. The ND control was planted at the same time the drainage treatments were planted, while the NDDP control was planted when the soil conditions were favorable for field operations. Subsurface tile drains (7.6 cm diameter) were installed in July 2001 at a 60 cm depth at 0.15% slope with a minimum flow velocity of 43 cm s⁻¹ and a drainage coefficient of 1.3 cm 24 h⁻¹. Subsurface tile drains with a 7.6 cm diameter and a shallow depth (60 cm) are not common throughout the Midwest; however, cost of the laterals was 25% less than 10 cm drainage tile at the time of installation and a 7.6 cm drainage tile had plenty of capacity to drain 6.1 or 12.2 m wide drainage tile laterals. In addition, the impermeable layer or claypan was approximately 50 to 60 cm deep at this location, but 60 cm of soil is recommended for the minimum backfill to prevent crushing of the subsurface drainage tile pipes. The subsurface drainage tile laterals were connected to a non-perforated 15 cm main with a 0.1% slope and drainage coefficient of 1.3 cm 24 h⁻¹. Other soil types throughout the Midwest may have a shallow fragipan or impermeable layer that may respond similarly to shallow claypan soils. Computer simulation research indicated the optimal spacing for a claypan soil similar to the soil series in this research in southern Illinois for subirrigation should be 6.1 m (Mostaghimi et al., 1985); however, no research had evaluated crop response due to the installation costs in the 1980’s. Plot size was 18 to 24 by 46 m during most years unless cultivars or management systems were evaluated and plot size was summarized in Nelson et al. (2012) or Nelson and Meinhardt (2011).

The site was arranged as a split-plot design with four replications. The main plots were DO or DSI and sub-plots were subsurface drainage tile spacing (ND, DO 6.1 m or 12.2 m, and DSI 6.1 m or 12.2 m). The DSI or DO main plot was either on the east or west side of the range and a non-drained control was included with each main plot. One of the non-drained controls was planted at the same time the drainage treatments were planted and the NDDP was planted when soils were favorable for planting (visual observation). The site was in a corn-soybean rotation with each crop represented each year (fig. 1). The sites were hydraulically isolated based on space between treatments and the split-plot arrangement of treatments. Lateral water movement did not affect adjacent plots (visual observations). Sub-sub-plots included five cultivars in 2007 and 2008 (Nelson et al., 2012) and five fungicide/insecticide management systems in 2009 and 2010 (Nelson and Meinhardt, 2011) (table 1). A representative randomization of DSI at 6.1 m for replication 1 is available in figure 1 for the sub-sub-plots. High yield practices have been implemented to maximize grain yields. Constant water table management (Belcher and D’Itri, 1995) was implemented to maintain a moist soil profile which allows capillary movement of water from the tile lines. It is the simplest management system for a DSI system which allows plants to do their own irrigation scheduling which works well for plants and water quality; however, root damage may occur in the presence of high rainfall events. Observation wells were installed and evaluated above and between the subsurface tile lines from 2003-2006 in soybean treatments. Methods and results were reported in Nelson et al. (2011) to evaluate the maintenance of the constant water table management. Selected soil and crop management practices are listed in table 1. All plots were maintained weed-free. Specific fungicide and insecticide amounts and timings are available (Nelson et al., 2011, 2012; Nelson and Meinhardt, 2011). Chlorpyrifos (O,O-diethyl O-3,5,6-trichloropyridin-2-ylphosphorothioate) was applied in 2005 and 2012 for control of two-spotted spider mites (Tetranychus urticae), while lambda-cyhalothrin [Ia(5°),3a(Z)]-(+)-cyano-(3-phenoxypyphenyl)methyl-3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethycyclopropa-carboxylate] was typically applied to control soybean aphids (Aphis glycines Matsumura) at threshold populations.

Plant populations (1 m of row), heights (three plants location⁻¹), and grain yield were determined above the subsurface tile lines and 3.1 m distances from the subsurface drainage tile lines for laterals that were installed at 6.1 and 12.2 m drain tile spacings. Grain yields and moisture were determined using a Massey 10 (Haven, Kan.) or Wintersteiger Delta (Salt Lake City, Utah) combine equipped with a 152 cm wide grain head and a Harvest Master Master GrainGage (Logan, Utah). Tile lines and distances from the tile lines were manually marked at 3.1 m intervals prior to harvest. Previous research has evaluated mean yields and production characteristics (Nelson et al., 2011, 2012; Nelson and Meinhardt, 2011); however, this research evaluates the spatial differences in crop production and growth characteristics for all of the year-cultivar-management systems at 3.1-m distances from the subsurface tile lines.

Data from the 30 year-cultivar-management systems were analyzed using PROC UNIVARIATE and MIXED models using SAS (2016). Years, cultivars, and management systems were considered fixed while all other variables were considered random. The entire data set was analyzed and
then sorted by high (>3,360 kg ha⁻¹, N=17) and low (<3,360 kg ha⁻¹, N=13) yielding year-cultivar-management systems (Ciampitti and Roozeboom, 2014). Box plots were utilized to visualize the variability between distances from the tile lines. The box represents 50% of the data and the whiskers represent 95% of the data. An asterisk represents the mean and dotted line is the median. Means were separated using Fisher’s Protected LSD (P=0.1) and letters above the box plots indicate significant differences among treatments. Similar letters indicate no significant differences (P=0.1) between treatment means.

RESULTS AND DISCUSSION

Seeding amounts targeted from 395,200 to 494,000 seeds ha⁻¹ which is typical for the row spacing and anticipated production environments (Robinson and Conley, 2007) (table 1). The average plant population at harvest of the 30 year-cultivar-management systems was greatest (348,000 plants ha⁻¹) when soybean were planted 3.1 m from the tile lines with DO or DSI systems at a 6.1 m spacing (fig. 2A). When DO or DSI systems were utilized and subsurface drainage tiles were 6.1 m apart, plant populations were similar or greater than the plant population above the tile lines. Similarly, plant populations were greatest (348,000 to 353,000 plants ha⁻¹) between the tile lines compared to above the tile lines (0 m) when drainage tile lines were installed for DSI at 12.2 m. The greatest plant population variability as indicated by the box plots was the ND control, while the NDDP control had less overall plant population variability which was probably due to more favorable conditions for plant germination and growth. For the drainage systems, the greatest plant population variability occurred with DSI at a 6.1 or 12.2 m spacing 3.1 and 6.1 m from the subsurface tile drainage line, respectively, which resulted in a greater plant population between the subsurface drain tiles compared to above the subsurface drainage tile line. Interestingly, above the subsurface tile drainage line (0 m) for DSI at 12.2 m spacing the plant population was similar to the ND or NDDP controls which was probably due to wetter soil conditions during the growing season especially during extremely wet years which may have resulted in stand loss. At times, plant populations were below 247,000 plants ha⁻¹. In most soybean production environments, plant populations should be greater than 247,000 plants ha⁻¹ in order to optimize yields in 19 to 38 cm wide rows (Robinson and Conley, 2007). Early in this research, non-treated seed was planted (data not presented) which could affect plant stand establishment, especially during cool and wet conditions in the spring, but treated seed wasn’t utilized until after 2010. Root diseases in the non-treated control or DSI treatments along with early planted soybean in the presence of cool, wet soils (Melgar et al., 1994; Scherm and Yang, 1996; Schmitthenner, 2000) may be greater and could have contributed to the variability observed in the plant populations observed in this research. Soybean plant heights for the 30 year-cultivar-management systems were greatest (88 cm) with DSI at a 12.2 m spacing above the tile line (0 m) compared to all other spatial/lateral spacing treatments followed by DSI at 6.1 m above the tile lines (fig. 2B). Heights decreased and were generally more...
Table 1. Field information and selected management practices for soybean from 2002-2015 at the MUDS (MU Drainage and Subirrigation) site.

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<td>NT</td>
<td>NT</td>
<td>NT</td>
<td>CT</td>
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<td>38</td>
<td>19</td>
<td>19</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td>Planting date</td>
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<td>27 May</td>
<td>21 May</td>
<td>2 May</td>
<td>11 May</td>
<td>23 May</td>
<td>16 June</td>
<td>12 May</td>
<td>27 May</td>
<td>11 May</td>
<td>26 Apr.</td>
<td>17 May</td>
<td>8 May</td>
<td>5 July</td>
</tr>
<tr>
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<td>23 May</td>
<td>16 June</td>
<td>12 May</td>
<td>27 May</td>
<td>11 May</td>
<td>26 Apr.</td>
<td>17 May</td>
<td>8 May</td>
<td>5 July</td>
</tr>
<tr>
<td>Cultivar</td>
<td>Pioneer</td>
<td>Kruger</td>
<td>Kruger</td>
<td>Kruger</td>
<td>Kruger</td>
<td>Asgrow</td>
<td>3602</td>
<td>Kruger</td>
<td>382</td>
<td>Pioneer</td>
<td>93M96</td>
<td>NK S37-N4</td>
<td>NK S37-N4</td>
<td>Morsoy3636</td>
</tr>
<tr>
<td>Seeding rate (seeds/ha)</td>
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<td>494,000</td>
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<td>494,000</td>
<td>494,000</td>
<td>444,600</td>
<td>444,600</td>
<td>395,200</td>
<td>444,600</td>
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<td>Controlled drainage date(s)</td>
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<td>25 June</td>
<td>1 July</td>
<td>1 June</td>
<td>15 June</td>
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<td>6 July</td>
<td>5 July</td>
<td>3 May</td>
<td>26 June</td>
<td>2 June</td>
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<td>None</td>
<td>L-c, Ch</td>
<td>L-c</td>
<td>L-c</td>
<td>L-c</td>
<td>L-c</td>
<td>See below</td>
<td>See below</td>
<td>None</td>
<td>L-c, Ch</td>
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<td>Disease management</td>
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<td>None</td>
<td>None</td>
<td>None</td>
<td>Py</td>
<td>Py</td>
<td>Az</td>
<td>Norte, Py at R3[iv], R5, R3+R5, and R3+R5, and Py + L-c at R3+R5</td>
<td>Norte, Py at R3+R5, R5, R3+R5, and R3+R5, and Py + L-c at R3+R5</td>
<td>Norte, Py at R3+R5, R5, R3+R5, and R3+R5, and Py + L-c at R3+R5</td>
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<td>SOM ± SD (g kg⁻¹)[v][vi]</td>
<td>26 ± 2</td>
<td>20 ± 1</td>
<td>22 ± 2</td>
<td>27 ± 2</td>
<td>20 ± 1</td>
<td>18 ± 1</td>
<td>20 ± 1</td>
<td>21 ± 2</td>
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<td>17 ± 1</td>
<td>20 ± 2</td>
<td>23 ± 3</td>
<td>22 ± 3</td>
<td>20 ± 1</td>
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[v] Abbreviations: Az, Azoxystrobin (methyl (E)-2-[6-ethyl-2-cyanothiophene) pyrimidin-4-yl]oxophenyl]-3-methoxyacrylate); Ch, chlorpyrifos (O,O-di-ethyl-O-(3,5,6-trichloro-2-pyridinyl) phosphorothionate); CT, conventional tillage; L-c, Lambda-cyhalothrin ([1a(S),3a(Z)]-+)-cyan-o-(3-phenoxophenyl) methyl-3-(2-chloro-3,3,3-trifl uoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate); NT, no-till; NTC, non-treated control; Py, Pyraclostrobin (carbamic acid, [2,1][1-(4-chlorophenyl)-1H-pyrazol-3-yl][methyl][phenyl][methyl]-, methyl ester); SD, standard deviation; and SOM, soil organic matter.
[vi] Top 15 cm of soil combined over each replication.

Variable farther away (3.1 or 6.1 m) from the tile lines for all spacings except DO at a 6.1 m spacing. Soybean plant height has not been correlated with higher yields (Diondrea et al., 2008), but yield reductions can occur if plant lodging is present at high risk stages of reproductive development (Noor and Caviness, 1980; Wilcox and Sediya, 1981; Shapiro and Flowerday, 1987). No lodging data were collected from this location.

All subsurface drainage tile spacings (6.1 and 12.2 m) and distances from the tile lines for DO or DSI yielded 11% to 21% greater than the ND control (fig. 2C). Average grain yields were greatest (3,680 kg ha⁻¹) above the tile lines of DSI at a 6.1 m spacing and decreased the farther yields were determined from the tile lines for DSI at a 6.1 and 12.2 m spacing. However, yields increased and were more variable with DO at 6.1 and 12.2 m spacings the farther yields were recorded from the subsurface drainage tile lines. The greater variability of yields above the drain tiles was probably due to extreme weather events such as above average precipitation or drought. In order to explore the yield variability in more detail, data were grouped by low (<3,360 kg ha⁻¹) and high yielding (>3,360 kg ha⁻¹) environments. There were 17 year-cultivar-management systems in the low yielding category and 13 year-cultivar-management systems in the high yielding category (fig. 3).
The low yielding (<3,360 kg ha⁻¹) year-cultivar-management systems averaged over all treatments from lowest to highest were ranked: 2015, 2008-NK S37-N4, 2008-Pioneer 93M96, 2008-Asgrow 3602, 2002, 2012, 2008-Morsoy 3636, 2013, 2008-Kruger 382, 2009-fungicide at R3 and R5, and 2009-fungicide at R5, and 2009-fungicide at R3 (data not presented). In a low-yield environment, plant populations generally increased at distances farther from the subsurface drain tile with the greatest plant populations (346,000 to 368,000 plants ha⁻¹) between the subsurface drain tiles (3.1 or 6.1 m) (fig. 3A). Grain yields above the subsurface tile lines were greatest with DSI at 6.1 m (3,150 kg ha⁻¹) followed by DSI at 12.2 m (3,060 kg ha⁻¹), but these locations had the greatest yield variability in a low-yielding environment (fig. 3B). This variability was probably due to a high water table that was maintained during wet conditions which reduced yield and high yields that were obtained during years with drought. In other research, overhead irrigation plus subsurface drainage increased soybean yield 610 kg ha⁻¹ compared to a non-irrigated, non-drained control in southern Illinois, but overhead irrigation without subsurface drainage reduced yield 340 kg ha⁻¹ in a non-drained control indicating excessive water can be detrimental to soybean yields in claypan soils (Walker et al., 1982). Improved water management scheduling is needed for DSI systems because of a concern about resaturating dry soil and timely removal of water prior to large rainfall events. In addition, yield could have been affected by soil disturbance during installation which brought low-pH soil to the soil surface and was a concern in other research where liquid CaCO₃ was used during the installation process (Rausch et al., 1990). DSI at 6.1 and 3.1 m between the tile lines had high variability that skewed toward lower yields which was again attributed to possibly slower water removal and reduced lateral water movement in subirrigation mode as a result of extreme weather events during this period (table 2). A high water table level (0.15 m) can reduce soybean photosynthetic rates, stomatal conductance, and ultimately reduce yields compared to a lower (0.6 m) water table (Sarwar, 2002). All DO and DSI treatments had yields that were 9 to 20% greater than the ND control depending on the proximity to the drainage tile line which indicated the importance of the drainage component of these systems. Yields generally decreased as the distance from the subsurface tile lines for DSI increased with yield variability skewed toward higher yields above the drain tile and skewed toward lower

Figure 2. Plant population (A), height (B), and grain yield (C) response to drainage (DO) and drainage plus subirrigation (DSI) systems at 6.1 (6) and 12.2 (12) m subsurface drain tile spacings compared to the non-drained (ND) and non-drained, delayed planting (NDDP) controls. Measurements were collected above the tile (0 m from tile) and 3.1 m from the tile lines. Letters indicate significant differences between mean values (asterisk). Similar letters indicate no significant differences (P=0.1) between treatment means. The box plots represent 50% of the data points while the whiskers represent 95% of the data points. Dotted lines are the median.
yields between the drain tiles. However, yields were greater between the tile lines for DO at a 6.1 m spacing, while yields were similar with DO at a 12.2 m spacing with more variability between the drain tiles (6.1 m from the tile).

Variability at the low yielding sites was generally caused by extreme weather conditions (table 2). In 2015, planting date was delayed (table 1) for all treatments (5 July) because rainfall was 22.3 cm greater than the 15-year average during a typical planting period during May. This also occurred in 2008 when overall planting dates were delayed until 16 June, which was followed by precipitation that was 24.4 cm greater than the 15-year average during the early stages of soybean growth and development. Cultivars were affected by planting date and high precipitation during 2008 since five cultivars were evaluated that year. This could be due to differences in saturation tolerance among cultivars (VanToai

Figure 3. Plant population (A, C) and grain yield (B, D) response to drainage (DO) and drainage plus subirrigation (DSI) systems at 6.1 and 12.2 m subsurface drain tile spacings compared to the non-drained (ND) and non-drained, delayed planting (ND DP) controls for low (A, B, < 3360 kg ha−1) and high yield (C, D, > 3360 kg ha−1) environments. Measurements were collected above the tile (0 m from tile) and 3.1 m from the tile lines. Letters indicate significant differences between mean values (asterisk). Similar letters indicate no significant differences (P=0.1) between treatment means. The box plots represent 50% of the data points while the whiskers represent 95% of the data points. Dotted lines are the median.

Table 2. Precipitation during two week periods of the growing season for 2002 to 2015 and the average precipitation for the 15 years of this research.

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<th>Time Period</th>
<th>2002 (cm)</th>
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<th>2004 (cm)</th>
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<th>2010 (cm)</th>
<th>2011 (cm)</th>
<th>2012 (cm)</th>
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<th>2014 (cm)</th>
<th>2015 (cm)</th>
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<tr>
<td>1 to 15 April</td>
<td>3.2</td>
<td>4.4</td>
<td>1.2</td>
<td>3.0</td>
<td>1.8</td>
<td>5.6</td>
<td>6.3</td>
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<td>4.4</td>
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<td>16 to 29 April</td>
<td>12.7</td>
<td>9.3</td>
<td>4.6</td>
<td>1.8</td>
<td>0.2</td>
<td>5.0</td>
<td>5.4</td>
<td>6.7</td>
<td>10.2</td>
<td>6.6</td>
<td>5.4</td>
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<td>30 Apr to 13 May</td>
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<td>9.3</td>
<td>2.2</td>
<td>3.7[^a]</td>
<td>5.6[^a]</td>
<td>6.8</td>
<td>6.2</td>
<td>4.0[^a]</td>
<td>4.0</td>
<td>3.2[^a]</td>
<td>4.1</td>
<td>6.2</td>
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<td>14 to 27 May</td>
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<td>1.8[^a]</td>
<td>4.6[^a]</td>
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<td>7.2</td>
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<tr>
<td>28 May to 10 June</td>
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<td>7.2</td>
<td>5.6</td>
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<td>8.4</td>
<td>7.5</td>
<td>8.6</td>
<td>9.7</td>
<td>1.9</td>
<td>7.6</td>
<td>13.8</td>
<td>5.4</td>
<td>6.9</td>
</tr>
<tr>
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<td>2.3</td>
<td>1.8[^b]</td>
<td>4.2[^b]</td>
<td>1.5</td>
<td>4.9[^b]</td>
<td>7.3</td>
<td>8.2</td>
<td>3.0</td>
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<td>4.0</td>
<td>15.3</td>
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<tr>
<td>25 June to 8 July</td>
<td>0.7</td>
<td>4.1</td>
<td>3.6</td>
<td>0.3</td>
<td>2.5</td>
<td>2.1</td>
<td>16.1</td>
<td>3.0</td>
<td>6.7</td>
<td>7.8</td>
<td>0.0</td>
<td>1.6</td>
<td>7.7</td>
<td>19.0[^a]</td>
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</tr>
<tr>
<td>9 to 22 July</td>
<td>2.0</td>
<td>5.1</td>
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<td>0.3</td>
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<td>1.5</td>
<td>3.4</td>
<td>4.9</td>
<td>2.6</td>
<td>3.0</td>
<td>0.0</td>
<td>2.2</td>
<td>0.7</td>
<td>14.9</td>
<td>3.2</td>
</tr>
<tr>
<td>23 July to 5 Aug</td>
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<td>7.3</td>
<td>4.6</td>
<td>1.4</td>
<td>1.8</td>
<td>18.4</td>
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<td>1.8</td>
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<td>11.5</td>
<td>4.7</td>
</tr>
<tr>
<td>6 to 19 Aug</td>
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<td>1.2</td>
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<td>4.4</td>
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<td>20 Aug to 2 Sep</td>
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<td>12.8</td>
<td>19.2</td>
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<td>3.6</td>
<td>5.2</td>
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<td>13.4</td>
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<td>3.3</td>
<td>0.2</td>
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<tr>
<td>3 to 16 Sep</td>
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<td>7.7</td>
<td>1.1</td>
<td>2.6</td>
<td>1.0</td>
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<td>22.3</td>
<td>0.1</td>
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<td>0.7</td>
<td>17.0</td>
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<tr>
<td>17 to 30 Sep</td>
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<td>7.8</td>
<td>0.6</td>
<td>1.2</td>
<td>0.7</td>
<td>0.0</td>
<td>1.3</td>
<td>8.5</td>
<td>12.1</td>
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<td>1.7</td>
<td>5.8</td>
<td>0.1</td>
<td>0.2</td>
<td>3.1</td>
</tr>
</tbody>
</table>

[^a] Planted during this period.
[^b] The amount of subirrigation water was measured and reported in 2004, 2005, and 2006 (Nelson et al., 2011).
et al., 1994) as well as a cultivar’s response to irrigation (Korte et al., 1983). This indicates that cultivar selection is important for helping mitigate plant stress due to saturated conditions. If the DSI system had been maintained in drainage mode throughout 2008, this may have helped reduce the variability observed above the tile lines with DSI. The systems were maintained in drainage mode throughout 2015, due to extensive precipitation, in order to minimize the effects of saturated conditions on soybean yield, but overall yields were already reduced due to a delayed planting date. In 2009, precipitation was 14.3 cm above average from planting until mid-August, but differences among fungicide treatments were observed which were due to a reduction in the severity of disease that was present and a synergistic increase in yield with the drainage and disease/insect management systems (Nelson and Meinhardt, 2011). On the other end of the spectrum, drought conditions lowered overall yields in 2002 (precipitation 14.5 cm below average from planting until harvest), 2005 (precipitation was 28.3 cm below average from planting until harvest), 2007 (precipitation was 25.5 cm below average from planting until harvest), 2012 (precipitation 24.6 cm below the average from planting until early September), and 2013 (precipitation was 10.7 cm below average from planting until harvest). During this research, 2012 and 2013 were classified as extreme and severe droughts, respectively (USDM, 2015). In addition, higher than normal air temperatures can exacerbate the effects of low precipitation (data not presented). During these years (2002, 2005, 2007, 2012, and 2013), grain yields above the subsurface drainage tile lines were 43% greater than 3.1 m from the tile line, but yields were 89% greater than the non-drained control (data not presented). In 2007, some cultivars were higher yielding indicating a difference in drought tolerance among cultivars that were tested and reported in other research (Sinclair et al., 2007). In 2005 and 2012, chlorpyrifos was applied to manage two-spotted spider mites (Tetranychus urticae Koch.). Spider mites are common during drought conditions which can further reduce yields (Cullen and Schramm, 2009). Spider mites were more prolific in the DO, ND controls, and between the DSI tile lines (3.1 or 6.2 m) compared to above the DSI tile lines (0 m) (personal observation). Late-season precipitation (table 2) can increase grain fill of soybean (R5-R6), but the effects of drought on flower abortion and poor seed fill had already reduced overall yield potential (Korte et al., 1983).

The high yielding (>3,360 kg ha\(^{-1}\)) year-cultivar-management systems, averaged over drainage treatments, were ranked from lowest to highest: 2007-Asgrow 3602, 2007-Morsoy 3636, 2009-fungicide + insecticide at R3 and R5, 2007-Kruger 382, 2011, 2010-no fungicide or insecticide, 2006, 2010-fungicide at R3, 2010-fungicide at R5, 2004, 2010-fungicide at R3 and R5, 2010-fungicide + insecticide at R3 and R5, and 2014. Median plant populations of DO or DSI treatments for high yielding environments at harvest were greater than 248,000 plants ha\(^{-1}\) except for the non-drained controls (fig. 3C). Similarly, average plant populations were greater than the ND control. This probably lowered the overall yield potential of the non-drained controls especially in a high yielding environment. The greatest plant populations were observed 3.1 m from the tile lines spaced 6.1 m apart. Plant populations that were less than 260,000 plants ha\(^{-1}\) could have reduced yields especially in high yield environments while research has reported that up to 370,000 plants ha\(^{-1}\) could be required to maximize yields (Ciampitti and Roozeboom, 2014). Unexpectedly, grain yields usually increased the farther away from the tile lines than the yields above the tile lines (0 m) for DO. Yields had less variability as indicated by the box plots with DSI above the 6.1 or 12.2 m spaced drain tiles compared to the other treatments while yields above the subsurface drain tiles were 200 to 780 kg ha\(^{-1}\). Greater than between the drainage lines. All drainage treatments increased average yields 200 to 640 kg ha\(^{-1}\) compared to the ND or NDDP controls. In a high-yield soybean production system in Ohio, DSI with tile lines on 6.1 m spacings increased soybean yields 1610 kg ha\(^{-1}\) compared to a non-irrigated control on soils with a fragipan that was 36 to 76 cm deep (Cooper et al., 1992) and reached a yield potential of over 5380 kg ha\(^{-1}\) in the 1980’s (Cooper et al., 1991). There were a few times yields reached this yield potential as indicated by DO at a 12.2 m spacing 6.1 m between the tiles. In the high yielding environments, precipitation was generally above average or below average following planting (table 2), but this was commonly followed by timely precipitation events throughout the summer months. For instance, precipitation in 2004 and 2011 was average from planting until early Sep.; precipitation in 2006 was dry in the spring followed by average precipitation through the summer; 2014 had average early season precipitation with moderate summer temperatures (data not presented) followed by timely precipitation during R5 and R6; and cultivar selection was a factor that affected yields in 2007 (Nelson et al., 2012, Cooper et al., 1992). While 2011 was classified as abnormally dry (USDM, 2015), late season precipitation helped mitigate the impact of these conditions on yields. Soybean are typically at R5 in early September (visual observation). Precipitation following this period is important for seed fill until R6 (green bean stage) (Korte et al., 1983). Although precipitation was generally above average in 2009, a split application (R3 and R5) of a fungicide and insecticide shifted this treatment into the high yielding data group due to added management which synergistically increased yields due to disease protection and control of soybean aphid (Aphis glycines Matsumura) (Nelson and Meinhardt, 2011).

There are several factors that could affect the yield potential and variability observed in this research for the ND and NDDP controls compared to distances from the tile lines of DO or DSI. For instance, planting date for the four of the 30 year-cultivar-management systems was delayed 4 to 14 d (table 1). Planting date has been reported to reduce soybean yield (0.7% d\(^{-1}\)) in the Midwestern United States starting around 30 May (Egli and Cornelius, 2009). Only 6 of the 30 year-cultivar-management systems evaluated had conventional tillage prior to planting soybean while the other 24 year-cultivar-management systems were no-till planted. Prior to planting corn at this site, the soil is typically chisel-plowed perpendicular to the tile lines followed by a disk-field cultivator-harrow single-pass, multi-purpose tillage implement (Tilloll 875, Marysville, Kan.). Such tillage prior to

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soybean could improve lateral water flow during free drainage or subirrigation. All treatments were fertilized so nutrients weren’t limiting; however, grain yield nutrient removal differences may cause soil fertility to vary over time. Shallow water table depths (40 cm) had the highest yields in Ohio (Cooper et al., 1992); however, water level depths could have been shallower in this research due to managing the system with a constant water level in order to maximize capillary movement of water laterally from the subsurface drainage tile. Drought or saturated soil conditions in corn could contribute additional N to the soybean crop the following year (Nelson et al., 2009), which could affect soybean yields the following year. An increase in soybean yields from rescue N applications in corn occurred when corn was saturated for seven days (Kaur et al., 2017). Nitrogen may have leached through the drain tile and was available to the soybean crop between the drain tiles since the claypan can have leached through the drain tile and was available to the saturated for seven days (Kaur et al., 2017). Nitrogen may have leached through the drain tile and was available to the soybean crop between the drain tiles since the claypan can reduce deep leaching of N (Blevins et al., 1996). Narrower subsurface drain tile spacings (4 m) were recommended for a claypan soils based on yields and visual observations of alfalfa with DSI on a 15 m drainage tile spacing (Raush et al., 1990). Although DRAINMOD indicated the optimal spacing for a claypan soil for subirrigation should be 6.1 m (Mostaghimi et al., 1985), narrower drainage tile spacings could help reduce soybean grain yield variability above and between the subsurface tile lines during extremely dry years and help remove water in a more timely fashion when rainfall events occur during critical periods affecting soybean grain yield.

**CONCLUSION**

Field research evaluating 30 year-cultivar-management systems on a claypan soil from 2002-2015 showed that the variability of plant populations, heights and grain yields was affected spatially by the distance from the subsurface drainage tile line. DSI at a 6.1 m spacing yielded 20% greater than the ND control. Averaged over all of the 30 year-cultivar-management treatments, the highest yields (4,050 kg/ha) were observed above the DSI drainage tile line at a 6.1 m spacing, and yields decreased the farther yields were determined from the tile lines for DSI at a 6.1 and 12.2 m spacing. However, yields increased and were more variable with DO at 6.1 and 12.2 m spacings the farther yields were determined from the subsurface drainage tile lines. In drought years (2005, 2007, 2012, and 2013), grain yields above the subirrigation/drainage tile lines were 43% greater than 3.1 m from the tile line, but yields were 89% greater than the non-drained control. In low yielding environments, extreme weather events, such as above average precipitation and droughts, contributed to a reduction in plant populations in the ND controls and greater yield variability above and between the drainage tiles. In high yielding environments, yields with DO were greatest between the 6.1 or 12.2 m drain tile spacings while yields were greatest above the tile lines with DSI. A narrower drain tile spacing may be needed to reduce yield variability in a claypan soil when yields are less than 3,360 kg/ha, but this was less evident in higher yielding environments. Additional research is needed to determine the cost-effectiveness of drain tile spacings less than 6.1 m for claypan soils.

**ACKNOWLEDGEMENTS**

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**REFERENCES**


**NOMENCLATURE**

DO: drainage only

DSI: drainage plus subirrigation

HYE: high yield environment

LYE: low yield environment

YCM: year-cultivar-management