Pearl Millet as a Rotation Crop for Peanut

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Abstract
In the southeastern United States, there are limited options for crops that can be grown in rotation with peanut (Arachis hypogaea). Pearl millet (Pennisetum glaucum) has potential as a grain crop, and some hybrids have shown resistance to the peanut root-knot nematode (Meloidogyne arenaria), the primary nematode pest of peanut in this region. The objective of this study was to determine whether pearl millet reduces M. arenaria when planted in rotation with peanut. The experiment was arranged as a randomized, complete-block design with six replications. The rotations were peanut following either 2 years of corn, HGM-100 pearl millet, or TifGrain 102 pearl millet. There were two staggered sequences of each rotation so that a cycle was completed in 2004 and in 2005. Pearl millet did not increase either stem rot or Rhizoctonia limb rot in peanut. In both years, root galling from M. arenaria was lower on peanut following TifGrain 102 (4.6 on a scale of 0 to 10) and corn (4.9) than following HGM-100 (7.5). Peanut yields in 2004 were low and unaffected by the preceding rotation crop; however, in 2005, yields were greater in peanut following 2 years of TifGrain 102 (2320 kg/ha) and corn (2504 kg/ha) than following HGM-100 (1821 kg/ha). The lower yields following HGM-100 were likely due to greater populations of M. arenaria that had developed on the susceptible pearl millet hybrid. Economic analyses showed greater returns above variable costs from the grain crops than from the peanut crops. We conclude that the resistant pearl millet hybrid TifGrain 102 is as effective as corn in limiting population increase of M. arenaria and in enhancing peanut yield compared to the susceptible pearl millet hybrid, HGM-100. Additional research is needed to improve the profitability of pearl millet, and nematode resistance should be an important component of crop improvement programs.

Introduction
Yield of peanut (Arachis hypogaea) is typically higher when it is grown in rotation with other crops than when it is continuously cultivated. Improvements in peanut yield following rotation have been associated with suppression of the peanut root-knot nematode (Meloidogyne arenaria) and soilborne diseases such as stem rot caused by Sclerotium rolfsii and Rhizoctonia limb rot caused by Rhizoctonia solani (7,12,13,14). Rotations for suppression of plant-parasitic nematodes and diseases must include one or more years of a poor host plant for pathogen reproduction. In the southeastern United States, there are limited options for crops that can be grown in rotation with peanut. Growers commonly rotate peanut with cotton (Gossypium hirsutum) and corn (Zea mays). Cotton is a nonhost and corn is a poor host for M. arenaria (1). Alternative rotation crops for peanut are needed, particularly crops that require few irrigation and nitrogen inputs.

Pearl millet (Pennisetum glaucum) has potential as a grain crop in the southeastern United States (Fig. 1). Unlike corn hybrids, pearl millet tolerates drought and low fertility conditions, thus requiring few irrigation and fertilizer inputs, and is not susceptible to pre-harvest aflatoxin contamination (11,16,19). The primary use of pearl millet grain in the United States is as a feed for livestock, poultry, and wild birds (5,9,10,15,17).
Pearl millet hybrids vary in their host status for *Meloidogyne* spp. For example, several grain hybrids were reported to be resistant to both *M. arenaria* and the southern root-knot nematode, *M. incognita*; however, HGM-100 was susceptible to the nematodes (18). Tift 454, used as a pollinator of Tift 99D1A1 to produce the grain hybrid TifGrain 102, confers resistance to *Meloidogyne* spp. (3,4). The objectives of this study were to determine whether pearl millet reduces the peanut root-knot nematode *M. arenaria* when planted in rotation with peanut, to determine if rotations with pearl millet affects stem rot in peanut caused by *S. rolfsii* and Rhizoctonia limb rot caused by *R. solani*, and to evaluate the economics of the rotation sequences.

**Comparing Pearl Millet to Corn as a Rotation Crop for Peanut**

The study was initiated in 2002 on the Gibbs Farm at the Coastal Plain Experiment Station, Tifton, Georgia. The soil was a Tifton loamy sand (85% sand, 10% silt, 5% clay; 0.5% organic matter) naturally infested with *M. arenaria* race 1, *S. rolfsii*, and *R. solani*. The field had previously been planted with peanut in the summer and hairy vetch (*Vicia villosa*) in the winter. Prior to planting, the soil was disc-harrowed, turned to a depth of 20 to 25 cm with a moldboard plow, and shaped into beds 1.8 m wide and 10 to 15 cm high. Plots were three beds wide and 9.1 m long. Data were collected from only the center bed. The experiment was arranged as a randomized, complete-block design. All treatments were replicated six times. Replications (blocks) were separated by 7.6-m alleys. The rotations were peanut (P) following either two years of corn (C-C-P), HGM-100 pearl millet (H-H-P), or TifGrain 102 pearl millet (T-T-P). There were two staggered sequences of each rotation so that a cycle was completed in 2004 and in 2005 (e.g., C-C-P-C and P-C-C-P).

Corn (Pioneer 3223) was planted at 4.6 seed/m row on 2 May, 1 May, 7 May, and 16 May in 2002, 2003, 2004, and 2005, respectively. Peanut (Georgia Green in 2002 and 2004, and Georgia-02C in 2005) was planted at 19.7 seed/m row on 7 May, 11 May, and 15 May in 2002, 2004, and 2005, respectively. No peanut was planted in any of the cropping sequences in 2003. Pearl millet was planted at 32.8 seed/m row on 23 May, 3 June, 8 June, and 20 June in 2002, 2003, 2004, and 2005, respectively. Cultural practices, fertilization, and pest management for the peanut, corn, and pearl millet crops were based on recommendations for the area (2,8,9). The primary exception was that irrigation is generally not recommended for pearl millet, but the entire experimental area was irrigated as required to maintain the corn and peanut. The peanuts were dug and inverted based on an optimum maturity index on 11 September, 20 September, and 4 October in 2002, 2004, and 2005, respectively. The pods were harvested with a combine when their moisture content was about 14%, and then dried to about 8% before yield weight was determined. Corn was harvested when the kernel moisture content was < 15% on 26 September, 10 September, 23 September, and 26 September in 2002, 2003, 2004, and 2005, respectively. Grain yields were adjusted to 15.5% moisture. To determine yield of pearl millet, 10 to 20 representative grain heads per plot were bagged after pollination to prevent bird damage. The bagged heads were harvested on 20 September, 3 September, 24 August, and 28 September in 2002, 2003, 2004, and 2005.
respectively. The heads were dried in a forced-air oven (38°C) for 4 days, and the grain was machine-threshed and bulked by plot. Grain yield at 11% moisture content was determined by multiplying the average seed weight per head by the total heads per plot.

At planting and harvest, 10 soil cores (2.5-cm diameter × 15-cm deep) were collected from each plot for extraction of *M. arenaria* second-stage juveniles. The 10 soil samples were combined, and the nematodes were extracted from a 150-cm³ subsample by centrifugal flotation (6). The at-plant soil samples were collected at the same time for all the crops; however, the at-harvest samples were collected within a week of harvest (or digging) of each crop. For the peanut crop, galling indices, incidence of stem rot, and severity of Rhizoctonia limb rot were determined for each plot immediately after the plants were inverted. Roots, pods, and pegs from 10 plants per plot were examined for galls of *M. arenaria* and rated on a scale of 0 to 10 based on the percentage of the root system with galls: 0 = no galls; 1 = 1% to 10%; 2 = 11% to 20%; etc. Stem rot incidence was based on the number of disease loci per 15.2 m row, where a locus represents one or more plants in 30 cm of row with signs or symptoms of *S. rolfsii*. Rhizoctonia limb rot severity on peanut stems and leaves was visually estimated for the entire plot (0 to 100%). Because Tomato spotted wilt virus (TSWV) severely affected the peanut crop in 2004, we determined the incidence of symptoms 26 and 22 days before digging in 2004 and 2005, respectively. The TSWV ratings were based on the number of plants in 0.3-m sections of row that were severely stunted and chlorotic. All disease ratings were converted to percentage of row length.

Analysis of variance (ANOVA) was used to determine the effect of crop rotation on peanut yield, root galling, incidence of soil-borne disease, and nematode numbers in soil (SAS Institute Inc., Carey, NC). Prior to analysis, nematode numbers were transformed by square root. When ANOVA indicated a significant (*P* ≤ 0.05) effect of rotation, then Fisher’s LSD test was used to separate the means.

The net return above variable costs (RAVC) for the rotation sequences was calculated as crop income minus variable costs. Variable costs included all cash operating expenses such as seed, fertilizer, lime, pest control, irrigation, fuel, equipment repairs, labor, interest on expenses, and drying, as outlined in crop production budgets for Georgia. Crop income was calculated as the average yield for each treatment multiplied by the average price received by Georgia farmers for the crop in each year. Prices received by growers for pearl millet vary based upon its value to the specific end-users, and no documentation by state or federal agencies exist. The shadow price value of the nutrient composition for poultry rations averages 15% over the value of corn. A floor value of 10% over the price of corn, and a test weight of 56 lb/bu were used for these economic analyses.

**Nematode Damage and Disease Severity**

At the start of the experiment, the field site was heavily infested with *M. arenaria*. Soil densities of second-stage juveniles averaged 168/100 cm³ of soil in the spring of 2002. The peanuts planted the first year were severely galled by root-knot nematodes at the end of the season, with an average root-gall index of 9.4 on a 0-to-10 scale. In the fall of 2003 and the spring of 2004, soil densities of *M. arenaria* were not different in plots that had been planted with 2 years of TifGrain 102, HGM-100, or corn (Table 1). However, nematode densities in fall of 2004, after the peanut crop, were greater in the rotation with HGM-100 than in the rotation with corn. In the second rotation sequence that ended with peanut in 2005, nematode densities did not differ among the rotations in either the spring or the fall. Compared to peanut, nematode densities were considerably lower in the fall following the pearl millet and corn crops. In both 2004 and 2005, root galling from *M. arenaria* was lower on peanut following TifGrain 102 and corn than following HGM-100 (Fig. 2).
Table 1. Soil densities of *Meloidogyne arenaria* second-stage juveniles in three different rotations involving peanut, pearl millet, and corn.

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Fall 2003</th>
<th>Spring 2004</th>
<th>Fall 2004</th>
<th>Spring 2005</th>
<th>Fall 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-T-P&lt;sup&gt;x&lt;/sup&gt;</td>
<td>7&lt;sup&gt;z&lt;/sup&gt;</td>
<td>5</td>
<td>577</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>T-T-P&lt;sup&gt;y&lt;/sup&gt;</td>
<td>—</td>
<td>—</td>
<td>2</td>
<td>5</td>
<td>761</td>
</tr>
<tr>
<td>H-H-P</td>
<td>15</td>
<td>11</td>
<td>685</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>H-H-P</td>
<td>—</td>
<td>—</td>
<td>12</td>
<td>2</td>
<td>1058</td>
</tr>
<tr>
<td>C-C-P</td>
<td>23</td>
<td>2</td>
<td>398</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>C-C-P</td>
<td>—</td>
<td>—</td>
<td>79</td>
<td>11</td>
<td>563</td>
</tr>
</tbody>
</table>

<sup>x</sup> Rotations were 2 years of either TifGrain 102 (T), HGM-100 (H), or corn (C) followed by peanut (P).

<sup>y</sup> There were two staggered sequences for each rotation: the 3-year rotation ended with peanut in 2004 in sequence 1 and with peanut in 2005 in sequence 2.

<sup>z</sup> Number of *M. arenaria* in 100 cm³ of soil starting in the fall of the second year of the rotation. Means in a column followed by the same letter are not significantly different, *P* < 0.05.

Even though we were unable to see a difference in soil populations of the nematode following the different rotation crops, corn and TifGrain 102 reduced root-galling on peanut compared with HGM-100 (Fig. 2). Variation in the nematode data from the soil tended to be greater than the gall-index data which may explain our inability to detect differences among the rotation crops. The coefficients of variation ranged from 14 to 49 for root-gall indices and 43 to 245 for nematode densities in soil. TifGrain 102 was equivalent to corn in reducing root galling from *M. arenaria* in the subsequent peanut crop. This supports a previous greenhouse study showing that reproduction of *M. arenaria* was similar on corn and TifGrain 102 (= hybrid 120 × 117) (17). In the same greenhouse study, nematode reproduction was 3- to 14-fold greater on HGM-100 than on the corn hybrid Pioneer 3146. The relative status of HGM-100 as a host for *M. arenaria* compared to peanut is unknown; however, fall densities of *M. arenaria* were considerably greater following the peanut crop than following HGM-100 suggesting that peanut is the better host (Table 1).
Disease ratings of stem rot and Rhizoctonia limb rot in peanut were not affected by rotation crop in either 2004 or 2005. The average percentage of row affected by *S. rolfsii* was 14.1 and 7.0 in 2004 and 2005, respectively. The average severity of Rhizoctonia limb rot was 5.7% in 2004; no limb rot was observed in 2005. In 2004, TSWV was severe in ‘Georgia Green’ peanut with 54.6% of the row affected by the virus. In 2005, ‘Georgia-02C’ was planted because it is more resistant than ‘Georgia Green’ to TSWV, and in this year 20.5% of the row was affected by the virus. There was no influence of rotation crop on the incidence of TSWV in peanut.

**Yields of Peanut Following Pearl Millet and Corn**

The yield of peanut in 2002 was 676 kg/ha. These extremely low yields were primarily due to heavy damage from *M. arenaria*. Peanut yields in 2004 were also low and unaffected by the preceding rotation crop (Fig. 3). In 2005, yields were higher than in 2004, and were greater in peanut following 2 years of TifGrain 102 and corn than following HGM-100. The lower peanuts yields following HGM-100 were likely due to greater densities of *M. arenaria* that had developed on the susceptible pearl millet hybrid. It is unclear why there was no yield suppression of peanut following HGM-100 in 2004. Similar yield suppression in 2004 and 2005 was expected given that root galling in peanut was 30% greater following HGM-100 than following TifGrain 102 in both years. Perhaps the heavy yield loss in 2004 from TSWV masked the effects of the nematodes. Although rotations with corn and TifGrain 102 reduced root galling in peanut compared to rotations with HGM-100, galling was heavy enough to cause peanut yield losses in all the rotations.

Average yield of the grain crops in metric tons/ha in 2002, 2003, and 2004, respectively were as follows: corn (at 15.5% moisture) was 9.1, 9.9, and 9.8; TifGrain 102 (at 11% moisture) was 6.6, 2.2, and 5.0; and HGM-100 (at 11% moisture) was 5.3, 3.0, and 3.7. None of the rotations provided an acceptable RAVC (Table 2). RAVCs were more variable across years for pearl millet compared to corn. The average RAVC over years was $11.62/ha for HGM 100 pearl millet, $15.44/ha for Tifgrain 102 pearl millet, $17.10/ha for corn, and - $67.72/ha for peanut. Actual returns for growers of pearl millet are often supplemented by paid dove shoots after harvest, and baling the residue for low-quality maintenance hay. The combined effects of the nematodes and TSWV caused peanut yields to be lower than the state average of 3360 and 3214 kg/ha for 2004 and 2005, respectively. This was the major factor contributing to the negative RAVC for peanut.
Table 2. Return above variable costs ($/ha) in three different rotations involving peanut, pearl millet, and corn in soils heavily infested with *Meloidogyne arenaria*.

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Return above variable cost (RAVC) by year</th>
<th>RAVC by rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2002</td>
<td>2003</td>
</tr>
<tr>
<td>T-T-P x</td>
<td>$72.24</td>
<td>-$14.47</td>
</tr>
<tr>
<td>T-T-P y</td>
<td>—</td>
<td>-$17.74</td>
</tr>
<tr>
<td>H-H-P</td>
<td>$47.28</td>
<td>-$1.37</td>
</tr>
<tr>
<td>H-H-P</td>
<td>—</td>
<td>-$0.28</td>
</tr>
<tr>
<td>C-C-P</td>
<td>$25.50</td>
<td>$21.89</td>
</tr>
<tr>
<td>C-C-P</td>
<td>—</td>
<td>$24.47</td>
</tr>
</tbody>
</table>

**Summary**

Corn is widely regarded as a compatible rotation crop for peanut in the southern United States. We showed that the resistant pearl millet hybrid TifGrain 102 is as effective as corn in limiting the population increase of *M. arenaria* and in reducing peanut yield losses. Moreover, pearl millet does not appear to increase soilborne diseases in peanut. Had we compared these rotations to continuous peanut, the yield benefit to peanut when rotated with corn or TifGrain 102 would probably have been greater than what we observed with HGM-100. *Meloidogyne arenaria* reproduces on both corn and TifGrain 102; however, they are relatively poor hosts for nematode reproduction. The pearl millet hybrid HGM-100 supports greater reproduction of *M. arenaria* than corn or TifGrain 102 which can result in lower yield of the subsequent peanut crop. The lower peanut yields following HGM-100 than following TifGrain 102 demonstrates the importance of incorporating resistance to *M. arenaria* in pearl millet hybrids if this crop is grown in peanut cropping systems.

**Acknowledgments**

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**Literature Cited**