Increasing Crop Rotation Diversity Improves Agronomic, Economic, and Environmental Performance of Organic Grain Cropping Systems at the USDA-ARS Beltsville Farming Systems Project

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Despite increasing interest in organic grain crop production, there is inadequate information regarding agronomic, economic and environmental performance of organically produced grain crops in the US, especially in the Coastal Plain soils of the mid-Atlantic region. The Beltsville Farming Systems Project (FSP), a long-term cropping systems experiment, was established in Maryland in 1996 to address these needs. The project includes three organic and two conventional cropping systems (Table 1). It is the only long-term project in the US that includes three organic cropping systems that differ in crop rotation length and complexity. Research results from this project show that increasing cropping system diversity improves agronomic, economic, and environmental performance of organic grain cropping systems.

Crop Yield
Corn grain yield in a six-year rotation (Org6), which includes summer annual (corn, soybean), winter annual (winter wheat), and herbaceous perennial (alfalfa for three years) cash crops was, on average, 10% greater than in a three-year rotation (Org3) that includes only summer and winter annual cash crops, and 30% greater than in a two-year rotation (Org2) that includes only summer annual cash crops (Table 1). These differences, which represent results for the first 10 years of the project, were the result of both increases in N availability and decreases in weed competition as crop rotation length and complexity increased (4,9,10). As a point of reference, mean corn yield for the two conventional systems during this same time period, which included substantial drought years, was 126 bu/acre, which is 29% greater than for Org6.
Table 1. Cropping systems in the USDA-ARS Beltsville Farming Systems Project.

<table>
<thead>
<tr>
<th>System</th>
<th>Crop rotation w/cover crops</th>
<th>Years in rotation</th>
<th>Tillage</th>
<th>Fertility</th>
<th>Mean poultry litter application rate (tons/acre/year)</th>
<th>Weed control</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-till (NT)</td>
<td>Corn-rye-Soybean-Wheat-Soybean</td>
<td>3</td>
<td>None</td>
<td>Mineral fertilizers</td>
<td>NA</td>
<td>Herbicide</td>
</tr>
<tr>
<td>Chisel Till (CT)</td>
<td>Corn-rye-Soybean-Wheat-Soybean</td>
<td>3</td>
<td>Chisel, Disk</td>
<td>Mineral fertilizers</td>
<td>NA</td>
<td>Herbicide</td>
</tr>
<tr>
<td>Organic, 2-year (Org2)</td>
<td>Corn-rye-Soybean-vetch</td>
<td>2</td>
<td>Moldboard plow, Chisel, Disk, Rotary hoe, Cultivator</td>
<td>Legume and animal manure</td>
<td>1.0</td>
<td>Cultural</td>
</tr>
<tr>
<td>Organic, 3-year (Org3)</td>
<td>Corn-rye-Soybean-Wheat-vetch</td>
<td>3</td>
<td>Moldboard plow, Chisel, Disk, Rotary hoe, Cultivator</td>
<td>Legume and animal manure</td>
<td>1.3</td>
<td>Cultural</td>
</tr>
<tr>
<td>Organic, 6-year (Org6)</td>
<td>Corn-rye-Soybean-Wheat-Alfalfa-Alfalfa-Alfalfa</td>
<td>6</td>
<td>Moldboard plow, Chisel, Disk, Rotary hoe, Cultivator</td>
<td>Legume and animal manure</td>
<td>0.7</td>
<td>Cultural</td>
</tr>
</tbody>
</table>

**Weed Pressure**

In Org2, opportunities to kill weeds occur at the same time each year since the two cash crops, corn and soybean, are planted at similar times. Thus, summer annual weeds (primarily *Amaranthus* spp., *Chenopodium album*, *Daturum stramonium*, *Setaria* spp., and *Abutilon theophrasti*) that escape weed management practices in these summer crops increase populations in this system. When wheat is added to the rotation (Org3), the summer annual weeds either do not germinate under the wheat canopy or do not reach reproductive maturity as they are cut prior to setting seed when the wheat is harvested, and killed when soil is prepared for planting cover crops after wheat harvest. In Org6, a perennial forage crop, alfalfa, provides an additional level of phenological complexity that provides further weed control opportunities. Alfalfa is cut three to five times per year, a disturbance regime that tends to favor perennial and annual grasses with a prostrate growth habit rather than annual broadleaf weeds. Tillage prior to corn planting provides control of the grasses favored during the alfalfa phase of the rotation. Corn yield loss to weeds, as measured in adjacent weed-free and weedy plots, was reduced from 35% in Org2 to 14% in Org6 (9).

**Economic Performance**

When organic price premiums for corn, soybean, and wheat were included in an economic analysis for the years 2000 to 2002, net returns for the three organic systems were similar (mean, $286/acre) and substantially higher than for the conventional systems (mean, $78/acre). Economic risk, however, was 7.5 and 3.9 times greater for Org2 and Org3, respectively, than for Org6 (2), indicating a substantial economic benefit to more phenologically diverse crop rotations, as risk is spread over crops growing and harvested during different parts of the year. Mean risk for the two conventional systems was similar to that for Org2.
Soil Organic Carbon

Soil organic C (SOC) to a depth of 40 inches was 10% greater in the organic systems (mean, 27.0 T C/acre) than in no-till (NT) (24.5 T C/acre) and 17% greater than in chisel-till (CT) (23.1 T C/acre) after 11 years [(1), and unpublished]. While SOC in surface soils (0 to 2-inch depth) was 18% greater in NT than in the organic systems, SOC at 2-4 and 10 to 20 inch depths was 13-16% greater in the organic systems than in NT. At the 4 to 10 inch depth increment, SOC was 27% greater in the organic systems than in NT. Burying C inputs thus protected SOC from losses that likely occur near the soil surface with repeated tillage in the organic systems. By contrast, SOC in the surface of NT systems is susceptible to loss if or when tillage is resumed (5). Since the majority of farmers using NT do not use continuous NT (7), results from continuous NT research sites such as FSP represent an upper limit to C sequestration levels likely achieved on-farm in the absence of manure inputs.

Soil Nitrogen

Greater soil organic C was associated with greater soil organic N. In addition, N mineralization potential in the organic systems was, on average, 34% greater than in NT after 14 years. In 2009, this increase in soil fertility resulted in up to 54% higher corn grain yields in the organic than the NT systems in weed-free microplots to which no exogenous N was added that year (8). These results illustrate the positive residual impact of organic management on soil fertility.

Nutrient Management

Increasing crop phenological diversity can benefit soil nutrient management. While N mineralization potential, particulate organic matter N, and SOC were similar among the three organic systems and all were greater than in CT and NT (8), these benefits were attained in Org6 with substantially fewer inputs of poultry litter than in the two shorter organic rotations (Org2 and Org3). During a six-year time period, typical poultry litter application rates were 6.0, 8.0, and 4.0 T/acre in Org2, Org3, and Org6, respectively. In addition, phosphorus (P) removal in harvested crops was greater in Org6 than Org2 and Org3 such that soil test P was 21% lower in Org6 (55 mg/kg Mehlich 3 extractable P) than in Org2 and Org3 (70 mg/kg Mehlich 3 extractable P) after 16 years (3). Thus, the possibility of overloading soils with phosphorus, an important concern in many watersheds, especially when animal manures are applied, was reduced considerably with Org6 compared to the shorter organic rotations.

Soil Erosion

Increasing crop phenological diversity also substantially decreased predicted soil erosion among organic systems. Predicted soil loss by erosion was reduced by 40% and 62% in Org3 and Org6, respectively, compared to Org2 when the Revised Universal Soil Loss Equation, Version 2 (RUSLE2) was applied to these systems (3). When compared using the Water Erosion Prediction Model (WEPP), predicted soil erosion was lower in Org3 than CT by 33% but NT reduced soil erosion an additional 54% (6).

In summary, increasing crop rotation length and complexity among organic systems—especially when perennial forages are included—increased corn grain yield and economic stability while reducing weed pressure, predicted soil erosion, animal manure inputs, and soil P loading. While crop yields were lower and predicted soil erosion was greater in organic than conventional systems, net returns, SOC, and soil fertility were all greater in organic than conventional systems.
Literature Cited


