MATERIALS AND METHODS

The field site was located near Mead, Nebr., in a subhumid area receiving an average of 690 mm of precipitation annually. The soil is a Sharpsburg silt loam (Typic Argiudolls). The experimental area received 50 kg/ha of P in 1972, and corn and sorghum treatments received 112 kg/ha of N annually, whereas the soybean and fallow treatment received no supplemental fertilizer. Each block of the randomized, complete block design consisted of 15 treatments with soybean (Glycine max L. Merr), corn (Zea mays L.), sorghum (Sorghum bicolor L. Moench), and fallow, from which the plots were chosen for the selected sequences (Fig. 1). The treatments were replicated three times. Tillage was uniform for all treatments each year and generally included chisel plowing to the 20-cm depth in the fall and double disk plowing about 8 cm deep in the spring. Eight of the 15 cropping sequences were selected in 1976 for measuring infiltration rate and water retention characteristics (Fig. 1). Treatments selected were: continuous soybean (B), continuous corn (C), continuous sorghum (S), corn after soybean (C-B), sorghum after soybean (S-B), fallow after soybean (F-B), corn after sorghum (C-S), and sorghum after corn (S-C).

The size distribution of water-stable aggregates was measured in the soybean treatments: continuous soybean (B), sorghum after soybean (S-B), fallow after soybean (F-B), corn after sorghum (C-S), and sorghum after corn (S-C).

Information on the effect of soybean on soil properties is sparse. Strickling (1951) showed a seasonal decrease of soil aggregates under soybean. Browning et al. (1942) and Wilson and Browning (1945) indicated that soybean and corn had the same negative effect on aggregation. Kidder et al. (1943) studied the effect of corn and soybean residue on infiltration and showed that the infiltration flux after 60 min was 1.2 and 3.2 cm/hour under soybean residue and corn stover, respectively.

The purpose of this investigation was to assess the influence of different cropping systems on infiltration, water content, and porosity of soil, and the influence of soybean cropping systems on size distribution of aggregates.
soybean after corn (B-C), soybean after sorghum (B-S), and soybean after fallow (B-F). Soil samples were taken from the 0- to 3- and 3- to 30-cm soil depths in September 1977. A combination of hydrometer and wet-sieving techniques (Kemper and Chepil, 1965) was used to determine the water-stable aggregates of different size. The aggregate percentages obtained from hydrometer and sieves were calculated on an oven-dry basis. The geometric mean diameter (GMD) (Mazurak, 1950) of the aggregates was then calculated.

Soil cores 7.5 cm in diameter and 7.5 cm in length for the surface soil were used to determine the water content at saturation (Miller and Bresler, 1977), and at 0.06- and 0.33-bar suction. Satiation refers to the near-saturated equilibrium water content resulting from free liquid water in contact with soil, but wherein complete saturation is prevented by the entrapment of air.

A double-ring technique was used to measure the infiltration flux in August 1976 on selected plots shown in Fig. 1. Infiltration data were analyzed by using the nonlinear regression program of the Statistical Analysis System (SAS). The Kostiakov (1932) equation was fitted to the data in the form of:

\[ I = \alpha^t \]

where \( I \) is the cumulative infiltration (cm of water), \( \alpha \) is a constant, \( t \) is the time (min), and \( c \) is a constant between zero and unity. The Philip (1957) equation was fitted in the form (Swartzendruber and Youngs, 1974):

\[ I = S t^{1/2} + K t \]

where \( I \) and \( t \) are the same as before, \( S \) is the constant sorptivity (cm/min\(^{1/2}\)), and \( K \) is the constant saturated hydraulic conductivity (cm/min).

**RESULTS AND DISCUSSION**

**Size Distribution of Water-stable Aggregates**

The size distributions of water-stable aggregates and particles for treatments B, B-C, B-S, and B-F for the 0- to 3- and 3- to 30-cm soil depths are shown in Fig. 2. The 0- to 3-cm depth was selected to be representative of soil influenced by raindrop impact and closely associated with and affected by the plant residue that remains at or near the surface. The 3- to 30-cm depth was indicative of the soil in the root zone where root activity is greatest. The area between the particle-size distribution (PSD) curve and the aggregate-size distribution (ASD) curve indicates the aggregation of soil particles. The larger the area between the two curves, the greater is the size difference between the primary particles and the aggregates. At the 0- to 3-cm soil depth, there are only slight differences between the curves for the four treatments, since this layer is subjected to mechanical disturbance from impact and dispersion by raindrops and by crushing from tillage operations. At the 3- to 30-cm soil depth, the area between the PSD and ASD curves was in the following order: B-F > B-S > B-C > B. The percentages of aggregates > 100 \( \mu \)m in diameter were 61, 50, 44, and 38 for treatments B-F, B-S, B-C, and B, respectively. Reduced aggregation in plots continuously cropped to soybean shows the negative effect of soybean on soil aggregation, which agreed with the work of Strickling (1951), who observed a seasonal decrease in soil aggregation under soybean.

To illustrate the effect of cropping sequence on soil aggregation, the GMD was calculated using each size distribution of soil aggregates (Table 1). There were no statistically significant (Duncan's Multiple Range Test at 0.05 probability) differences in GMD due to cropping sequences, but the order of the GMD of aggregates showed that numerical values were smaller in treatments continuously cropped to soybean. The low GMD is attributed to reduced binding of soil particles (Mazurak and Ramig, 1962) and aggregate breakdown by roots (Kolodny and Neal, 1941). Soybean roots, like other legumes, are high in nitrogen, which favors more rapid decomposition than the carbonaceous roots. Wilson and Browning (1945) showed that legumes are less effective than grasses in building stable soil structure.

**Water Retention Characteristics**

From an analysis of water retention curves (data not presented here), soil under treatment B retained less water at all suctions than the soil under any of the other cropping sequences. The largest difference in volumetric water content between the treatments was found at low water suction. Satiation water content and macroporosity (arbitrarily defined as the difference between water content at saturation and 0.06 bar suction) for the eight treatments are shown in Fig. 3. At saturation, the F-B treatment contained the highest water content (56.3%), whereas the B treatment
contained the lowest water content (41.4%). The saturation water content among treatments was in the following order: F-B > C-S > S-C > C-B > C > S-B > B. The macroporosity was also the highest for treatment F-B. The larger macroporosity of treatments F-B and C-S was associated with high infiltration rate. Jamison (1953) and Salter and Williams (1963) reported that soil structure is an important factor influencing the quantity of water held at low suction, because the larger pores are affected more by structural changes than are the smaller pores.

From data analyzed but not shown here, we found no significant differences at either the 0.33 or 15 bar water content for the soil (0- to 15-cm depth). When we calculated available water content as the difference between water content at 0.33 and 15 bar, the C treatment released significantly more water than the S treatment, but we detected no significant difference among the other treatments.

Table 1—Geometric mean diameter of Sharpsburg soil aggregates for the 0- to 3- and 3- to 30-cm soil depths. Each value is an average of three replications.

<table>
<thead>
<tr>
<th>Cropping treatments</th>
<th>Geometric mean diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–3 cm</td>
</tr>
<tr>
<td>Continuous soybean (B)</td>
<td>82</td>
</tr>
<tr>
<td>Soybean after corn (B-C)</td>
<td>83</td>
</tr>
<tr>
<td>Soybean after sorghum (B-S)</td>
<td>82</td>
</tr>
<tr>
<td>Soybean after fallow (B-F)</td>
<td>86</td>
</tr>
</tbody>
</table>

Table 2—Fitted constants in the Kostiakov and Philip equations for each plot in each cropping treatment.

<table>
<thead>
<tr>
<th>Treatment†</th>
<th>Plot</th>
<th>Kostiakov equation</th>
<th>Philip equation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>( I = a) x^c )</td>
<td>( I = S + K t^r )</td>
</tr>
<tr>
<td></td>
<td>( cm/min^2 )</td>
<td>( cm/min )</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>107</td>
<td>1.506 0.3486 0.947</td>
<td>0.886 -0.030 0.918</td>
</tr>
<tr>
<td></td>
<td>215</td>
<td>1.140 0.1979 0.798</td>
<td>0.599 -0.028 0.918</td>
</tr>
<tr>
<td></td>
<td>304</td>
<td>1.085 0.2277 0.849</td>
<td>0.670 -0.030 0.923</td>
</tr>
<tr>
<td>C</td>
<td>115</td>
<td>0.466 0.5780 0.979</td>
<td>0.643 +0.012 0.939</td>
</tr>
<tr>
<td></td>
<td>208</td>
<td>1.118 0.4407 0.974</td>
<td>0.943 -0.005 0.951</td>
</tr>
<tr>
<td></td>
<td>312</td>
<td>0.875 0.4520 0.962</td>
<td>0.746 -0.010 0.920</td>
</tr>
<tr>
<td>S</td>
<td>111</td>
<td>0.984 0.5847 0.991</td>
<td>1.178 +0.026 0.859</td>
</tr>
<tr>
<td></td>
<td>204</td>
<td>1.799 0.5599 0.988</td>
<td>2.058 +0.029 0.960</td>
</tr>
<tr>
<td></td>
<td>308</td>
<td>2.837 0.2734 0.940</td>
<td>1.716 -0.062 0.922</td>
</tr>
<tr>
<td>C-B</td>
<td>112</td>
<td>1.655 0.4605 0.975</td>
<td>1.561 -0.016 0.918</td>
</tr>
<tr>
<td></td>
<td>205</td>
<td>1.138 0.2945 0.928</td>
<td>0.680 -0.020 0.929</td>
</tr>
<tr>
<td></td>
<td>309</td>
<td>1.267 0.1809 0.850</td>
<td>0.690 -0.033 0.960</td>
</tr>
<tr>
<td>S-B</td>
<td>110</td>
<td>1.264 0.4070 0.971</td>
<td>1.047 -0.019 0.943</td>
</tr>
<tr>
<td></td>
<td>203</td>
<td>0.777 0.8528 0.978</td>
<td>0.677 +0.015 0.923</td>
</tr>
<tr>
<td></td>
<td>307</td>
<td>1.357 0.3562 0.957</td>
<td>0.976 -0.024 0.928</td>
</tr>
<tr>
<td>F-B</td>
<td>102</td>
<td>1.870 0.3807 0.970</td>
<td>1.428 -0.029 0.933</td>
</tr>
<tr>
<td></td>
<td>210</td>
<td>1.206 0.1600 0.748</td>
<td>0.621 -0.031 0.942</td>
</tr>
<tr>
<td></td>
<td>314</td>
<td>0.572 0.8389 0.993</td>
<td>0.913 +0.179 0.995</td>
</tr>
<tr>
<td>C-S</td>
<td>113</td>
<td>1.127 0.6962 0.991</td>
<td>1.632 +0.111 0.944</td>
</tr>
<tr>
<td></td>
<td>206</td>
<td>2.231 0.3751 0.961</td>
<td>1.729 -0.043 0.962</td>
</tr>
<tr>
<td></td>
<td>310</td>
<td>2.004 0.5084 0.986</td>
<td>2.520 +0.060 0.932</td>
</tr>
<tr>
<td>S-C</td>
<td>108</td>
<td>0.999 0.7702 0.995</td>
<td>1.573 +0.185 0.963</td>
</tr>
<tr>
<td></td>
<td>201</td>
<td>0.719 0.7232 0.991</td>
<td>1.110 +0.088 0.972</td>
</tr>
<tr>
<td></td>
<td>305</td>
<td>0.590 0.4413 0.972</td>
<td>0.488 -0.004 0.944</td>
</tr>
</tbody>
</table>

† B = continuous soybean, C = continuous corn, S = continuous sorghum, C-B = corn after soybean, S-B = sorghum after soybean, F-B = fallow after soybean, C-S = corn after sorghum, and S-C = sorghum after corn.

**Infiltration**

Samples of graphical representations of least squares fitting of both the Kostiakov and Philip equations to the experimental data are presented in Fig. 4 for treatments B, C, and S for the three replications. Both equations fitted the data reasonably well, but the Kostiakov equation gave a better fit, especially at the early and late stages of the infiltration process.

Numerical values of the fitted constants in the two equations are given in Table 2. More than one-half of the values of \( K \) in the Philip equation are negative—a physical incongruity since it implies that, in the later

Fig. 3—Soil water content at satiation and percent macroporosity of Sharpsburg silty clay loam for 0- to 15-cm soil depth for eight different cropping treatments at Mead, Nebr. Means for saturation water content or macroporosity with the same letter are not different at the 0.05 probability using the Duncan Multiple Range Test.
Fig. 5—Cumulative infiltration values as determined by Kostiakov's equation after 4 hours and the range of infiltration in the replicates for the cropping treatments. Means with the same letter are not different at 0.05 probability using the Duncan Multiple Range Test.

Fig. 6—Instantaneous infiltration flux vs. time for the cropping treatments, as determined from the fitted constants of the Kostiakov equation.

stages of ponding, water will be moving out of the soil rather than into it. However, fitted negative K values have been reported by Skaggs et al. (1969) and Taylor and Ashcroft (1972), and, in the case of a different infiltration equation, by Swartzendruber and Huberty (1958). A negative K in Philip's equation (Eq. [2]) means mathematically that the curve of I vs. t will become a maximum at some positive finite time. Small but detectable manifestations of such maxima can be observed in Fig. 4 for treatment B in the second and third replications and for treatment S in the third replication. At the later times, the Philip equation curves yield negative slopes, whereas the field data implied positive slopes.

A quantitative comparison of the ability of the equations to fit the experimental data is given by the average of the coefficient of determination, $r^2$ values (Table 2). The average $r^2$ values, 0.946 and 0.940 for Kostiakov’s and Philip’s equations, respectively, illustrate the good fit for both equations. Because of the difficulty with negative K values, however, we will not discuss the use of the Philip equation any further.

Cumulative infiltration values, as determined by Kostiakov’s equation after 4 hours of water application, and the range of infiltration values in the replications are presented in Fig. 5. Continuous soybean (B) had significantly lower infiltration (5.8 cm) after 4 hours. The low cumulative infiltration in treatment B was probably due to the low macroporosity and the decreased size of water-stable aggregates.

In addition to fitting the infiltration equations individually to each data set for each plot of each cropping treatment, as reported in Table 2, we also made a single fitting of the Kostiakov equation for each cropping treatment. The three replicate data sets for each treatment were pooled, and then the equation was fitted to this composite set of data points. The resulting constants were then used in the time-differentiated form of Eq. [1], namely $i = \frac{dl}{dt} = cat^{-1}$, to calculate a curve of infiltration flux vs. time for each cropping treatment, as plotted in Fig. 6. Mathematically, all curves become infinite at zero time. The infiltration flux after 5 min of water application was 7.9, 10.1, 24.1, 21.9, and 30.8 cm/hour for treatments B, C, S, F-B, and C-S, respectively, and decreased to 0.53, 1.3, 3.5, 8.5, and 7.5 cm/hour after 240 min of water application.

Soil cropped continuously to soybeans for 6 years had the lowest infiltration flux. A possible explanation is that the soybean roots might have increased the growth of certain types of microorganisms which, in turn, affected the water movement by clogging soil pores. McCalla (1951) reported that microorganisms may reduce water movement through the soil by producing gases or highly hydrated organic materials, which might interfere with water movement or decompose or change the aggregate-stabilizing agents, and this might result in structure deterioration.

LITERATURE CITED


