SOIL WATER CONTENT AND INFILTRATION IN AGROFORESTRY BUFFER STRIPS

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ABSTRACT

Agroforestry practices are receiving increased attention in temperate zones as a soil and water conservation method and an economical alternative. We examined water infiltration and seasonal profile water content as influenced by agroforestry buffer strips for a Putnam soil (fine, smectitic, mesic Vertic Albaqualf) in northeast Missouri to test the hypothesis that agroforestry buffers reduce nonpoint source pollution by increased infiltration, water use, and water storage. The watershed was under no-till management with a corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation since 1991 with soybeans in 2003. Agroforestry buffer strips, 4.5 m wide and 36.5 m apart, were planted with redtop (*Agrostis gigantea* Roth), brome (*Bromus* spp.), and birdsfoot trefoil (*Lotus corniculatus* L.). Pin oak (*Quercus palustris* Muenchh.), swamp white oak (*Q. bicolor* Willd.), and bur oak (*Q. macrocarpa* Michx.) trees were planted at 3-m intervals in the center of the agroforestry buffers in 1997. Ponded water infiltration was measured in single rings in June 2003 in agroforestry and grass buffers and row crop areas. Water content in agroforestry and row crop areas at 5, 10, 20, and 40 cm depths at 10-minute intervals were recorded beginning in June 2003 through the year. Quasi-steady infiltration rates were not significantly different ($P>0.05$) among the treatments. Agroforestry had significantly lower soil water content than row crop areas ($P<0.05$) during the growing season. Significantly higher water content after the principal recharge event in the agroforestry treatment was attributed to better infiltration through the root system. Results show that agroforestry buffer strips reduce soil water content via evapotranspiration during critical times such as fallow periods and periods of low crop water use, thereby increasing water infiltration and water storage. Therefore, adoption of agroforestry buffer practices may reduce runoff and soil loss from watersheds in row crop management.

Keywords: agroforestry, automated water content sensors, Green-Ampt equation, Parlange equation, saturated hydraulic conductivity.

INTRODUCTION

Control of nonpoint source pollution (NPSP) is needed for many areas in the semihumid and humid regions of the US to improve water and environmental quality. Despite our best efforts, it is unlikely that significant reduction in NPSP to water bodies can be achieved through traditional management alone (Dinnes et al. 2002). Agroforestry, a land management program that intersperses agricultural crops with trees and grass buffers, is being promoted as an alternative management system that can bring economic and environmental benefits (Garrity 2004). Recent studies show that agroforestry practices reduce NPSP from row crop watersheds (Jin et al. 2000; Udawatta et al. 2002). A deeper understanding of agroforestry is needed to develop recommendations relevant to landowners, farmers, and regulatory agencies. Furthermore, management principles need to be refined for different scales of operation (Garrity 2004).

Filter strips of permanent vegetation reduce runoff and trap sediment, which decreases NPSP. Aboveground stems and roots can reduce the runoff flow rate and enhance sedimentation and water infiltration; roots can also use excess nutrients and improve soil physical properties. Buffer strips increase infiltration capacity and reduce the slope length, which assists in reducing runoff volume and velocity (Munoz-Carpena et al. 1993).

Grass and agroforestry buffers reduce runoff and increase water infiltration (Schmitt et al. 1999). Bharati et al. (2002) found five times greater infiltration rates in a multispecies riparian buffer compared to cultivated and grazed fields. In northeast Missouri claypan soils, agroforestry, and grass buffers increased saturated hydraulic conductivity (*Ksat*) by 14 and 3 times compared to the row-crop areas (Seobi et al. 2005). The presence of large and deep tree roots and decaying roots result in a greater proportion of larger pores that enhance soil hydraulic properties compared to a cropping system (Cadisch et al. 2004).

Buffer strips influence the soil water deficit (Munoz-Carpena et al. 1993) through increased transpiration from these strips. Trees in agroforestry systems use water from soil that shallower plant roots cannot access (Dupraz 1999; Gillespie et al. 2000; Jose et al. 2000). On average, corn and soybeans use 647 and 563 mm of water during the season in Nebraska (http://ianrpubs.unl.edu/irrigation/g992.htm). In Missouri, mature oak trees transpire 4.83 mm d^{-1} (Zahner 1955). This amounts to 883 mm of potential evapotranspiration during the 183 d growing season (Udawatta and Henderson 2003).

Claypan soils occur in the Midwest of the US on about 4 million ha in Illinois, Iowa, and Missouri. Clay-enriched soils need distinctive management for runoff control due to the lower soil hydraulic conductivity (Jamison and Peters 1967; Bouma 1980). Central and northeastern regions of Missouri are dominated by soils with an argillic (clay > 45%) subsoil horizon within the top 50 cm of the soil profile (Blanco-Canqui et al. 2002). Infiltration measurements in claypan soils are highly influenced by antecedent soil water content (Schwab et al. 1993). McGinty (1989) showed that quasi-steady infiltration rates of 5 mm hr^{-1} in the summer increased to 32 mm hr^{-1} due to the development of shrinkage cracks after a very dry summer and fall.

Studies examining agroforestry influences on soil water infiltration and changes in water content are limited. The objectives of this study were to investigate (1) grass and agroforestry buffer strip influences on infiltration for a claypan soil, and (2) agroforestry buffer strip effects on soil water content in a claypan soil during the growing season and the fall recharge period. Results will help in understanding soil water dynamics in an agroforestry alley cropping system and provide data for modeling these systems.

MATERIALS AND METHODS
Experimental Site

The study was conducted at the University of Missouri Greenley Memorial Research Center in Knox County, Missouri (Figure 1). Details on watershed characteristics, soils, weather, and management practices can be found elsewhere (Udawatta et al. 2002; 2004). The 4.44 ha agroforestry buffer strip watershed was under corn-soybean rotation with no-till management since 1991. Four and a half m wide and 36.5 m apart (22.8 m at lower slope positions) contour strips were planted in redtop (*Agrostis gigantea* Roth), brome grass (*Bromus* spp.), and birdsfoot trefoil (*Lotus corniculatus* L.) in 1997. Pin oak (*Quercus palustris* Muenchh.), swamp white oak (*Q. bicolor* Willd.), and bur oak (*Q. macrocarp* Michx.) were planted 3 m apart in the center of the contour strip buffers.

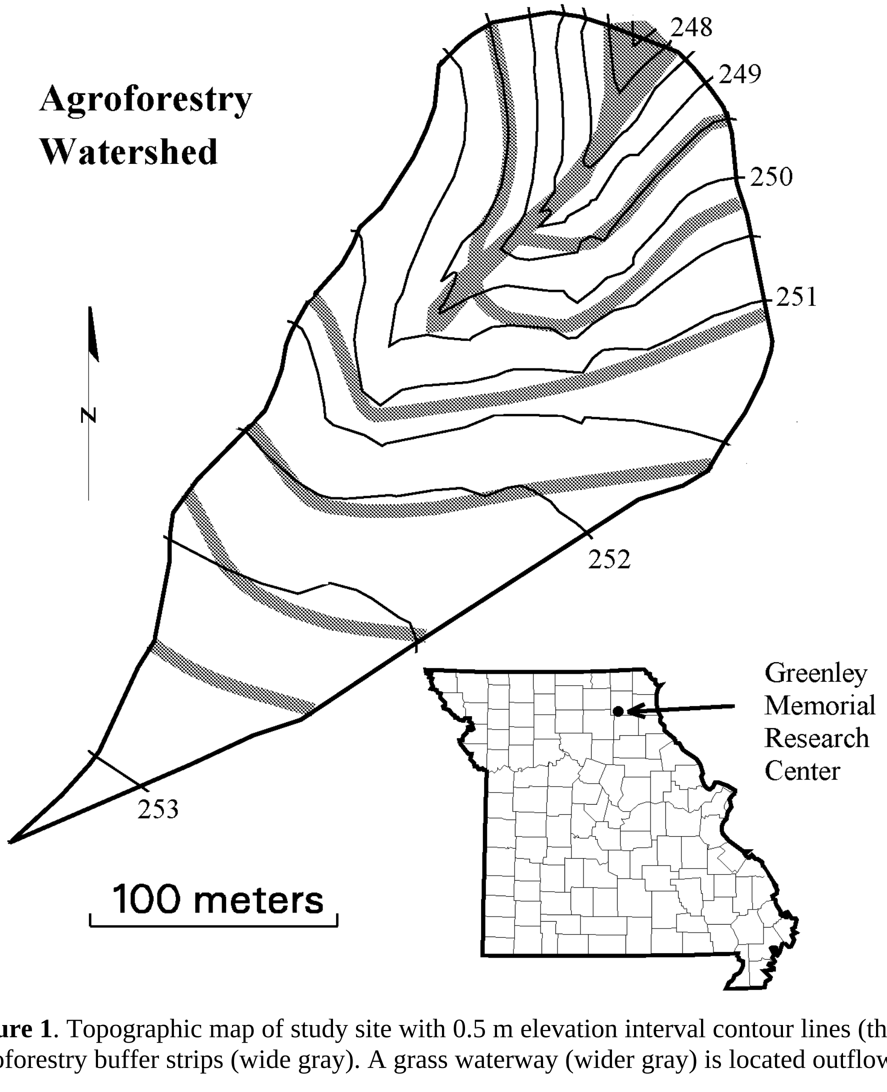

Figure 1. Topographic map of study site with 0.5 m elevation interval contour lines (thin black), agroforestry buffer strips (wide gray). A grass waterway (wider gray) is located outflow end of the

The soils in the study area were mapped as Putnum silt loam (fine, smectitic, mesic Vertic Albaqaulfs) and Kwilwinning silt loam (fine, smectitic, mesic Vertic Epiaqaulfs). The watershed has a drainage restrictive B horizon with a claypan at a variable depth between 4 and 37 cm (Udawatta et al. 2002). Ponded infiltration measurements and continuous water monitoring were conducted on Putnam silt loam soil. Average slope in the monitoring area was 1–2 % and soils on average had 219 g kg^{-1} clay, 729 g kg^{-1} silt, 21g kg^{-1} organic C, and 6.8 pH_w in the surface horizon; while the argillic horizon started at about the 38 cm depth, and had 531g kg^{-1} clay, 439 g kg^{-1} silt, 9 g kg^{-1} organic C, and 5.2 pH_w.

Daily and hourly rainfall data were obtained from a University of Missouri webpage (http://agebb.missouri.edu/weather/stations/knox/). Weather data were accessed for daily and hourly time frequencies for Knox County.

Ponded Infiltration

Ponded infiltration measurements were conducted on 2 to 4 June 2003. For the agroforestry buffer treatment, three pin oak trees each were selected on the second and third agroforestry buffer strips, counting from the south. Six areas to the west of each tree and midway between trees (1.5 m from either tree) within the buffer were selected for measurements in the grass buffer treatment. Six areas midway between buffers (18 m from each buffer) to the north of the agroforestry treatment locations were selected for measurements in the row crop treatment. Infiltration rings were placed on the west side of each tree, 20 cm from the trunk for the agroforestry treatment. Measurements for the row crop treatment were conducted within nontrafficked inter rows.

Single infiltration rings (diam. 25 cm) were driven 18 cm into the soil and a ponded depth of water was maintained at 5.0 cm. Infiltration measurements were recorded for 1.5 hours at selected time intervals after stabilization of the ponded water in the ring. Water used for infiltration had an EC value of 0.85 dS m^{-1} and a SAR value of 0.381.

The calculated quasi-steady infiltration rate (q_s) was used as the final infiltration rate. The hydraulic conductivity (K_s) and sorptivity (S) parameters for the Parlange et al. (1982) and the Green and Ampt (1911) infiltration models were estimated according to Clothier and Scotter (2002). The Parlange et al. (1982) model will be referred to as the Parlange model in this paper. The Green and Ampt model gave the best parameter confidence interval for a two-parameter model, and the Parlange equation fit infiltration data well for a two-parameter model (Clausnitzer et al. 1998). The Green and Ampt equation was modified by Philip (1957) for time (t) vs. cumulative infiltration (I), as follows:

$$t = \frac{I}{K_S} - \frac{[S^2 \ln(1 + 2IK_S / S^2)]}{2K_S^2} \qquad [1]$$

The physically based Parlange equation for t vs. I is as follows:

$$t = \frac{I}{K_S} - \frac{S^2[1 - \exp(-2IK_S / S^2)]}{2K_S^2} \qquad [2]$$

where t (T) is time, I (L) is the cumulative infiltration, S (L $T^{-0.5}$) is the sorptivity, and K_S (L T^{-1}) is the saturated hydraulic conductivity. The sorptivity and K_S for the two-parameter physically based Green and Ampt and Parlange equations were estimated according to Clothier and Scotter (2002).

Water Content Monitoring

Campbell CS-616 (Campbell Scientific, Inc., Logan, UT) water content sensors (Or and Wraith 2002) were horizontally installed at 5-, 10-, 20-, and 40-cm depths in four replicate locations for the agroforestry (3rd buffer) buffer and row crop treatments (between the 2nd and 3rd buffers) in May 2003. Readings were collected beginning in the middle of June 2003. Sensors were placed in two replicate positions under two different pin oak trees (48 cm from tree trunk) for a total of four replicates. The selected pair of trees was about 10 m apart. No differences were found between the positions around the trees and therefore these two positions were used as replicates. The first pair of row crop treatment sensors were placed 10 m directly southwest of the trees, while the other pair was 20 m from the trees. No differences were found between the two locations within the row crop treatment and therefore the two locations were used as replicates. The sensors were connected to a data-logger to collect 10-minute interval data.

Soil samples were taken near the sensors for gravimetric water content determination and calibration of the sensors. When the soil was relatively dry (13 August 2003) and relatively wet (19 September 2003), samples were collected from the following depths: 0–7.5, 7.5–15, 15–30, and 30–50 cm at two replicate positions in the row crop and agroforestry buffer treatments. Gravimetric water contents were converted to volumetric water content with measured bulk density values. Regression curves were developed between water content estimated with the sensors and measured volumetric water content for each depth. Three different calibration curves were used: one for the combined 5- and 10-cm depths, one for the 20-cm depth, and one for the 40-cm depth.

Data were extracted from the data logger each week from 17 June 2003 through 16 December 2003. Weekly water content values were obtained using data measured at 12:00 noon each Tuesday. A major recharge period was identified in late August and early September. Soil water content on a 10-minute interval was used to compare soil water recharge between treatments during this recharge period.

Statistical Analysis

Homogeneity of variance tests were conducted to check for variability within treatments for measured infiltration and water content due to the systematic arrangement of treatments. Analysis of variance (ANOVA) was further conducted with SAS using the GLM procedure when variances within treatments were homogeneous (SAS Institute, 1989). Data for all properties had homogeneous variances. Least significant differences (Duncan's LSD) were calculated to find significant differences between treatments at each soil depth. LSD values were calculated using the Proc Mixed procedure from SAS with the appropriate error terms. Statistics were done on log-transformed data for the infiltration parameters. Volumetric water content values for treatments were analyzed by date.

RESULTS AND DISCUSSION

Ponded Infiltration

Typical infiltration curves as a function of time for the agroforestry buffer, grass buffer and row crop treatments are shown in Figure 2. Curves illustrate the typical early rapid increase in infiltration followed by slower increases as time progressed. Statistical analysis of the estimated Green-Ampt and Parlange infiltration parameters are shown in Table 1. Quasi-steady infiltration rate (q_s), K_s, and S were not significantly different ($P>0.05$) among the treatments.

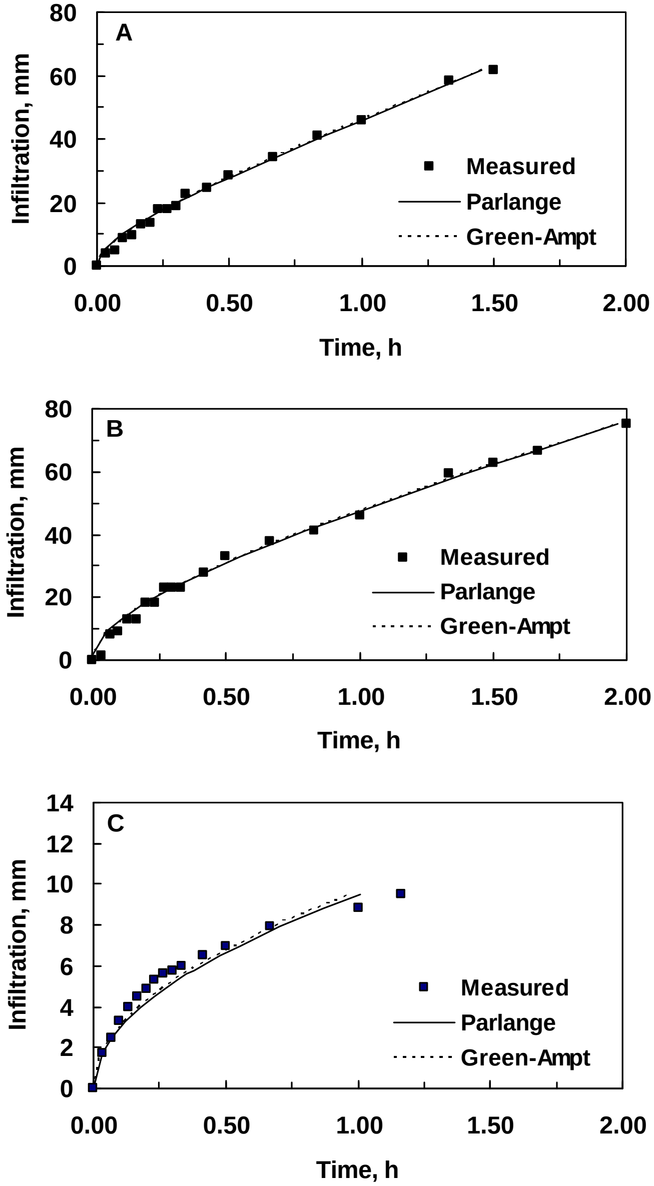

Figure 2. Models of Green and Ampt and Parlange fitted to measured infiltration data for typical replicates under A) agroforestry, B) grass buffer, and C) row crop treatments.

Table 1. Geometric means of parameters calculated from ponded infiltration data and the Green-Ampt and Parlange models (n = 6).

Parameter	Row Crop	Grass Buffer	Agroforestry Buffer
q_s (mm h^{-1})	10.2a†	13.9a	17.0a
Green-Ampt Model			
K_s (mm h^{-1})	1.05a	3.42a	3.16a
S (mm h$^{-1/2}$)	16.7a	17.6a	12.8a
Parlange Model			
K_s (mm h^{-1})	1. 50a	4.86a	4.75a
S (mm h$^{-1/2}$)	17.1a	21.4a	15.4a

†Means with different letters for an infiltration parameter are significantly different at the 0.05 probability level.

Studies support that vegetation and soil management often have more influence on water infiltration compared to soil variability (Sharma et al. 1980; Tricker 1981). Grass hedges reduce runoff and soil loss (Gilley et al. 2000; Schmitt et al. 1999) probably due to increased hydraulic conductivity, macroporosity, and pore continuity (Rachman et al. 2004b). Agroforestry and grass buffers had 3.13 and 3.20 times greater (not significant) K_s for Green Ampt and Parlange models, respectively, than the row crop area. Rachman et al. (2004b) observed significantly higher infiltration for soils under 10-yr old switchgrass (*Panicum virgatum* L.) on Monona silt loam compared to row crop areas. Grass and trees in the agroforestry buffers in this study are only six years old; significant changes in soil properties may not yet have been pronounced. Another reason that might influence infiltration is the relative magnitude of infiltration of the lower horizon compared to the surface horizon (Haws et al. 2004). They found that abundant large macropores in the lower horizons corresponded to larger infiltration rates for the soils. Claypan soils have a shallow top soil layer, with sufficient water transmission pores. This surface horizon is underlain by an argillic horizon containing more than 40% smectitic clays, which restricts vertical water movement (Blevins et al. 1996). Data from Blanco-Canqui et al. (2002) indicate that after approximately 48 hours of saturation, water movement through the claypan was only 1.5% and reached a hydraulic conductivity of 0.001 mm h^{-1}. The influence of the clay horizon may be partially responsible for not detecting differences among the treatments. It is anticipated as trees mature and their roots occupy more soil volume, the agroforestry treatments may increase infiltration.

The results of not detecting significant differences among the treatments may also be due to the relatively high antecedent water content (0.36 m^3 m^{-3} average for the three treatments which corresponds to approximately -20 kPa) and high variability among replicate measurements. Antecedent water contents among the treatments were not significantly different. In other studies, grass hedges reduced runoff and soil loss (Gilley et al. 2000; Schmitt et al. 1999) probably due to increased hydraulic conductivity, macroporosity, and pore continuity (Rachman et al. 2004b).

The hydraulic conductivity parameter (K_s) values estimated using the Parlange model were 46% higher compared to the Green-Ampt model estimates. Similar to our results, Rachman et al. (2004b) also found that the Parlange model estimated higher values of K_s compared to the Green-Ampt model for three different positions for two years of infiltration measurements: grass hedge (15.7%), row crop (19.1%), and deposition zone (22.2%). The sorptivity (S) parameter estimated using the Parlange model was also higher (14%) compared to the Green-Ampt model estimates.

Rachman et al. (2004b) found higher estimates of *S* with the Parlange model compared to the Green-Ampt model for three positions with two years of infiltration measurements: grass hedge (3.0%), row crop (9.0%), and deposition area (10.7%).

Soil Water Content

Rainfall for this site in 2003 (Fig. 3) relative to the 30-yr average indicated that precipitation during the first three months (62.0 mm) of the year was 44% of the average rainfall. However, rainfall in April (160.0 mm) was 197% of the normal. The study location received 92, 92 and 82% of the normal rain in May (315.2 mm), June (82.3 mm) and July (83.1 mm), respectively. During the first three weeks of August (31.8 mm) the rainfall was 39% of normal. Total rainfall during August (156.4 mm) and September (158.7 mm) were 190 and 168% of normal, respectively. Rainfall during the last three months (232.2 mm) of the year was about 113% of normal.

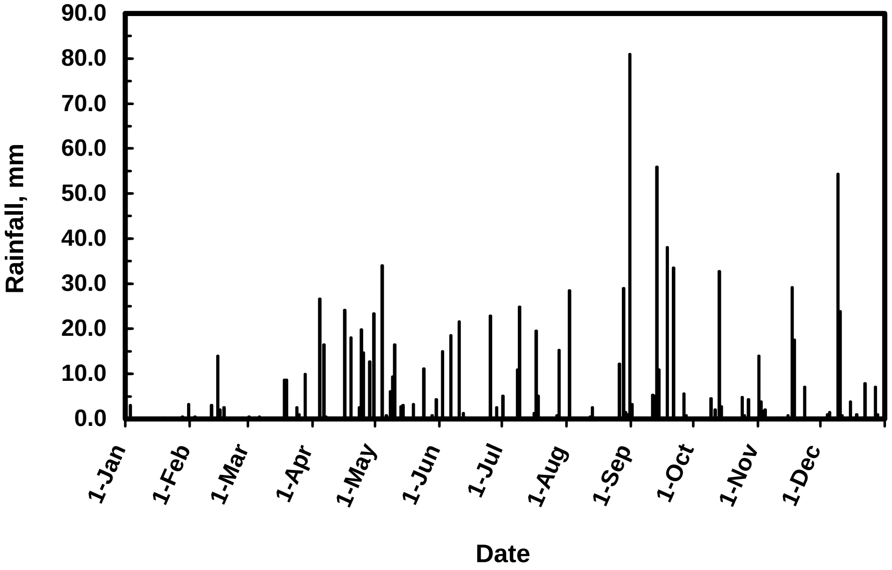

Figure 3. Daily rainfall at the watershed site for 2003.

Statistical comparisons of weekly water content data for the treatments are shown in Table 2. On the first measurement date of 17 June, water content in the agroforestry treatment was significantly lower (P<0.10) compared to the row crop treatment. The higher water content in the row crop treatment compared to the agroforestry treatment was probably due to more water depletion by the trees compared to the row crop area which did not have soybeans planted until 19 June. In Missouri, bud breaks for oaks occur during the March-April period and the three oak species in the study had 300 g dry leaves tree^{-1} in 2002 (Udawatta et al. 2005). Five-year old, 1.2 by 1.2 m spaced abandoned northern red oak plantations, had leaf area indices between 0.5 and 1.2 (m^2 leaf area/m^2 soil area, Farmer 1980). Statistically lower (P<0.05) soil water content persisted in the agroforestry treatment compared to the row crop treatment from 24 June through 12 August. Studying infiltration and surface soil cracks, Wells et al. (2003) noticed that runoff commenced after most cracks were filled with storm water. In this study with lower soil water

Table 2. Treatment and depth means of soil water content for weekly sampling dates along with probability values from analysis of variance.

	Sampling Date						
	17 Jun	**24 Jun**	**1 Jul**	**8 Jul**	**15 Jul**	**22 Jul**	**29 Jul**
	------------------------------------ $m^3\ m^{-3}$ ------------------------------------						
Treatment mean							
Row crop	0.405	0.385	0.391	0.368	0.373	0.343	0.322
Agroforestry buffer	0.374	0.292	0.269	0.227	0.265	0.233	0.233
Depth mean							
5 cm	0.363	0.287	0.287	0.238	0.263	0.229	0.249
10cm	0.396	0.338	0.332	0.290	0.313	0.275	0.270
20cm	0.383	0.329	0.311	0.283	0.316	0.273	0.231
40cm	0.416	0.401	0.390	0.381	0.383	0.373	0.361
Analysis of variance P > F							
Treatment	0.077	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Depth	0.012	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Treatment by Depth	0.222	0.076	0.093	0.080	0.559	0.403	0.516

	Sampling Date						
	5 Aug	**12 Aug**	**19 Aug**	**26 Aug**	**2 Sep**	**9 Sep**[†]	**16 Sep**
	------------------------------------ $m^3\ m^{-3}$ ------------------------------------						
Treatment mean							
Row crop	0.306	0.264	0.250	0.224	0.396		0.385
Agroforestry buffer	0.220	0.204	0.203	0.191	0.401		0.410
Depth mean							
5 cm	0.224	0.173	0.163	0.138	0.378		0.380
10cm	0.257	0.222	0.213	0.193	0.403		0.399
20cm	0.222	0.203	0.193	0.170	0.391		0.390
40cm	0.348	0.339	0.337	0.328	0.422		0.421
Analysis of variance P > F							
Treatment	<0.010	0.036	0.088	0.197	0.719		0.099
Depth	<0.010	<0.010	<0.010	<0.010	0.012		0.016
Treatment by Depth	0.736	0.772	0.871	0.844	0.866		0.658

[†] Data were missing on the 9 September sampling date.

	Sampling Date						
	23 Sep	**30 Sep**	**7 Oct**	**14 Oct**	**21 Oct**	**28 Oct**	**4 Nov**
	------------------------------------ $m^3\ m^{-3}$ ------------------------------------						
Treatment mean							
Row crop	0.391	0.357	0.350	0.401	0.366	0.365	0.396
Agroforestry buffer	0.430	0.366	0.342	0.427	0.364	0.347	0.401
Depth mean							
5 cm	0.400	0.329	0.305	0.426	0.336	0.338	0.393
10cm	0.414	0.363	0.345	0.414	0.367	0.357	0.400
20cm	0.408	0.353	0.338	0.401	0.357	0.337	0.391
40cm	0.421	0.402	0.396	0.414	0.401	0.392	0.408
Analysis of variance P > F							
Treatment	0.019	0.473	0.560	0.075	0.832	0.195	0.695
Depth	0.375	<0.010	<0.010	0.300	<0.010	<0.010	0.530
Treatment by Depth	0.394	0.726	0.781	0.173	0.816	0.697	0.961

	Sampling Date					
	11 Nov	**18 Nov**	**25 Nov**	**2 Dec**	**9 Dec**	**16 Dec**
	------------------------------------ $m^3\ m^{-3}$ ------------------------------------					
Treatment mean						
Row crop	0.360	0.404	0.354	0.340	0.344	0.371
Agroforestry buffer	0.362	0.428	0.398	0.367	0.364	0.406
Depth mean						
5 cm	0.346	0.449	0.363	0.331	0.337	0.403
10cm	0.363	0.420	0.374	0.354	0.356	0.390
20cm	0.345	0.395	0.370	0.341	0.338	0.374
40cm	0.389	0.402	0.396	0.387	0.384	0.387
Analysis of variance P > F						
Treatment	0.828	0.031	<0.010	0.052	0.115	0.011
Depth	<0.010	<0.010	0.076	<0.010	<0.010	0.092
Treatment by Depth	0.799	0.140	0.101	0.372	0.660	0.063

content for the agroforestry treatment, increased soil water storage may occur during precipitation events before runoff is generated thus reducing runoff and possibly NPSP. It is assumed that incorporation of agroforestry and/or other permanent vegetation with longer growing seasons might reduce runoff and NPSP from watersheds under row crop management.

After the principal recharge period in late August, the agroforestry treatment had significantly ($P<0.10$) higher soil water content on 16 and 23 September, 14 October, 18 and 25 November, and 2 and 16 of December. The significantly higher water content in the agroforestry treatment after recharge was attributed to better infiltration through the root system within this buffer treatment. Development of more macropores (Chang and Mead 1989; Rachman et al. 2004b), pore continuity (Cadisch et al. 2004; Rasse et al. 2000), formation of soil aggregates (Wienhold and Tanaka 2000) and decayed roots may have probably increased soil water storage.

Significant differences ($P<0.05$) in water content among soil depths were found for the study (Table 2). On only five of the 26 weekly measurements were there no differences ($P>0.05$) found among depths; these dates were all after the middle of September following recharge. The average water content at the 5 cm depth ranged from 0.36 on 17 June to a low of 0.14 on 26 August; it then recharged to 0.38 on 2 September. The water content at the 40 cm depth ranged from 0.42 on 17 June to a low of 0.33 on 26 August and recharged to 0.42 on 2 September. No significant ($P>0.05$) interactions between treatment and soil depth were found during the study period.

The weekly soil water contents at the 5, 10, and 20 cm depths were significantly different ($P<0.05$) between treatments from 24 June through 5 August (Figure 4). For the fourth depth, the differences exist from 8 July through 29 July. This was attributed to the greater transpiration from the trees in the agroforestry buffer treatment compared to the soybeans in the row crop treatment. Soybeans take about 15 and 30 days to spread roots within the surface 30 cm depth. On seven dates after the principal recharge period in late August, the soil water content was significantly higher for the agroforestry buffer treatment compared to the row crop treatment at the 5 cm depth. The higher water content in the agroforestry treatment may have been due to slightly greater recharge in the treatment during rainfall. This could be attributed to greater macroporosity (Rachman et al. 2004a) for this treatment.

Principal Recharge Period

The principal recharge period in soil water occurred during the week of 26 August to 2 September (Figures 3, 4, and 5). The recharge period was initiated with 12.19 mm of rain on 26 August followed by 30.47 mm of rain beginning on 28 August. A high rainfall period began on 30 August and delivered 85.32 mm of rain (Figure 5). No runoff was measured from the watershed during this week of high rainfall.

During the week of 26 August through 2 September, three major rainfall events occurred (Figure 5). The first rainfall event started at 20:00 h on 26 August and lasted for 2 hours. Ninety-six percent of the rain in this storm occurred during the first hour. The second rainfall event during this recharge period started at 15:00 h on 28 August and lasted for 13 hours. Forty-nine percent of the rain occurred during the first hour and 28.4% occurred during the second hour. The third

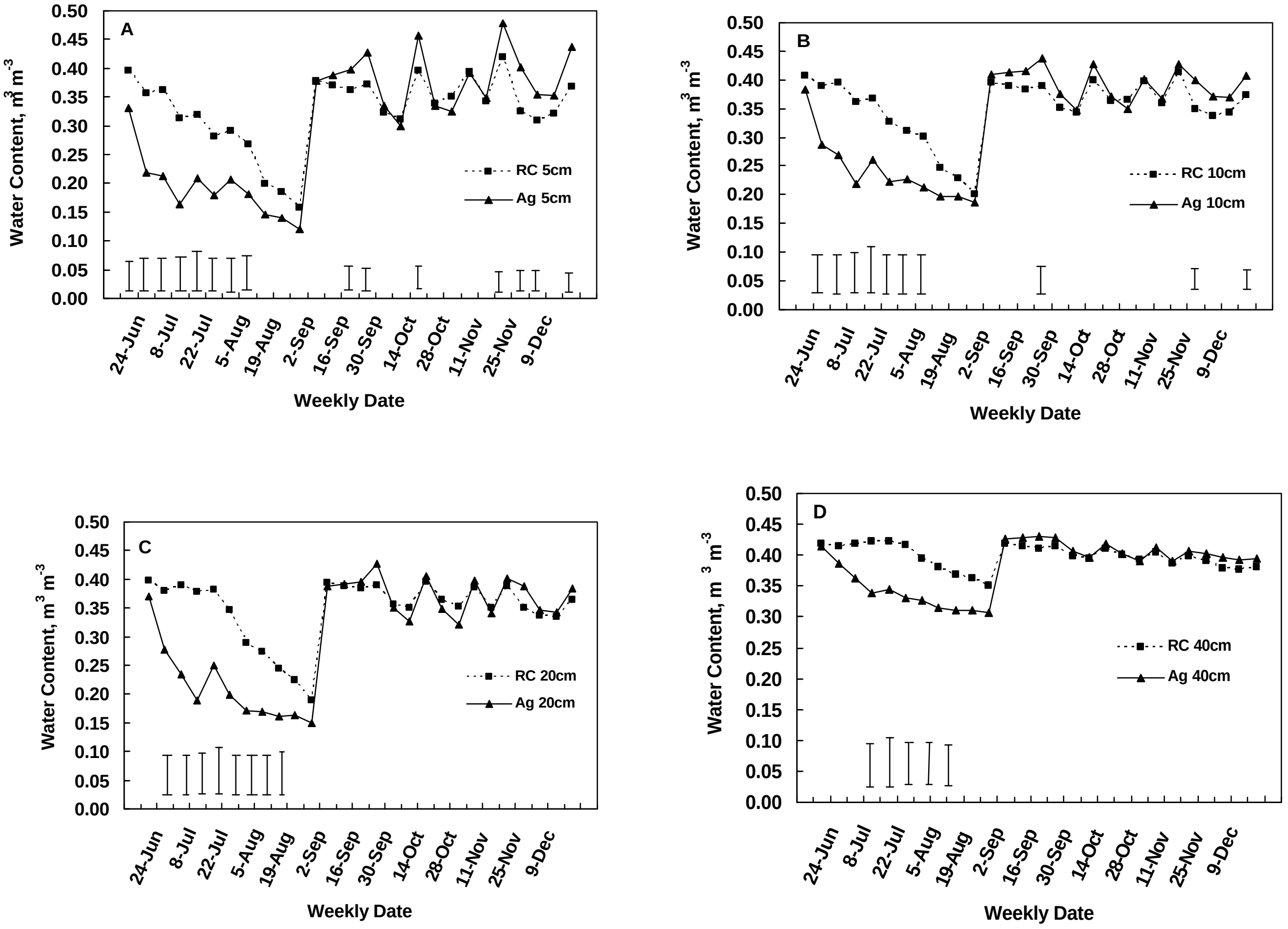

Figure 4. Average soil water content detected at 12:00 noon each Tuesday for a six month period in 2003 as affected by treatments for A) 5 cm, B) 10 cm, C) 20 cm, and D) 40 cm depths (n=4). RC = row crop, Ag = agroforestry buffer. Bars indicate LSD (0.05) values for dates with differences between treatments.

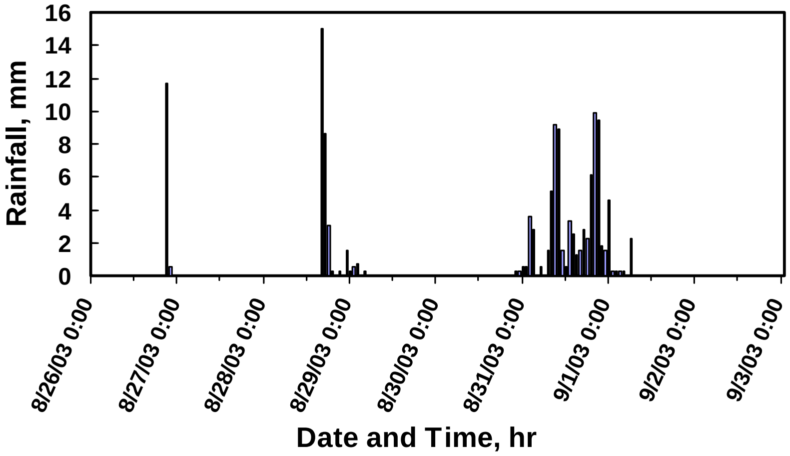

Figure 5. Hourly rainfall during the principal recharge period in 2003 from 26 August through 2 September at the watershed site.

rainfall event was the longest of the three and began at 21:00 h on 30 August and lasted 33 hours. Two periods during the third rainfall event accounted for 56.9% of the 85.32 mm for the event. The first high rainfall period was for three hours beginning at 7:00 h on 31 August and accounted for 27.1% of the rain event. The second high rainfall period was also for three hours beginning at 18:00 hours on 31 August and accounted for 29.8% of the rain for this event.

Water content values as a function of time (10-minute intervals) and treatment for the four soil depths during 26 August to 3 September are shown in Figure 6. Data in Figure 6A show that all three rainfall events changed the water content for both treatments at the 5 cm depth. Only slight changes in water content occurred for the first event at the 10 cm depth (Figure 6B); no changes in water content were observed at the 20 and 40 cm depths for this event (Figures 6C and 4D). Only the third rainfall event during this week caused significant changes in soil water content for all four depths. No significant differences ($P>0.05$) were found between water content values between treatments for the four soil depths. This was probably due to variability between the four replicates.

Increases in soil water content for each rainfall event during this principal recharge week were summed (weighted averages) across the four soil depth increments (7.5, 7.5, 15, and 20 cm) to estimate soil profile recharge within 50 cm for the three events. No significant differences in profile recharge between treatments were found for the three different events. Profile recharge averaged across treatments and depths for the three events were 2.58, 24.96, and 73.74 mm, respectively. This indicates that this method accounted for 21.1, 81.9, and 86.4% of the rainfall for the three events, respectively, or 79.1% of the total rain for the week. All of the rain was not accounted for (no runoff measured from watershed) possibly due to higher increases in water content at soil depths at the soil surface or between sensors and the fact that the sensors were installed horizontally and thus would not capture the entire soil water profile (Zegelin et al. 1992).

There were significant differences ($P<0.05$) between the treatments for the soil profile recharge summed across the three rainfall events. The agroforestry buffer treatment had 23% higher profile recharge with 111.8 mm of recharge compared to 90.8 mm for the row crop treatment. This was probably due to lower water content in the profile prior to recharge for the agroforestry treatment and subsequent greater infiltration during recharge.

CONCLUSIONS

Water infiltration and flow dynamics in soil are significant factors for crop growth, nutrient cycling, and contaminant transport. A study was conducted to examine influences of agroforestry on infiltration and changes in water content throughout the growing season. *In situ* ponded infiltration measurements were conducted on row crop, grass buffer and agroforestry buffer treatments. Water monitoring sensors were installed in the row crop and agroforestry buffer treatments at four depth increments. No significant differences were found among treatments in the quasi-steady infiltration rate (q_s), the Green-Ampt model estimated hydraulic conductivity (K_s) and sorptivity (S), and the Parlange model estimated K_s and S. The Parlange model parameter estimates were slightly higher than the Green-Ampt model parameter estimates

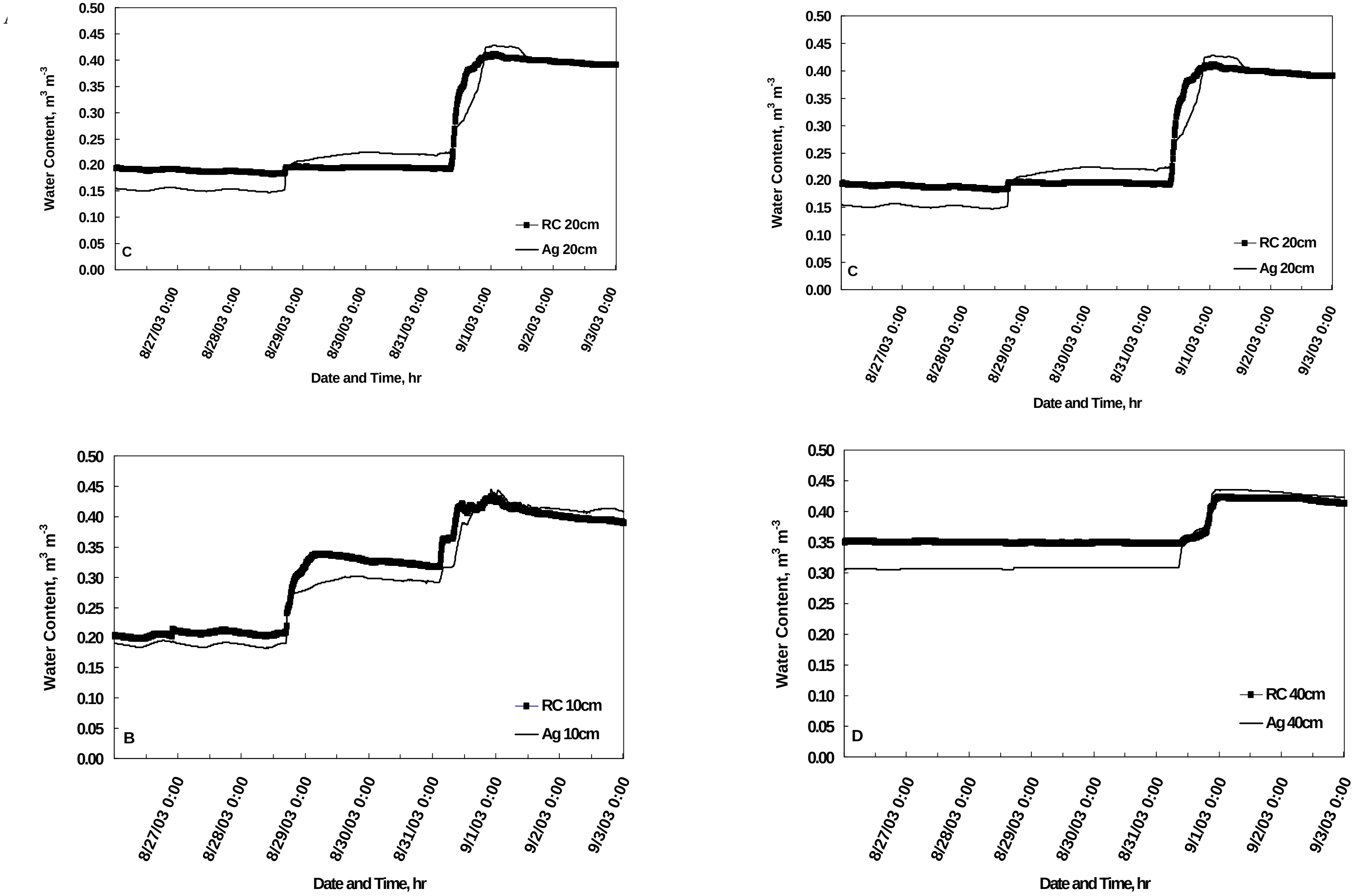

Figure 6. Average water content detected at 10 minute intervals for eight days as affected by treatments for A) 5 cm, B) 10 cm, C) 20 cm, and D) 40 cm depths (n=4). RC = row crop, Ag = agroforestry buffer. No significant differences (P>0.05) were detected.

The agroforestry treatment had lower water content compared to the row crop treatment near the beginning of the season in mid-June. This was attributed to greater transpiration from trees and grasses relative to the soybean plants. A principal recharge period occurred from 26 August to 2 September with three major rain events. After the recharge period, water content in the agroforestry treatment was significantly higher at shallow depths (5 and 10 cm) than the row crop treatment for some dates during the fall recharge. Profile recharge averaged over the top 50 cm was significantly higher ($P<0.05$) for the agroforestry than the row crop treatment during the principal recharge period.

Although there were no significant treatment effects in measured ponded infiltration, soil water content monitoring indicated that the agroforestry treatment had more water depletion compared with the row crop treatment during the growing season. Greater profile recharge during subsequent rainfall periods occurred in the agroforestry treatment relative to the row crop treatment indicating more water storage. The results of the study indicate that agroforestry buffer strips had more water use/transpiration during the growing season that allowed more water to be stored in the profile through increased water infiltration thus reducing runoff and soil loss for watersheds under this management system. Incorporation of agroforestry practices may help reduce nonpoint source pollution from row crop agriculture. Assessment of long-term effects and site-specific management requires continued research to meet production objectives and environmental benefits.

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REFERENCES

Bharati, L., K.-H. Lee, T. M. Isenhart, and R. C. Schultz. 2002. Soil-water infiltration under crops, pasture, and established riparian buffer in Midwest USA. *Agrofor. Syst*. 56:249-257.

Blanco-Canqui, H., C. J. Gantzer, S. H. Anderson, E. E. Alberts, and F. Ghidey. 2002. Saturated hydraulic conductivity and its impact on simulated runoff for claypan soils. *Soil Sci. Soc. Am. J*. 66:1596-1602.

Blevins, D. W., D. H. Wilkison, B. P. Kelly, and S. R. Silva. 1996. Movement of nitrate fertilizer to glacial till and runoff from a claypan soil. *J. Environ. Qual*. 25:584-593.

Bouma, J. 1980. Field measurement of soil hydraulic properties characterizing water movement through swelling clay soils. *J. Hydrology* 45:149-158.

Cadisch, G., P. de Willigen, D. Suprayogo, D. C. Mobbs, M. van Noordwijk, and E. C. Rowe. 2004. Catching and competing for mobile nutrients in soils. In *Below-ground interactions in tropical agroecosystems*, eds., van Noordwijk, M., G. Cadisch, and C. K. Ong, 171-191. CABI Publishing, MA.

Chan, K. Y., and J. A. Mead. 1989. Water movement and macroporosity of an Australian Alfisol under different tillage and pasture conditions. *Soil Tillage Res*. 14:301-310.

Clausnitzer, V., J. W. Hopmants, and J. L. Starr. 1998. Parameter uncertainty analysis of common infiltration models. *Soil Sci. Soc. Am. J*. 62:1477-1487.

Clothier, B., and D. Scotter. 2002. Unsaturated water transmission parameters obtained from infiltration. In *Methods of soil analysis*. Part 4, eds., Dane, J. H., and G. C. Topp, 879-898. Madison, WI: SSSA.

Dinnes, D. L., D. L. Karlen, D. B. Jaynes, T. C. Kaspar, J. L Hatfield, T. S. Colvin, and C. A. Cambardella. 2002. Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. *Agron. J*. 94:153-171.

Dupraz, C. 1999. Adequate design of control treatments in long term agroforestry experiments with multiple objectives. *Agrofor. Syst*. 43:35-48.

Farmer, R. E. 1980. Relationship of leaf area and dry weight to height and volume in a young plantation of northern red oak. *Tree Planters' Notes* 16-17.

Garrity, D. P. 2004. Agroforestry and the achievement of the millennium development goals. In *New vistas in agroforestry, A compendium for the 1st world congress of agroforestry*, eds., Nair, P.K.R., M. R. Rao, and L. E. Buck, 5-17. New York: Kluwer Academic Publishers.

Gillespie, A. R., S. Jose, D. B. Mengel, W. L. Hoover, P. E. Pope, J. R. Seifert, D. J. Biehle, T. Stall, and T. Benjamin. 2000. Defining competition vectors in a temperate alleycropping system in the Midwestern USA: I. Production physiology. *Agroforestry Systems* 48:25-40.

Gilley, J. E., B. Eghball, L. A. Kramer, and T. B. Moorman. 2000. Narrow grass hedge effects on runoff and soil loss. *J. Soil and Water Conserv*. 55:190-196.

Green, W. H., and G. A. Ampt. 1911. Studies on soil physics:1. Flow of air and water through soils. *J. Agric. Sci*. 4:1-24.

Haws, N. W., B. Liu, C. W. Boast, P. S. C. Rao, E. J. Kladivko, and D. P. Franzmeier. 2004. Spatial variability and measurement scale of infiltration rate on an agricultural landscape. *Soil Sci. Soc. Am. J.* 68:1818-1826.

Jamison, V. C., and D. B. Peters. 1967. Slope length of claypan soil affects runoff. *Water Resour. Res*. 3:471-480.

Jin, C. X., M. J. M. Romkens, and F. Griffioen. 2000. Estimating Manning's roughness coefficient for shallow overland flow in non-submerged vegetative filter strips. *Trans. ASAE* 43:1459-1466.

Jose, S., A. R. Gillespie, J. R. Seifert, and D. J. Biehle. 2000. Defining competition vectors in a temperate alley cropping system in the Midwestern USA: II. Competition for water. *Agrofor. Syst*. 48:41-59.

McGinty, K. S. 1989. Tillage and temporal variability of infiltration. MS Thesis. Columbia, MO: University of Missouri-Columbia.

Munoz-Carpena, R., J. E. Parson, and J. W. Gillian. 1993. Numerical approach to the overland flow process in vegetative filter strips. *Trans. ASAE* 36:761-770.

Or, D., and J. M. Wraith. 2002. Soil water content and water potential relationships. In *Soil physics companion*, ed., Warrick, A. W., 49-84. Boca Raton, FL: CRC Press.

Parlange, J. Y., I. Lisle, R. D. Braddock, and R. E. Smith. 1982. The three-parameter infiltration equation. *Soil Sci*. 133:337-341.

Philip, J. R. 1957. The theory of infiltration: 4. Sorptivity and algebraic infiltration equation. *Soil Sci.* 84:257-264.

Rachman, A., S. H. Anderson, C. J. Gantzer, and A. L. Thompson. 2004. Influence of stiff-stemmed grass hedge systems on infiltration. *Soil Sci. Soc. Am. J*. 68:2000-2006.

Rachman, A., S. H. Anderson, C. J. Gantzer, and E. E. Alberts. 2004b. Soil hydraulic properties influenced by stiff-stemmed grass hedge system. *Soil Sci. Soc. Am. J*. 68:1386-1393.

Rasse, D. P., A. J. M. Smucker, and D. Santos. 2000. Alfaalfa root and shoot mulching effects on soil hydraulic properties and aggregartion. *Soil Sci. Soc. Am. J*. 64:725-731.

SAS Institute. 1989. *SAS/STAT user's guide*. Ver. 6. 4th ed. Cary, NC: SAS Institute, Inc.

Schwab, G. O., D. D. Fangmeier, W. J. Elliot, and K. K. Frevert. 1993. *Soil and water conservation engineering*. 4th ed. New York, NY: Wiley, New York.

Schmitt, T. J, M. G. Dosskey, and K. D. Hoagland. 1999. Filter strip performance and processes for different vegetation, widths, and contaminants. *J. Environ. Qual*. 28:1479-1489.

Seobi, T., S. H. Anderson, R. P. Udawatta, and C. J. Gantzer. 2005. Influence of grass and agroforestry buffer strips on soil hydraulic properties for an Albaqualf. *Soil Sci. Soc. Am. J.* 69: *In press.*

Sharma, M. L., G. A. Gander, and C. G. Hunt. 1980. Spatial variability of infiltration in a watershed. *J. Hydrol*. (Amsterdam) 45:101-122.

Tricker, A. S. 1981. Spatial and temporal patterns of infiltration. *J. Hydrol*. (Amsterdam) 49:261-277.

Udawatta, R. P., and G. S. Henderson. 2003. Root distribution relationships to soil properties in Missouri oak stands: A productivity index. *Soil Sci. Soc. Am. J*. 67:1869-1878.

Udawatta, R. P., J. J. Krstansky, G. S. Henderson, and H. E. Garrett. 2002. Agroforestry practices, runoff, and nutrient loss: a paired watershed comparison. *J. Environ. Qual*. 31:1214-1225.

Udawatta, R. P., P. P. Motavalli, and H. E. Garrett. 2004. Phosphorus loss and runoff characteristics in three adjacent agricultural watersheds with claypan soils. *J. Environ. Qual*. 33:1709-1719.

Udawatta, R. P., P. Nygren, and H. E. Garrett. 2005. Growth of three oak species during establishment in an agroforestry practice for watershed protection. *Canadian J. For. Res*. 35: (*in press*).

Wells, R. R., D. A. DiCarlo, T. S. Steenhuis, J-Y. Parlange, M. J. M. Römkens, and S. N. Prasad. 2003. Infiltration and surface geometry of a swelling soil following successive simulated rainstorm. *Soil Sci. Soc. Am. J.* 67:1344-1351.

Wienhold, B. J., and D. L. Tanaka. 2000. Haying, tillage, and nitrogen fertilization influences on infiltration rates at a conservation reserve program site. *Soil Sci. Soc. Am. J*. 64:379-381.

Zahner, R. 1955. Soil moisture depletion by pine and hardwood stands during dry season. *For. Sci*. 1:258-265.

Zegelin, S. J., I. White, and G. F. Russell. 1992. A critique of the time domain reflectometry technique for determining field soil-water content. In *Advances in measurement of soil physical properties: bringing theory into practice. Proc. Symp. SSSA,* eds., Topp, G. C., et al., 187-208, San Antonio, TX. 21-26 Oct. 1990. SSSA Spec. Publ. 30. Madison, WI: SSSA.