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AGROFORESTRY AND GRASS BUFFER INFLUENCES ON WATER INFILTRATION FOR A GRAZED PASTURE SYSTEM

Sandeep Kumar¹, Stephen H. Anderson¹, Ranjith P. Udawatta^{1,2}, and
Robert L. Kallenbach³

¹Soil, Environmental and Atmospheric Sciences, University of Missouri-Columbia.

²Center for Agroforestry, University of Missouri-Columbia.

³Division of Plant Sciences, University of Missouri-Columbia Columbia, MO 65211, USA.

Contact: sk9fd@mizzou.edu

Abstract: Agroforestry and grass buffers are often adopted as an alternative resource management system in agriculture for environmental and economic benefits. The objective of the study was to compare agroforestry (AgB) and grass buffer (GB) systems under rotationally grazed (RG) and continuously grazed (CG) pasture systems on water infiltration measured using ponded infiltration and tension infiltration methods. Buffer areas were fenced which prevented cattle grazing in buffer areas. Soils at the site are Menfro silt loam (fine-silty, mixed, superactive, mesic Typic Hapludalfs). Infiltration rates were measured using ponded ring infiltration units in 2007 and 2008 for the four treatments with six replicates. Infiltration rate as a function of tension (at 50-, 100-, and 150-mm) was also measured using a tension infiltrometer in 2007. Water infiltration parameters were estimated using Green-Ampt and Parlange infiltration equations. Quasi-steady state infiltration rates (q_s) and field-saturated hydraulic conductivity (K_{fs}) for the buffers were about 30 and 40 times higher compared to pasture treatments, respectively. Green-Ampt and Parlange models appeared to fit measured data with r^2 values ranging between 0.91 to 0.98. The infiltration rate in 2007 for the GB treatment was the highest (221.4 mm h⁻¹) and for the CG treatment was the lowest (3.73 mm h⁻¹). Estimated sorptivity (S) and saturated hydraulic conductivity (K_s) parameters were higher for buffers compared to the pasture treatments. Grazing reduced infiltration rates for the pasture (CG and RG) treatments. Results show that the buffer areas have higher infiltration rates which imply lower runoff compared to pasture areas.

Keywords: Agroforestry buffer, grass buffer, Green-Ampt equation, Parlange equation, sorptivity, saturated hydraulic conductivity, water infiltration.

INTRODUCTION

Water infiltration is affected by various factors such as soil texture and structure, landscape position, management system, soil organic carbon, vegetative cover and antecedent water content. Vegetative covers have been found to increase soil organic carbon content which improves soil properties and to increase the infiltration rate. Meek et al. (1992) reported that channels formed by perennial roots are the major cause of increasing the infiltration rate. Management practices which increase soil macropores usually increase the infiltration rate.

Reduced infiltration leads to less water stored in the soil for later use by crops and often reduces crop yields (Connolly et al., 1997). Runoff associated with low infiltration is also the driving

force for soil erosion, a serious problem for sloping lands (Freebairn et al., 1986; Radford et al., 1992). Hoof trampling by grazing cattle damages the vegetation and soils of pasture areas with high stock densities (Betteridge et al., 1999; Sheath and Boom, 1997) which affects infiltration.

Agroforestry and grass buffers establish deep root systems which increase the proportion of macropores and improve the soil hydraulic properties as compared to row crop systems (Cadisch et al., 2004). Agroforestry and grass buffers are sometimes used in combination with pastures with fencing for the buffers to prevent disturbance by grazing animals. In these buffer systems where the tree and grass buffer areas are left undisturbed by grazing animals, soil properties are different compared to pasture areas which are disturbed by grazing (Kumar et al. 2008). Frequent and uneven grazing in pasture areas has been found to lower infiltration due to compaction from continuous animal traffic (Daniel et al., 2002). However, rotational grazing where cattle are allowed to graze in sequence has been shown to improve productivity of cattle compared to conventional grazing (Warren et al., 1986).

Very few studies have been conducted to evaluate the impact of buffers on water infiltration compared to grazed pasture systems. The purpose of the current study was to compare the effects of agroforestry and grass buffers on water infiltration relative to rotationally grazed and continuously grazed pasture systems. The objective of the study was to measure and compare water infiltration parameters among agroforestry buffer, grass buffer, rotationally grazed pasture and continuously grazed pasture treatments.

MATERIALS AND METHODS

Experimental site and management

The experimental site is located at the Horticulture and Agroforestry Research Center (HARC) in New Franklin, Missouri (39°02'N, 92°46'W, 195 m above mean sea level). The study site was established in 2000 to compare the influence of grass and agroforestry buffers on runoff water quality. The pasture areas and grass buffers were re-seeded with tall fescue (*Festuca arundinacea* Schreb; Kentucky 31) in 2000. Red clover (*Trifolium pretense* L.) and lespedeza (*Kummerowia stipulacea* Maxim.) were seeded into the fescue in 2003 (Kumar et al., 2008). Eastern cottonwood trees (*Populus deltoids* Bortr. ex Marsh.) were planted in 2001 into the fescue for areas designated to be agroforestry buffers. Additional information about the experimental site can be found in Kumar et al. (2008).

Soils at the site are Menfro silt loam (fine-silty, mixed, superactive, mesic Typic Hapludalfs). The grass and agroforestry buffer areas were fenced from pasture areas preventing access by cattle. The rotationally grazed pasture treatment area was rotationally grazed with six fenced areas (paddocks) within the small watershed. The continuously grazed pasture treatment was continuously grazed by cattle with no rest. Treatments included agroforestry buffer (AgB), grass buffer (GB), rotationally grazed pasture (RG), and continuously grazed pasture (CG).

Beef cows were introduced each year in the pasture area with weights between 450 kg to 590 kg. The number of cattle for the small watershed (0.8 ha) was three. Eighty-five percent of the grazing area (0.64 ha) of the watershed was divided into six smaller rotationally grazed paddocks

with single wire electric fences for cattle management. The other 15% of the grazing area was continuously grazed. The cows were moved between paddocks on each Monday and Thursday with each paddock being grazed for 3.5 days and rested for 17.5 days (Kumar et al., 2008).

Ponded infiltration measurements

Water infiltration was measured using ponded ring infiltration units for four treatments with six replicates. The AgB measurements were taken from soil under six replicate trees, three each from two tree rows in the agroforestry buffer area. These infiltration measurements were taken at a distance of 20 cm from the base of tree trunks in the agroforestry buffer. The GB treatment measurements were taken from six replicate grass buffer areas. The RG samples were taken from six replicate rotationally grazed areas and the CG treatment measurements were taken from six replicate continuously grazed areas.

Infiltration rates were measured in late May 2007 and June 2008 using a single-ring infiltrometer with 25-cm inner diameter and 30-cm length. The ring was driven 15-cm into the soil. A positive head of 50 mm was maintained inside the ring using a Mariotte system. Infiltration measurements were conducted for about 90 to 120 minutes. Two infiltration models were used to fit infiltration data which include the Green-Ampt model (1911), and the Parlange et al. (1982) model. Throughout this paper, the Parlange et al. (1982) model will be used to referred to the Parlange model.

The Green-Ampt (1911) infiltration equation was modified by Philip (1957) for time (t) vs. cumulative infiltration (I), as follows:

$$t = \frac{I}{K_s} - \frac{\left[S^2 \ln\left(1 + \frac{2IK_s}{S^2}\right) \right]}{2K_s^2} \quad [1]$$

The physically based Parlange equation for t vs. I is

$$t = \frac{I}{K_s} - \frac{S^2 \left[1 - \exp(-2IK_s / S^2) \right]}{2K_s^2} \quad [2]$$

where t (T) is time (h), I (L) is the cumulative infiltration (mm), S ($L T^{-0.5}$) is the sorptivity ($mm h^{-0.5}$), and K_s ($L T^{-1}$) is the saturated hydraulic conductivity ($mm h^{-1}$). For estimating the S and K_s parameters, the method proposed by Clothier et al. (2002) was used.

The method to estimate field saturated hydraulic conductivity (K_{fs}) suggested by Reynolds et al. (2002) was used for estimating this parameter. It assumes one-dimensional water flow in the infiltration ring, and uses the following equation:

$$K_{fs} = \frac{q_s}{\left(\frac{H}{C_1d + C_2a} \right) + \left\{ \frac{1}{\chi^* (C_1d + C_2a)} \right\} + 1} \quad [3]$$

where K_{fs} is the field-saturated hydraulic conductivity (mm h^{-1}), q_s is the quasi-steady infiltration rate (mm hr^{-1}), a is the radius of the infiltration ring (mm), H is the hydraulic head of ponded water in the ring (mm), d is the depth of ring insertion into the soil (mm), C_1 and C_2 are dimensionless quasi-empirical constants ($C_1=0.993$ and $C_2=0.578$ for this infiltrometer), and α^* is the soil macroscopic capillary length, assumed to be equal to 0.036 mm^{-1} for the agroforestry buffer and grass buffer treatments, 0.012 mm^{-1} for the rotationally grazed pasture treatment, and 0.004 mm^{-1} for the continuously grazed pasture treatment (Reynolds et al., 2002).

Tension infiltration measurements

After completion of the measurements for ponded infiltration, without removing the ring infiltrometer, infiltration was measured with a tension infiltrometer at 50-, 100-, and 150-mm tensions. The ring was filled with a 0.5 cm deep sand layer. Infiltration was measured for 20 minutes at 1-minute intervals. After infiltration data at 50-mm tension were recorded; the tension was increased by removing the bubbling tube from the disc and then setting the tension to 100 mm. This procedure was repeated for the 150-mm tension setting. Tension infiltration measurements were only conducted during 2007.

Statistical Analysis

A test for homogeneity of variance was conducted to evaluate the variability in the infiltration measurements within the different treatments 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, 1999). Different contrasts were also determined and were conducted for the following contrasts: *buffers vs. pastures*, *grass buffer vs. agroforestry buffer*, and *rotationally grazed pasture vs. continuously grazed pasture*. Statistical differences were declared significant at the $\alpha = 0.05$ level.

RESULTS AND DISCUSSION

Ponded infiltration measurements

Two infiltration models were fit to infiltration data as a function of time for typical replicates for the agroforestry buffer (AgB), grass buffer (GB), rotationally grazed pasture (RG) and continuously grazed pasture (CG) treatments for 2007 (Fig. 1). The Green-Ampt and Parlange models fit the measured infiltration data reasonably well with the average coefficients of determination (r^2) ranging from 0.91 to 0.98.

The K_s and S parameters estimated with the Green-Ampt model were significantly higher for the AgB and GB treatments as compared to pasture treatments for both years (Table 1). Both parameters were also significantly higher for the GB treatment compared to AgB (except the Green-Ampt estimated K_s parameter for 2008; Table 1). These parameters were not significantly different between the RG and CG pasture treatments for both years. The continuously grazed pasture (CG) treatment had the lowest numerical values for K_s and S parameters estimated by the Green-Ampt and Parlange models for 2007 but not in 2008 (Table 1). In 2007, the Green-Ampt estimated K_s and S parameters were about 15.6 and 13.7 times higher in the buffer treatments

compared to pasture treatments, while values were about 8 and 15.8 times higher for buffers in 2008 as compared to pasture treatments. The values for these parameters estimated with the Parlange model were 22.7 and 12 times higher for the buffer treatments in 2007 compared to pasture treatments, while buffer treatments were 8.7 and 12.4 times higher in 2008 relative to pasture treatments.

Coefficients of variation for the fitted parameters (Green-Ampt and Parlange models) ranged from 14.0 to 106.6 for the four treatments in 2007 and 2008 (Table 1). One possible reason for the higher values for the S parameter may be due to slightly lower antecedent water content; the volumetric water content for the 0-30 cm soil profile for the buffers was 7.7 and 13.5% lower as compared to pastures in 2007 and 2008, respectively.

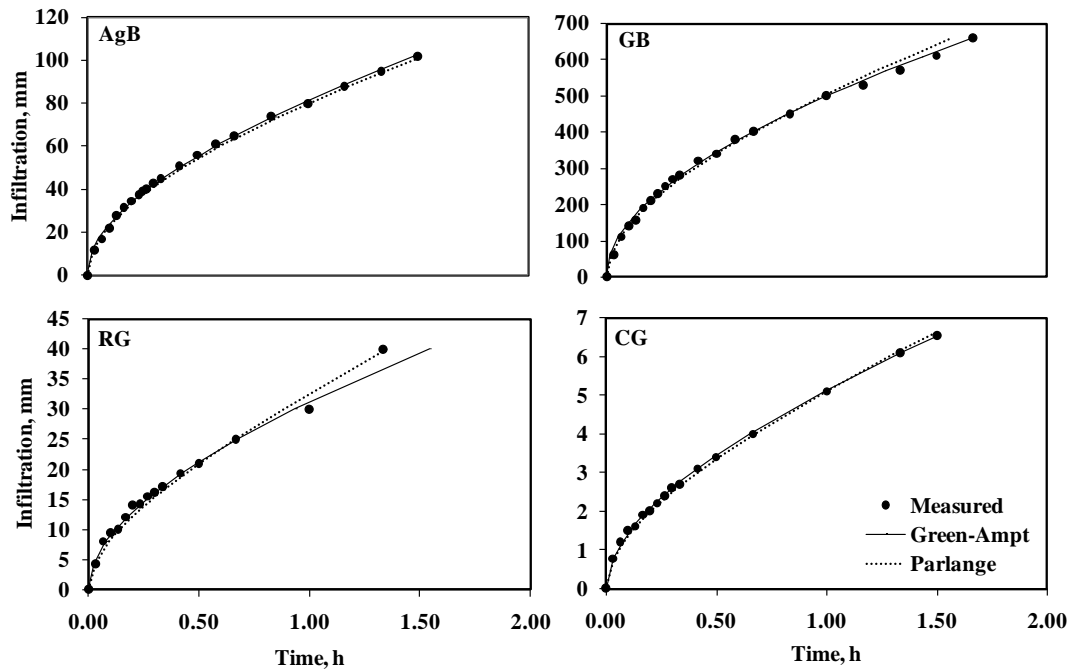


Figure 1. The Green-Ampt and Parlange models fitted to measured ponded infiltration data for typical replicates under agroforestry buffer (AgB), grass buffer (GB), rotationally grazed pasture (RG), and continuously grazed pasture (CG) treatments for 2007. Please note that y-axis scale is different for the treatments.

The quasi-steady state infiltration rate (q_s) and field saturated hydraulic conductivity (K_{fs}) were significantly different ($P < 0.01$) among the treatments. The q_s and K_{fs} values were significantly higher for GB treatment compared to other treatments in 2007 but significant differences were not observed among the other three treatments (Table 2). In 2008, both these parameters for the AgB and GB treatments were significantly higher as compared to pasture treatments (Table 2). The q_s and K_{fs} parameters were not significantly different between the RG and CG treatments for both years. The q_s and K_{fs} parameters for the buffers were about 14 and 19 times higher, respectively, as compared to pasture treatments in 2008 (Table 2).

The coefficients of variation (CV) for the CG treatment were found to be higher for these parameters in 2007 (81 %) and 2008 (66 %) compared to the other treatments. Similar CV values were found for the GB and RG treatments with average CV values of 63 and 55% for these years. The lowest CV values were found for the AgB treatment. The higher values of CV for the RB and CG treatments were probably due to lower mean values of q_s and K_{fs} parameters.

The buffers, which are prevented from cattle grazing by fences, had better plant root and shoot growth which improved the soil properties compared to grazed pasture areas. Kumar et al. (2008) reported 16.7 times higher saturated hydraulic conductivity and 11.2% lower bulk density for buffers compared to grazed pasture areas at the same site. Thus, higher infiltration is expected due to the higher saturated hydraulic

Table 1. Geometric means and coefficients of variation (CV) for saturated hydraulic conductivity (K_s) and sorptivity (S) parameters estimated by the Green-Ampt and Parlange models in the agroforestry buffer (AgB), grass buffer (GB), rotationally grazed pasture (RG), and continuously grazed pasture (CG) treatments in 2007 and 2008 (n=6).

Year	2007				2008			
	K_s		S		K_s		S	
Treatments	Mean mm h ⁻¹	CV %	Mean mm h ^{-0.5}	CV %	Mean mm h ⁻¹	CV %	Mean mm h ^{-0.5}	CV %
Green-Ampt model								
AgB	46.2 ^{b†}	53.0	94.6 ^b	38.4	71.6 ^a	49.1	133.0 ^b	57.9
GB	120.3 ^a	44.2	258.1 ^a	46.6	81.7 ^a	66.4	325.8 ^a	28.8
RG	8.59 ^c	73.3	19.5 ^b	42.8	7.90 ^b	92.2	10.8 ^c	59.2
CG	2.07 ^c	58.3	6.32 ^c	46.0	11.3 ^b	47.9	18.1 ^c	42.9
Parlange model								
AgB	40.0 ^b	23.5	80.8 ^b	14.0	83.2 ^b	64.6	110.6 ^b	43.1
GB	158.7 ^a	35.5	239.9 ^a	50.7	159.8 ^a	39.9	257.8 ^a	45.7
RG	6.75 ^{bc}	105.6	21.3 ^b	48.4	14.2 ^c	106.6	12.5 ^c	73.4
CG	2.00 ^c	50.9	5.17 ^b	56.2	13.8 ^c	58.4	17.1 ^c	41.0

[†]Means with different letters are significantly different at the 0.05 probability level.

Table 2. Geometric means and coefficients of variation (CV) of quasi-steady state infiltration rate (q_s) and field-saturated hydraulic conductivity (K_{fs}) for the agroforestry buffer (AgB), grass buffer (GB), rotationally grazed pasture (RG), and continuously grazed pasture (CG) treatments in 2007 and 2008 (n=6).

Treatments	Year							
	2007				2008			
	q_s		K_{fs}		q_s		K_{fs}	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV
	mm h ⁻¹	%	mm h ⁻¹	%	mm h ⁻¹	%	mm h ⁻¹	%
AgB	80.4 ^{b†}	14.7	59.5 ^b	14.7	105.8 ^b	16.6	78.2 ^b	16.6
GB	221.4 ^a	61.1	163.8 ^a	61.1	245.0 ^a	51.7	181.2 ^a	51.7
RG	6.15 ^b	65.6	3.84 ^b	65.6	14.8 ^c	58.4	9.23 ^c	58.4
CG	3.73 ^b	81.0	1.58 ^b	81.0	9.93 ^c	65.7	4.22 ^c	65.7

†Means with different letters are significantly different at the 0.05 probability level.

conductivity in the buffers. Hence, buffers were shown to improve water infiltration into the soil which would indicate less runoff from these areas compared to grazed pastures areas (RG and CG treatments).

Tension infiltration measurements

Measured infiltration rates at 50-, 100-, and 150-mm tensions for the AgB, GB, RG and CG treatments are shown in Table 3. Infiltration rates at 50 and 100 mm tension were significantly affected by the treatments (P<0.05; Table 3). The infiltration rate values measured at 50 and 100 mm were significantly higher for the GB treatment as compared to the other three treatments,

Table 3. Means of infiltration rate (q_s) as a function of tension for the agroforestry buffer (AgB), grass buffer (GB), rotationally grazed pasture (RG), and continuously grazed pasture (CG) treatments in 2007 year (n=6).

Treatments	Tension, mm water		
	50	100	150
	q_s (mm h ⁻¹)		
AgB	1.04 ^{b†}	0.32 ^b	0.21 ^{ab}
GB	2.77 ^a	1.45 ^a	0.40 ^a
RG	0.37 ^b	0.21 ^b	0.12 ^{ab}
CG	0.21 ^b	0.14 ^b	0.06 ^b
Analysis of variance P > F			
Treatment	<0.01	0.02	0.08
Buffers vs. Pastures	<0.01	0.03	0.02
GB vs. AgB	0.02	<0.01	0.20
RG vs. CG	0.80	0.88	0.66

†Means with different letters within a column are significantly different at the 0.05 probability level.

while the infiltration rate at 150 mm tension was significant only between GB and CG treatments (Table 3). The infiltration rate at 50 mm tension for the GB treatment was about 2.7, 7.5, and 13 times higher compared to AgB, RG and CG treatments, respectively. Single degree of freedom contrasts *buffers vs. pastures* and *GB vs. AgB* were found to be significant at 50- and 100-mm tensions ($P < 0.05$). At 150 mm tension, the infiltration rate was significant only for *buffers vs. pastures*. Infiltration rate decreased with increased applied tension with the highest decrease occurring between the 0- to the 50-mm tension values. The decrease for AgB, GB, RG and CG treatments was about 99, 99, 94 and 94% between 0- to 50-mm tension.

Correlation between K_{fs} and K_{sat} .

Laboratory data for saturated hydraulic conductivity (K_{sat}) measured in 2007 for the 0-10 cm soil depth were correlated with K_{fs} values estimated from 2007 (Fig. 2). The coefficient of determination for this regression was found to be 0.56 between K_{fs} and K_{sat} . The slope of the regression was estimated as 0.39. Bouwer (1986) and Rachman et al. (2004) proposed that K_{fs} could be estimated as $0.5 \times K_{sat}$ and $0.65 \times K_{sat}$, respectively. In the current study, this coefficient was estimated as $0.4 \times K_{sat}$, which is slightly lower than the other two studies. Rachman et al. (2004) reported that K_{fs} and K_{sat} can be related when K_{sat} is measured in small cores of 76 by 76 mm dimensions (cores of similar dimensions used in the current study) if the potential rapid-pipe flow conduits are eliminated. This was also followed in the current study.

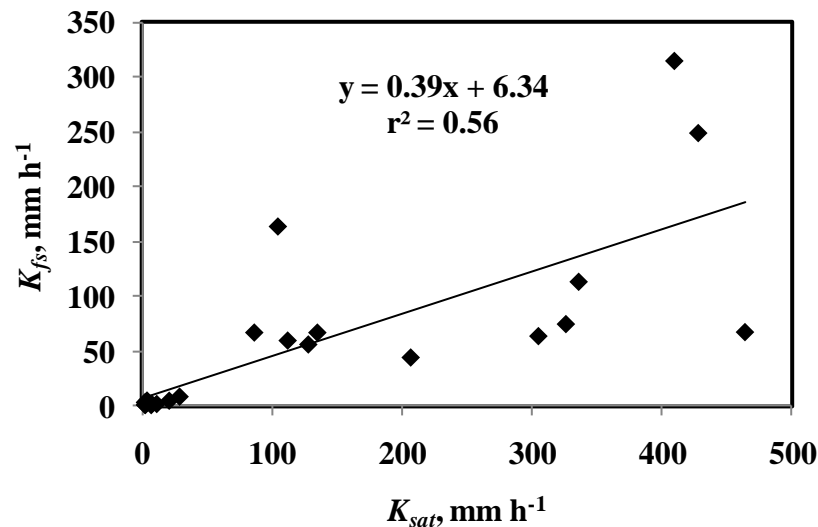


Figure 2. Field saturated hydraulic conductivity (K_{fs} , 2007 data) vs. laboratory measured saturated hydraulic conductivity (K_{sat} , 2007 data; $n=24$).

SUMMARY/CONCLUSIONS

Infiltration measurements were taken to evaluate the effects of buffers on water infiltration under grazed pasture systems. Agroforestry and grass buffers were compared to rotationally grazed and continuously grazed pasture areas. Buffers had 30 and 14 times higher quasi-steady state infiltration (q_s) in 2007 and 2008, respectively, as compared to pasture treatments. The q_s for the GB treatment (233.2 mm h^{-1}) was highest and for the CG treatment (6.83 mm h^{-1}) was lowest for the two year study. The Green-Ampt and Parlange models appeared to adequately fit the

measured infiltration data for the treatments as estimated using coefficients of determination. Fitted S and K_s parameters were highest for the GB treatment and lowest for the CG treatment. The infiltration rate decreased more between 0 and 150 mm tension for the buffer treatments compared to the pasture treatments. This was attributed to more macropores present in the buffer treatments.

Grazing reduced infiltration rates for pasture areas compared to buffer areas. Results show that the buffer areas had higher infiltration rates which imply lower runoff compared to pasture areas. Buffer areas were fenced which prevented cattle grazing in these areas which probably benefitted infiltration.

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