Bioenerg. Res. (2017) 10:824–831
DOI 10.1007/s12155-017-9843-6

The Effect of Five Biomass Cropping Systems on Soil-Saturated Hydraulic Conductivity Across a Topographic Gradient

Usman Anwar [1] · **Lisa A. Schulte** [1] · **Matthew Helmers** [2] · **Randall K. Kolka** [3]

Published online: 13 May 2017
© Springer Science+Business Media New York 2017

Abstract Understanding the environmental impact of bioenergy crops is needed to inform bioenergy policy development. We determined the effects of five biomass cropping systems—continuous maize (*Zea mays*), soybean (*Glycine max*)-triticale (*Triticosecale* ×)/soybean-maize, maize-switchgrass (*Panicum virgatum*), triticale/sorghum (*Sorghum bicolor*), and triticale-aspen (*Populus alba* × *P. grandidentata*)—on soil-saturated hydraulic conductivity (K_S) across a toposequence in central Iowa, USA. We compared data from the time of cropping system establishment in 2009 to 4 years post-establishment. Both our 2009 and 2013 data confirmed that cropping system impacts on K_S vary by landscape position. We found that differences in cropping system impacts were more likely to occur at lower landscape positions, specifically, within footslope and floodplain positions. Previous research on cropping system impacts suggested that grass and woody systems were associated with a general increase in K_S over time, with greater changes likely occurring at landscape positions with a higher erosive potential or lower SOC content. Our results confirmed that the triticale-aspen woody system was associated with a significant increase in K_S across all landscape positions. In contrast, we did not observe an increase in K_S under maize-switchgrass, which we attributed to the high density of switchgrass roots by the fourth year of study, but expect an increase in K_S under switchgrass under longer measurement periods. We also found a significant increase in K_S in the annual systems, likely due to the conversion to no-till soil management with cropping system establishment. We expect such differences to become more apparent over longer time scales as cropping systems continue to impact soil hydraulic properties.

Keywords Infiltration · Landscape biomass project · Maize · Soybean · Switchgrass · Woody biomass

✉ Usman Anwar
uanwar88@gmail.com

[1] Department of Natural Resource Ecology and Management, Iowa State University, 339 Science II, Ames, IA 50011, USA

[2] Department of Agricultural and Biosystems Engineering, Iowa State University, 1340 Elings Hall, Ames, IA 50011, USA

[3] Center for Research on Ecosystem Change, USDA Forest Service, 1831 Hwy 169 East, Grand Rapids, MN 55744, USA

Introduction

The development of sustainable bioenergy systems will require the expansion and use of alternative biomass feedstocks with varying environmental impacts. Globally, the conversion of native perennial vegetation to annual crops has led to declining water quality, freshwater habitat, and biodiversity [1]. Increased cultivation of annual crops such as maize (*Zea mays*) has led to an increase in runoff, erosion, and nutrient losses [2]. In contrast, perennial bioenergy crops are associated with reduced nutrient pollution, improved soil quality, lower nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions, and lower runoff and subsequent soil erosion [3, 4].

To better understand the potential environmental impacts of alternative energy crops, we investigated steady-state infiltration rates associated with five different cropping systems across five different landscape positions. K_S can significantly influence hydrological processes such as infiltration, runoff generation, and soil moisture content [5–7]. An understanding of how K_S differs among biomass cropping systems and landscape positions will improve our understanding of their potential environmental and hydrologic impacts.

K_S is influenced to a large degree by processes that contribute to soil structure and macropore formation [8, 9]. Higher soil organic carbon (SOC) content impacts hydraulic conductivity by influencing the production of stable soil aggregates, which affects pore size distribution and soil structure [10]. Soil management practices affect soil organic carbon and therefore also K_S [4, 11]. Tillage results in the loss of SOC and can also prevent the formation of stable soil aggregates and inhibit the development of a soil structure conducive to high infiltration rates [10, 12, 13]. Conversion from conventional till to no till can increase the rate of SOC accumulation [14–16]. Logsdon et al. found that minimum tillage and no tillage had significantly higher K_S values than tillage systems [17]. Edwards et al. attributed reduced surface runoff in a no-till watershed to greater infiltration and number of macropores compared to conventional tillage [18].

Plant systems with a higher rate of root growth and decay may contribute to both higher soil macroporosity and greater organic matter accumulation [19, 20]. Several studies have shown differences in K_S among cropping and perennial treatments. Soil under dense perennial vegetation, as in a natural prairie, can have nearly double the organic matter content of crop fields, and the K_S of such fields can be nearly 10 times higher than in crop fields [21]. Udawatta et al. found significantly greater numbers of macropores and macroporosity in soils from tree and grass systems compared to row-crop areas, which was correlated with higher K_S in those treatments [22]. The number of macropores accounted for as much as 64% of the variation in K_S. Eldridge and Freudenberger found significantly higher K_S values under eucalyptus trees compared to pasture or cultivated cropland, though this effect was only observed on fine-textured soil [23]. Jung et al. observed significantly lower K_S in three annual cropping systems (two with a maize-soybean [*Glycine max*] rotation at different fertilization rates and one with a winter cover crop) compared to three perennial cropping systems (multi-species perennial systems), and no significant differences among individual annual cropping systems [24].

The case is not settled, however, on the impacts of perennial versus annual plants on K_S. Anderson et al. found no significant differences in K_S among annual crop, grass, and forest treatment plots [25]. Similarly, Schwartz et al. did not find a significant difference in K_S between cropland (wheat [*Triticum aestivum*]/sorghum [*Sorghum bicolor*]) converted to grassland, suggesting that even after 10 years, conversion of cropland to grasses did not ameliorate changes in soil structure related to previous land use history [26].

Differences in K_S among treatments may partially be attributed to landscape position effects. Jiang et al. found that K_S and bulk density were significantly related to landscape position, with the midslope having significantly lower K_S than summit or footslope positions [19]. They also observed K_S was significantly higher in Conservation Reserve Program (CRP) plots compared to a mulch-till maize-soybean system at the backslope position [19], suggesting that perennial systems are more likely to improve soil hydraulic properties at slope positions with greater vulnerability to soil degradation.

Experimental Goals and Hypotheses

Improved understanding of the impacts of contrasting land uses on hydraulic properties of soils is critical for understanding the potential environmental and hydrological impacts of potential biomass cropping systems. Numerous factors may be involved in the development of hydraulic properties of soils under different cropping and management regimes. Specifically, the question of whether or not perennial systems alter the hydraulic properties of soils after conversion from annual cropping systems remains inconclusive.

To partially fill this knowledge gap, we compared K_S among five potential biomass cropping systems across a toposequence for a period of 4 years. Cropping systems included (1) continuous maize, (2) a modified rotation of soybean-triticale (*Triticosecale* ×)/soybean-maize, (3) maize-switchgrass, (4) triticale/sorghum, and (5) triticale-aspen (*Populus alba* × *P. grandidentata*), all under no-till soil management. We specifically sought to account for the influence of soil properties and landscape factors on hydraulic properties relative to crop or management effects. As reviewed above, previous research indicates that landscape position can interact with cropping and management treatments to influence soil hydraulic properties [15, 19]. Based on this research, we hypothesized the following:

- An increase in K_S over time with conversion from a maize-soybean system using conventional tillage to no-till biomass cropping systems;
- Greater increases in K_S over time in perennial than annual biomass systems;
- Higher K_S values in footslope and floodplain landscape positions than summit, shoulder, and backslope positions.

Materials and Methods

Site Description and Experiment Design

The Landscape Biomass experiment was established in fall 2008 at the Uthe Farm, an Iowa State University Research and Demonstration Farm located 20 km southwest of Ames, Iowa. The Uthe Farm provided the optimal landscape context and hillslope properties for the experiment, which sought to understand soil-water-crop relationships over a topographic gradient. The experiment was established on an eastward facing hillslope in a randomized, replicate block design. Two treatment factors (landscape position and cropping system) were applied to a total of 75 0.2-ha plots. Prior to establishment, the land use of the majority of the site was agriculture in a maize-soybean rotation with tillage, while approximately one half of the riparian floodplain plots were in mixed grasses. A full description of the experiment can be found in Wilson et al. [27].

Landscape Positions

We considered the five landscape positions as a blocking factor in this experiment. Within each position, plots were randomly assigned to a cropping treatment. The point of highest elevation along the hillslope was designated the summit. The position at the lowest elevation was designated the floodplain. The shoulder, backslope, and footslope positions are intervening positions with progressively lower elevation between the summit and floodplain; their delineation was also based on slope angle. The average slope across the entire site is 6%, with an elevation difference of 20 m between the summit and floodplain.

Soils vary across the site by landscape position and replicate. Ontl et al. [28] provide a characterization of the soils at the Landscape Biomass experimental site. Briefly, they have been classified as Nicollet loam (fine-loamy, mixed, superactive, mesic Aquic Hapudolls), Clarion loam (fine-loamy, mixed, superactive, mesic Typic Hapludolls), Coland clay loam (fine-loamy, mixed, superactive, mesic Cumulic Endoaqualls), Spillville loam (fine-loamy, mixed, superactive, mesic Cumulic Hapludolls), and Zenor sandy loam (coarse-loamy, mixed, superactive, mesic Typic Hapludolls). Clarion loam is most predominant across the site. Summit plots are found on Clarion, Nicollet, and Zenor; shoulder plots are found on Clarion and Zenor; backslope plots are entirely found on Clarion; and footslope plots are found on Clarion and Spillville soils. The floodplain plots, however, are entirely located on Coland soil.

Cropping Systems

All five biomass cropping systems investigated in this study were established in fall 2008 or spring 2009; cropping systems with triticale were established in fall 2008, while other crops were planted in spring 2009. Fertilization of treatments was based on soil nutrient tests; herbicide application was based on weed pressure. Detailed information on cropping system establishment and crop management can be found in Wilson et al. [27]. Within the maize-switchgrass system, maize was double cropped with switchgrass in 2009, while only switchgrass was grown in those plots between 2010 and 2013. The aspen trees in the triticale-aspen system were not harvested during the period of this study.

Sampling Procedure

Measurements were taken using a constant-head permeameter (Precision Permeameter, Johnson Permeameter LLC, Fairfax, VA, USA), which maintains a hydraulic head of water and pressure difference within the borehole during measurement. We used a soil auger to create boreholes for sampling. The borehole dimension measured 4.5-cm radius and 19-cm depth. The constant height of water in this borehole measured 15 cm. Measurements of K_S were taken between May and July in each of 2009 and 2013. Three measurements were taken at random locations within each of the 75 treatment plots (5 replicates × 5 cropping systems × 5 landscape positions), for a total of 225 measurements for each year. As the samples were randomly taken within plots, the measurements and analysis did not account for any soil characteristics.

K_S is a measure of the ability of a soil to transmit water and is a measure of hydraulic conductivity under saturated conditions, or when the hydraulic gradient is at unity [29]. K_S is typically reported as a rate. Under steady-state conditions, the infiltration rate is equivalent to K_S near the surface. The saturated hydraulic conductivity is estimated by an analytical solution that incorporates the steady-state flow rate of water into the soil, height of water in the borehole, and borehole geometry, known as the Glover solution [30].

$$K_S = Q_S\left[\sinh^{-1}(H/r) - \left(r^2/H^2+1\right)^{0.5} + r/H\right]/\left(2\pi H^2\right) \qquad \text{(Glover solution)}$$

where K_S is the saturated hydraulic conductivity, Q_S is the steady-state flow rate of water into the soil, H is the constant height of water in the borehole, and r is the radius of the borehole.

The steady-state flow rate, Q, was determined by visually observing the changing volume of water in a graduated cylinder at an interval of 1 min, until steady-state flow was achieved. Steady-state flow was considered the point at which the rate of volume change within the cylinder achieved a constant value. Using this procedure, K_S can be considered the average K_S of the entire wetted region [31].

Data Analyses

The observed measurements were analyzed using analysis of variance. Landscape position, cropping system, and year were treated as fixed effects. Interaction effects included landscape by cropping system, year by cropping system, and year by landscape position. A random effect was included to account for repeated measures within a plot. Comparison of individual treatments was achieved using the Holm-Tukey adjustment for multiple comparisons. Due to the difference in land use history for about one half of the floodplain, in preliminary investigations, we analyzed the data with and without floodplain measurements; because exclusion of the floodplain did not change our overall results or other pairwise comparisons [32], only analyses including data from the floodplain position are presented here. Significance of model parameters was determined at $P < 0.05$.

Results

Initial Conditions Following the Establishment of Treatments (2009)

In 2009, we observed a significant landscape position effect, but no significant effect of cropping system or interaction between landscape position and cropping system (Table 1). Differences by landscape position were driven by higher K_S in the backslope and floodplain positions (Table 2 and Fig. 1a).

Conditions 4 Years After the Establishment of Treatments (2013)

The landscape position effect, cropping system effect, and interaction between landscape position and cropping system were all significant in 2013 (Table 1). The landscape position effect and landscape position by cropping system interaction were affected by differences associated with the footslope and floodplain positions; average K_S values are higher in these positions (Fig. 1b and Table 2).

All cropping systems except maize-switchgrass were significantly affected by landscape position, although there were no significant differences among the upper four landscape positions for any cropping system (Table 2). Continuous maize, triticale/sorghum, and triticale-aspen all had significantly lower K_S values at the summit, shoulder, backslope, and footslope compared to the floodplain (Table 2 and Fig. 1b). The soybean-triticale/soybean-maize system showed significant differences amount the summit, footslope, and floodplain positions (Table 2).

Within landscape position, differences in cropping systems were only found in the footslope and floodplain positions (Table 2). Specifically, the continuous maize, soybean-triticale/soybean-maize, triticale/sorghum, and triticale-aspen systems each had significantly higher K_S values than the maize-switchgrass system at the footslope position. In total, seven significant differences were found within nine pairwise comparisons at the floodplain position; continuous maize, maize-switchgrass, and triticale/sorghum all had lower K_S values than triticale-aspen (Table 2). Continuous maize and the modified rotation had significantly higher K_S values than maize-switchgrass (Table 2).

Change in K_S Between 2009 and 2013

We found significant effects for year, year by landscape position, and year by cropping system (Table 2). This indicates that K_S changed significantly over time by both landscape position and cropping system (Fig. 2). Multiple comparisons showed that the footslope and floodplain landscape positions had significantly higher K_S in 2013 (Fig. 2a). All cropping system treatments, except switchgrass, had significantly higher K_S in 2013 than in 2009 (Fig. 2b).

Table 1 ANOVA results from 2009 and 2013 testing for differences in hydraulic conductivity by year, landscape position, and cropping system

Year	Source of Variation	Num *df*	Den *df*	*F*	*P*
2009	Landscape position	4	195	6.08	0.0001
	Cropping system	4	195	2.06	0.0873
	Landscape position × cropping system	16	195	1.47	0.1152
2013	Landscape position	4	198	31.12	<0.0001
	Cropping system	4	198	6.34	0.0002
	Landscape position × cropping system	16	198	2.4	0.0125
2009 and 2013	Year	1	409	404.33	<0.0001
	Year × landscape position	4	409	60.61	<0.0001
	Year × cropping system	4	409	1.44	0.0006
	Landscape position	4	409	31.12	<0.0001
	Cropping system	4	409	6.34	<0.0001
	Landscape position × cropping system	16	409	2.4	0.0019

Table 2 Mean saturated hydraulic conductivity (K_S; cm/d) of cropping systems and landscape positions in 2009 and 2013

Landscape position	Cropping system	2009[a]			2013[a]		
Summit	Continuous maize	48.3	A	a	51.3	A	a
	Soybean-triticale/soybean-maize	38.1	A	a	54.0	A	a
	Maize-switchgrass	32.0	AB	a	50.1	A	a
	Triticale/sorghum	29.5	A	a	43.0	A	a
	Triticale-aspen	26.9	A	a	80.0	AB	a
Shoulder	Continuous maize	25.9	A	a	42.9	A	a
	Soybean-triticale/soybean-maize	33.3	A	a	68.7	AB	a
	Maize-switchgrass	56.6	A	a	46.3	A	a
	Triticale/sorghum	35.3	A	a	34.4	A	a
	Triticale-aspen	42.1	A	a	66.9	AB	a
Backslope	Continuous maize	27.4	A	a	43.1	A	a
	Soybean-triticale/soybean-maize	26.3	A	a	65.9	AB	a
	Maize-switchgrass	23.0	B	a	31.7	A	a
	Triticale/sorghum	18.9	A	a	54.9	AB	a
	Triticale-aspen*	15.3	A	a	81.2	AB	a
Footslope	Continuous maize*	21.7	A	a	117.0	B	a
	Soybean-triticale/soybean-maize *	23.9	A	a	121.4	B	a
	Maize-switchgrass	30.5	AB	a	23.3	A	b
	Triticale/sorghum*	17.5	A	a	105.0	B	a
	Triticale-aspen*	37.8	A	a	162.2	C	a
Floodplain	Continuous maize*	48.3	A	a	312.9	C	a
	Soybean-triticale/soybean-maize *	41.7	A	a	400.0	C	ad
	Maize-switchgrass	48.3	A	a	111.9	A	be
	Triticale/sorghum*	22.7	A	a	220.9	C	ae
	Triticale-aspen*	79.1	B	a	533.2	D	cd

*Significant difference between years. $P < 0.05$

[a] Uppercase letters indicate significant differences between landscape positions within a cropping system. Lowercase letters indicate cropping system differences within a landscape position. $P < 0.05$

Discussion

Saturated hydraulic conductivity primarily describes saturated water flow through macropores; in previous studies, as much as 64% of the variability in K_S measurements can be explained by the number of macropores [22, 33]. Macropore formation is significantly influenced by cropping effects and tillage [26, 34]. Tillage can form large, unstable fractures and macropores, while lowering macropore connectivity, but may initially lead to significantly higher saturated hydraulic conductivity. The general trend for no-till is an increase in macropore connectivity and saturated hydraulic conductivity over time [35].

The broad, site-wide increase in K_S across four of five cropping systems and four of five landscape positions over a 4-year period (2009–2013) is consistent with the adoption of site-wide no-till management during the establishment phase of the experiment in 2008 [35]. This was consistent with our first hypothesis, which tested for an increase in K_S over time across all systems. Elliott and Efetha also observed significantly higher K_S in no-till plots compared to conventionally tilled plots at all landscape positions and sampling dates [15]. In their study, for the conventionally tilled plots, the backslope and shoulder positions had lower K_S than other positions, suggesting that lower K_S is correlated with landscape positions that have greater slopes and erosion potential.

We observed that footslope and floodplain landscape positions had significantly higher K_S values in 2013, which confirms our third hypothesis, which tested whether the footslope and floodplain positions had higher K_S values than the summit, shoulder, and backslope positions. Higher K_S values at the footslope may be caused by SOC accumulation [36]. The summit and backslope are more likely to suffer erosion and losses of SOC, which can accumulate at lower elevations at the footslope and floodplain positions [37]. All cropping systems, except switchgrass, had showed a significantly higher K_S at the footslope and floodplain positions in 2013 compared to 2009; the K_S of triticale-aspen was also significantly higher in 2013 at the backslope position.

Results surrounding our second hypothesis regarding K_S rates in annual versus perennial systems were more equivocal.

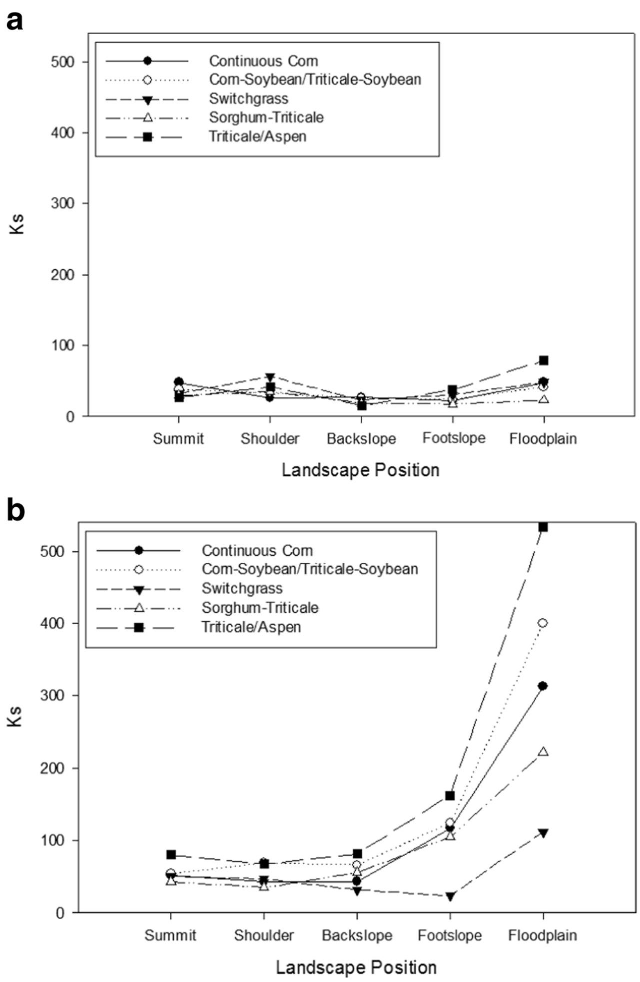

Fig. 1 Saturated hydraulic conductivity (K_S) among five landscape positions in 2009 and 2013

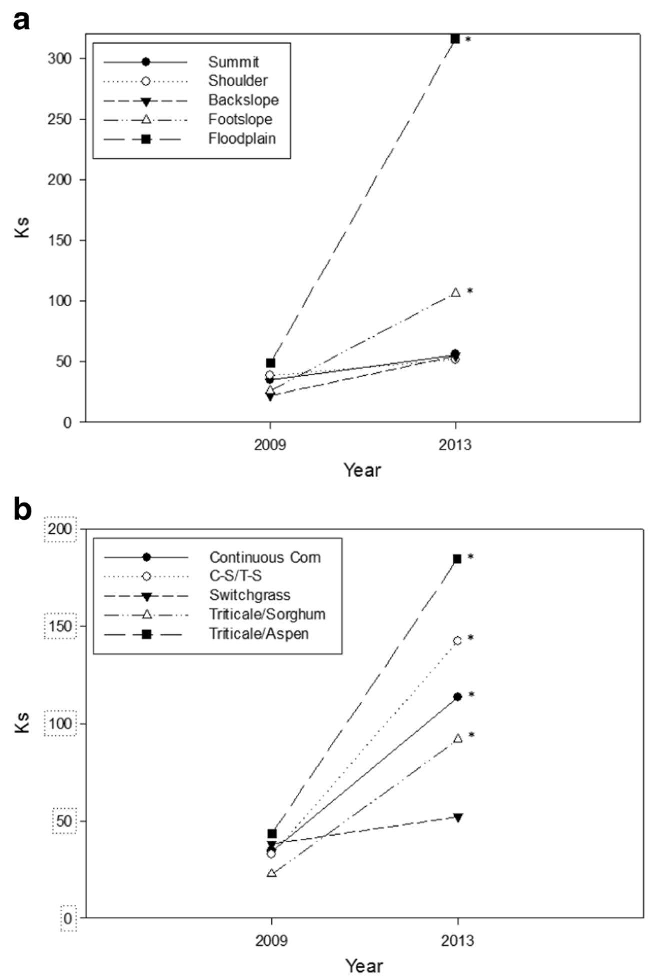

Fig. 2 Change in saturated hydraulic conductivity (K_S) from 2009 to 2013 for five landscape positions (**a**) and five biomass cropping systems (**b**). *Asterisk* indicates significant difference between years at the $P < 0.05$ level

We did not observe any cropping system differences at the summit, shoulder, and backslope positions. However, we did find that the triticale-aspen treatment had significantly higher K_S than the continuous maize, switchgrass, and sorghum/triticale treatments when considered across all landscape positions. This partially confirms our second hypothesis, as we did not observe an increase over time in K_S for the switchgrass system. Eldridge and Freudenberger also observed significantly higher K_S under woodland trees compared to pasture or cultivated areas, and attributed this result to a greater proportion of soil macropores under trees [23]. In a meta-analysis of K_S studies in the tropics, Ilstedt et al. concluded that afforestation of agricultural fields led to an average threefold increase in K_S [38].

Our results also indicate that maize-switchgrass had the lowest associated K_S compared to other cropping treatments. Maize-switchgrass measurements were conducted in late May and early June. The low saturated hydraulic conductivity below maize-switchgrass may partly be explained by the high density of living roots of the switchgrass by 2013. Living roots may initially reduce hydraulic conductivity by compacting soil and filling macropore channels. Gish and Jury observed that infiltration was highest following crop removal due to the presence of root channels left behind by decomposed roots [39]. Preferential flow paths or macropores were observed after root decay. Active switchgrass rhizomes can essentially be sod forming, and 68.2–90.4% of switchgrass root weight density occur in the upper 15 cm of soil [40, 41]. Although density of living switchgrass roots reaches a peak in August [42], we noted a high density of living roots in the boreholes when conducting field measurements during the spring, when switchgrass infiltration is typically thought to be at its peak [43]. This was confirmed by root biomass measurements, which indicate that switchgrass had significantly higher root productivity than the annual cropping systems, with nearly double the root biomass compared to continuous maize [28]. The high root productivity of switchgrass may explain the relatively low observed K_S during this period.

While we observed a broad, site-wide increase in K_S across all cropping systems when considering all landscape positions over a period of 4 years, it is likely that more time may be required to observe additional individual treatment effects. We observed significant increases in K_S over time at the footslope and floodplain positions, and for all cropping systems except switchgrass. Rachman et al. observed significantly greater hydraulic conductivities under stiff-stemmed grass hedge systems as compared to maize and soybean systems 10 years after establishment [44]. However, Schwartz and Unger suggest than conversion of cropland to perennial grasses had little impact on soil hydraulic properties even after a period of 10 years [26].

Conclusion

The widespread adoption of perennial biomass crops and associated land use changes may have beneficial or adverse impacts on the environment. Our research fulfills a key knowledge gap by revealing how alternative biomass cropping systems impact saturated hydraulic conductivity across landscape positions. Our results demonstrate that, over a 4-year period, alternative cropping systems can have significant though variable impacts on soil hydraulic properties. We observed a significant increase in K_S over a period of 4 years at the footslope and floodplain positions and for all cropping systems except switchgrass. Differences among cropping system treatments were only observed at the floodplain position. We also observed a broad site-wide increase in K_S, consistent with the adoption of no-till management.

We expect that cropping system treatment effects will become more apparent over longer timescales, as the ecological processes that contribute to changes in soil hydraulic properties, such as SOC accumulation and macropore development, evolve over extended periods. While we observed significant changes in soil hydraulic conductivity over a short period, some systems did not complete a harvest cycle (triticale-aspen). Due to the establishment time associated with perennial systems, some longer-term impacts may not be apparent at this time.

Acknowledgements Funding for this work was provided by the McIntire-Stennis Program (Project IOW3805) and the US Forest Service Northern Research Station. The broader Landscape Biomass Project is supported by the Iowa State University College of Agriculture and Life Sciences and Department of Agronomy, Leopold Center for Sustainable Agriculture (Project E2008-24), USDA AFRI (Project IOW5249), and the National Science Foundation Iowa EPSCoR (Project EPS-1101284). We thank the Landscape Biomass team for the assistance and specifically Nic Boersma, Mike Fiscus, Theo Gunther, Emily Heaton, and Ken Moore for the crop management, and Todd Ontl for his assistance with the 2009 soil hydraulic conductivity measurements and other soil property measurements.

References

1. Foley J, DeFries R, Asner G, Barford C, Bonan G, Carpenter S, Chapin F, Coe M, Daily G, Gibbs H, Helkowski J, Holloway T, Howard E, Kucharik C, Monfreda C, Patz J, Prentice I, Ramankutty N, Snyder P (2005) Global consequences of land use. Science 309(5734):570–574
2. Thomas M, Engel B, Chaubey I (2009) Water quality impacts of corn production to meet biofuel demands. J. Environ. Eng. ASCE 135(11):1123–1135
3. Blanco-Canqui H (2010) Energy crops and their implications on soil and environment. Agron J 102(2):403–419
4. Robertson G, Dale V, Doering O, Hamburg S, Melillo J, Wander M, Parton W, Adler P, Barney J, Cruse R, Duke C, Fearnside P, Follett R, Gibbs H, Goldemberg J, Mladenoff D, Ojima D, Palmer M, Sharpley A, Wallace L, Weathers K, Wiens J, Wilhelm W (2008) Sustainable biofuels redux. Science 322(5898):49–50
5. Collis-George N (1977) Infiltration equations for simple soil systems. Water Resour Res 13(2):395–403
6. Hall GF, Olson CG (1991) Predicting variability of soils from landscape models. Spatial variabilities of soils and landforms. J. Soil Sci. Soc. Am. 29:9–24
7. Bronstert A, Plate E (1997) Modelling of runoff generation and soil moisture dynamics for hillslopes and micro-catchments. J Hydrol 198(1–4):177–195
8. Beven K, Germann P (2013) Macropores and water flow in soil revisited. Water Resour Res 49:1–22
9. Edwards W, Shipitalo M, Owens L, Dick W (1993) Factors affecting preferential flow of water and atrazine through earthworm burrows under continuous no-till corn. J Environ Qual 22(3):453–457
10. Boyle M, Frankenberger W, Stolzy L (1989) The influence of organic-matter on soil aggregation and water infiltration. J Prod Agric 2(4):290–299
11. Robertson G, Hamilton S, Del Grosso S, Parton W (2011) The biogeochemistry of bioenergy landscapes: carbon, nitrogen, and water considerations. Ecol Appl 21(4):1055–1067
12. Six J, Elliott E, Paustian K (1999) Aggregate and soil organic matter dynamics under conventional and no-tillage systems. Soil Sci Soc Am J 63(5):1350–1358
13. Chan KY, Heenan DP, Oates A (2002) Soil carbon fraction and relationship to soil quality under different tillage and stubble management. Soil Tillage Res 63:133–139
14. Bouma J (1991) Influence of soil macroporosity on environmental-quality. Adv Agron 46:1–37
15. Elliott J, Efetha A (1999) Influence of tillage and cropping system on soil organic matter, structure and infiltration in a rolling landscape. Can J Soil Sci 79(3):457–463
16. West T, Post W (2002) Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis. Soil Sci Soc Am J 66(6):1930–1946
17. Logsdon S, Jordahl J, Karlen D (1993) Tillage and crop effects on ponded and tension infiltration rates. Soil Tillage Res 28(2):179–189
18. Edwards WM, Shipitalo MJ, Norton LD (1988) Contribution of macroporosity to infiltration into a continuous corn no-tilled watershed: implications for contaminant movement. J Contam Hydrol 3(2–4):193–205
19. Jiang P, Anderson S, Kitchen N, Sadler E, Sudduth K (2007) Landscape and conservation management effects on hydraulic properties of a claypan-soil toposequence. Soil Sci Soc Am J 71(3):803–811
20. Chan KY, Mead JA (1989) Water movement and macroporosity of an Australian Alfisol under different tillage and pasture conditions. Soil Tillage Res 14:301–310

21. Fuentes J, Flury M, Bezdicek D (2004) Hydraulic properties in a silt loam soil under natural prairie, conventional till, and no-till. Soil Sci Soc Am J 68(5):1679–1688
22. Udawatta R, Anderson S, Gantzer C, Garrett H (2006) Agroforestry and grass buffer influence on macropore characteristics: a computed tomography analysis. Soil Sci Soc Am J 70(5):1763–1773
23. Eldridge D, Freudenberger D (2005) Ecosystem wicks: woodland trees enhance water infiltration in a fragmented agricultural landscape in eastern Australia. Austral Ecol. 30(3):336–347
24. Jung WK, Kitchen NR, Anderson SH, Sadler EJ (2007) Crop management effects on water infiltration for claypan soils. J Soil Water Conserv 62(1):55–63
25. Anderson S, Udawatta R, Seobi T, Garrett H (2009) Soil water content and infiltration in agroforestry buffer strips. Agrofor Syst 75(1):5–16
26. Schwartz RC, Evett SR, Unger PW (2003) Soil hydraulic properties of cropland compared with reestablished and native grassland. Geoderma 116:47–60
27. Wilson DM, Heaton EA, Schulte LA, Gunther TP, Shea ME, Hall RB, Headlee WL, Moore KJ, Boersma NN (2014) Establishment and short-term productivity of annual and perennial bioenergy crops across a landscape gradient. Bioenergy Res 7(3):885–898
28. Ontl TA, Hofmockel KS, Cambardella CA, Schulte LA, Kolka RK (2013) Topographic and soil influences on root productivity of three bioenergy cropping systems. New Phytologist:1–11.
29. Raoof M, Nazemi AH, Sadraddini AA, Marofi S (2011) Measuring and estimating saturated and unsaturated hydraulic conductivity in steady and transient states on sloping lands. World Appl Sci J 13(4): 747–755
30. Zangar CN (1953) Theory and problems of water percolation. Engineering Monogram no. 8. Bureau of Reclamation, United States Department of the Interior. Denver, CO.
31. Amoozegar A (1989) Comparison of the glover solution with the simultaneous-equations approach for measuring hydraulic conductivity. Soil Sci Soc Am J 53(5):1362–1367
32. Anwar, Usman (2014) Soil moisture patterns and hydraulic properties associated with alternative biomass cropping systems across a landscape gradient. Graduate Theses and Dissertations. Paper 14029. Iowa State University. Ames, IA.
33. Messing I (1989) Estimation of the saturated hydraulic conductivity in clay soils from soil-moisture retention data. Soil Sci Soc Am J 53(3):665–668
34. Shipitalo M, Dick W, Edwards W (2000) Conservation tillage and macropore factors that affect water movement and the fate of chemicals. Soil Tillage Res 53(3–4):167–183
35. Strudley M, Green T, Ascough J (2008) Tillage effects on soil hydraulic properties in space and time: state of the science. Soil Tillage Res 99(1):4–48
36. Guzman J, Al-Kaisi M (2011) Landscape position effect on selected soil physical properties of reconstructed prairies in south central Iowa. J Soil Water Conserv 66(3):183–191
37. Gregorich E, Greer K, Anderson D, Liang B (1998) Carbon distribution and losses: erosion and deposition effects. Soil Tillage Res 47(3–4):291–302
38. Ilstedt U, Malmer A, Elke V, Murdiyarso D (2007) The effect of afforestation on water infiltration in the tropics: a systematic review and meta-analysis. For Ecol Manag 251(1–2):45–51
39. Gish T, Jury W (1983) Effect of plant-roots and root channels on solute transport. Trans ASABE 26(2):440–451
40. Parrish D, Fike J (2005) The biology and agronomy of switchgrass for biofuels. Crit Rev Plant Sci 24(5–6):423–459
41. Ma Z, Wood CW, Bransby DI (2000) Impacts of soil management on root characteristics of switchgrass. Biomass Bioenergy 18(2): 105–112
42. Tufekcioglu A, Raich JW, Isenhart TM, Schultz RC (1999) Fine root dynamics, coarse root biomass, root distribution, and soil respiration in a multispecies riparian buffer in central Iowa. USA Agrofor. Syst. 44:163–174
43. Bharati L, Lee K, Isenhart T, Schultz R (2002) Soil-water infiltration under crops, pasture, and established riparian buffer in Midwestern USA. Agrofor Syst 56(3):249–257
44. Rachman A, Anderson S, Gantzer C, Alberts E (2004) Soil hydraulic properties influenced by stiff-stemmed grass hedge systems. Soil Sci Soc Am J 68(4):1386–1393