ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/320003237

Evaluation of bioenergy crop growth and the impacts of bioenergy crops on streamflow, tile drain flow and nutrient losses in an extensively tile-drained watershed using SWAT

Article *in* Science of The Total Environment · September 2017

DOI: 10.1016/j.scitotenv.2017.09.148

CITATIONS
19

READS
220

8 authors, including:

Tian Guo
Heidelberg University
19 PUBLICATIONS 117 CITATIONS
SEE PROFILE

Cibin Raj
Pennsylvania State University
46 PUBLICATIONS 614 CITATIONS
SEE PROFILE

Indrajeet Chaubey
Purdue University
209 PUBLICATIONS 4,521 CITATIONS
SEE PROFILE

Margaret Gitau
Purdue University
48 PUBLICATIONS 1,182 CITATIONS
SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project Best Management Practice (BMP) Effectiveness View project

Project Multiple Metrics - Environmental Management View project

All content following this page was uploaded by Tian Guo on 14 January 2018.

The user has requested enhancement of the downloaded file.

Science of the Total Environment 613–614 (2018) 724–735

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Evaluation of bioenergy crop growth and the impacts of bioenergy crops on streamflow, tile drain flow and nutrient losses in an extensively tile-drained watershed using SWAT

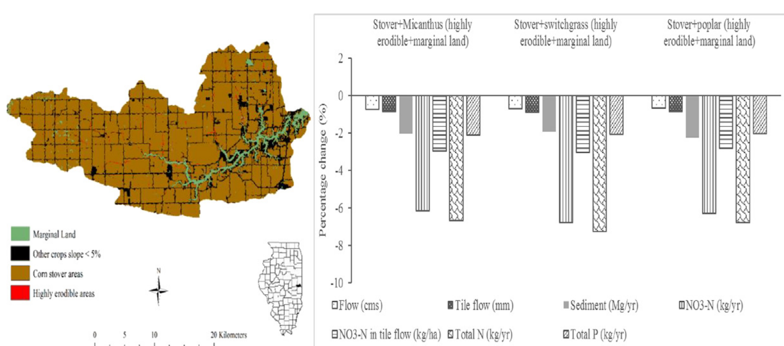
Tian Guo [a,b,*], Raj Cibin [a,c], Indrajeet Chaubey [a,d], Margaret Gitau [a], Jeffrey G. Arnold [e], Raghavan Srinivasan [f], James R. Kiniry [e], Bernard A. Engel [a]

[a] Department of Agricultural and Biological Engineering, Purdue University, 225 South University Street, West Lafayette, IN 47907, USA
[b] National Center for Water Quality Research, Heidelberg University, 310 E Market St, Tiffin, OH 44883, USA
[c] Department of Agricultural and Biological Engineering, Pennsylvania State University, University Park, PA 16802, USA
[d] Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, IN 47907, USA
[e] Grassland Soil and Water Research Laboratory, USDA-ARS, 808 East Blackland Rd, Temple, TX 76502, USA
[f] Spatial Sciences Laboratory, Texas A&M University, College Station, TX 77843, USA

HIGHLIGHTS

- Calibrated parameter sets for bioenergy crop growth and tile drainage were used.
- Corn stover removal (38%) did not result in significant water quality impacts.
- Bioenergy crops can offset adverse water quality impacts of corn stover removal.
- Small bioenergy crop areas provided limited ability to improve water quality.
- Results provide guidance for evaluation of bioenergy scenarios in tile-drained areas.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 29 May 2017
Received in revised form 12 September 2017
Accepted 14 September 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Biofeedstock production
Perennial grasses
Short rotation woody crops
Tile drainage
Hydrologic modeling
Water quality modeling

ABSTRACT

Large quantities of biofuel production are expected from bioenergy crops at a national scale to meet US biofuel goals. It is important to study biomass production of bioenergy crops and the impacts of these crops on water quantity and quality to identify environment-friendly and productive biofeedstock systems. SWAT2012 with a new tile drainage routine and improved perennial grass and tree growth simulation was used to model long-term annual biomass yields, streamflow, tile flow, sediment load, and nutrient losses under various bioenergy scenarios in an extensively agricultural watershed in the Midwestern US. Simulated results from bioenergy crop scenarios were compared with those from the baseline. The results showed that simulated annual crop yields were similar to observed county level values for corn and soybeans, and were reasonable for *Miscanthus*, switchgrass and hybrid poplar. Removal of 38% of corn stover (3.74 Mg/ha/yr) with *Miscanthus* production on highly erodible areas and marginal land (17.49 Mg/ha/yr) provided the highest biofeedstock production (279,000 Mg/yr). Streamflow, tile flow, erosion and nutrient losses were reduced under bioenergy crop scenarios of bioenergy crops on highly erodible areas and marginal land. Corn stover removal did not result in significant water quality changes. The increase in sediment and nutrient losses under corn stover removal could be offset with the combination of other bioenergy crops. Potential areas for bioenergy crop production when meeting

* Corresponding author at: National Center for Water Quality Research, Heidelberg University, 310 E Market St, Tiffin, OH 44883, USA.
E-mail addresses: tguo@heidelberg.edu (T. Guo), craj@psu.edu (R. Cibin), ichaubey@purdue.edu (I. Chaubey), mgitau@purdue.edu (M. Gitau), Jeff.Arnold@ARS.USDA.GOV (J.G. Arnold), r-srinivasan@tamu.edu (R. Srinivasan), Jim.Kiniry@ARS.USDA.GOV (J.R. Kiniry), engelb@purdue.edu (B.A. Engel).

http://dx.doi.org/10.1016/j.scitotenv.2017.09.148
0048-9697/© 2017 Elsevier B.V. All rights reserved.

the criteria above were small (10.88 km^2), thus the ability to produce biomass and improve water quality was not substantial. The study showed that corn stover removal with bioenergy crops both on highly erodible areas and marginal land could provide more biofuel production relative to the baseline, and was beneficial to water quality at the watershed scale, providing guidance for further research on evaluation of bioenergy crop scenarios in a typical extensively tile-drained watershed in the Midwestern U.S.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

One of the grand challenges in meeting the US biofuel goal is supplying large quantities of cellulosic materials for biofuel production at a national scale (Cibin et al., 2016). Based on productivity and adaptability in different regions, the selection of biofeedstocks will vary geographically. It is necessary to evaluate potential environmental impacts before considering implementation of bioenergy crops on a large scale (Love and Nejadhashemi, 2011). Land cover change, management practices and climate change have impacts on water quantity, sediment and nutrient losses. Thus, it is challenging to take advantage of the opportunity bioenergy crops offer, while safeguarding against their potential environmental disadvantages.

Bioenergy crops, such as corn (*Zea mays* L.), corn stover, switchgrass (*Panicum virgatum* L.), *Miscanthus* (*Miscanthus* × *giganteus*) and *Populus* 'Tristis #1' (*Populus balsamifera* L. × *P. tristis* Fisch), are biofeedstock sources for biofuel production in U.S. (Cibin et al., 2016; Gamalero et al., 2012; Guo et al., 2015; Kiniry et al., 2012; McIsaac et al., 2010; Parajuli et al., 2017; Thomas et al., 2014). Using marginal land to grow non-grain bioenergy crops helps minimize impacts on food security while reducing ecological restoration costs (He et al., 2017; Zhuang et al., 2010).

Bioenergy crops have different yields estimated by simulation models under different scenarios. For example, simulated biofeedstock production from the same bioenergy crop, such as *Miscanthus*, switchgrass or corn stover, differed when growing on pasture, agricultural marginal land or highly erodible areas (Cibin et al., 2016). Additionally, simulated biomass yields of five forest scenarios (clear cutting at 10%, 20%, 30%, 55% and 75% of the total forest area) increased as the forest area clearcut increased (Khanal and Parajuli, 2013). Simulated annual average biomass yields for corn stover with 38%, 52% and 70% removal rates were 4.1 Mg/ha, 6 Mg/ha and 7.5 Mg/ha (Cibin et al., 2012).

Bioenergy crop planting in large areas can affect hydrology and water quality (Guo et al., 2012a; Guo et al., 2012b; He and Guo, 2012; Liu et al., 2015; Ng et al., 2010; Srinivasan et al., 2010; Yan et al., 2015). For example, simulated streamflow was reduced, and nitrate and mineral phosphorus loading were reduced at the watershed outlet with 38%, 52% and 70% corn stover removed in watersheds in Indiana (Cibin et al., 2012; Thomas et al., 2011). Additionally, corn stover removal can reduce soil cover (Delgado, 2010), reduce organic carbon and total nitrogen and increase soil erosion, and additional fertilizer was recommended to compensate for nutrient reduction by corn stover removal. However, 30 to 50% of corn stover could be removed without significantly impacting soil erosion and crop production (Brechbill and Tyner, 2008; Graham et al., 2007; Hoskinson et al., 2007; Kim and Dale, 2004; Lindstrom, 1986). Moreover, Hickman et al. (2010) predicted that switchgrass could increase evapotranspiration by 25% during the growing season compared with corn. Switchgrass and *Miscanthus* scenarios could reduce sediment and nutrient loadings at the watershed outlet simulated by SWAT (Boles, 2013; Love and Nejadhashemi, 2011; Parajuli and Duffy, 2013). Additionally, measured sediment loss and nutrient movement from a *Populus* tree plot was lower than that from a conventional cotton plot in Mississippi (Thornton et al., 1998; Tolbert et al., 1997). Moreover, fast growing hybrid poplar trees were also predicted to decrease total nitrogen and phosphorus loading (Sood and Ritter, 2010).

Tile drainage of agricultural fields in the Midwestern U.S. provides the majority of the nitrate that enters the Mississippi River and contributes to hypoxia in the northern Gulf of Mexico (Jaynes and James, 2007; Kalita et al., 2007). Models that link Mississippi River discharge with Gulf of Mexico hypoxia have shown that a decrease of nutrient loading can alleviate hypoxia in the Gulf of Mexico (Rabalais et al., 1999). The Little Vermilion River (LVR) watershed is a typical tile-drained watershed with altered hydrology from subsurface drainage systems in east central Illinois, USA (Kladivko et al., 2001). Surface runoff rarely occurs in the LVR, and the removal of water from soils was mainly by subsurface drainage systems (Kalita et al., 2006).

Subsurface drainage systems can increase hydrological connectivity to the channels (Basu et al., 2010; Evans et al., 1999; Kuzmanovski et al., 2015), enhance water transport through soils and serve as major transport pathways for soluble chemicals such as nitrate-N and atrazine and affect plant growth (Buhler et al., 1993; Kalita et al., 1998; Randall and Iragavarapu, 1995). Plant growth also influences nutrient transport in the tile drainage system. For example, nitrate-N concentrations in tile drains were higher from fields with more N fertilization, particularly when fertilization occurred prior to planting (Borah et al., 2003; Mitchell et al., 2000). Thus, it is important to take tile drainage system into consideration for examination of hydrologic and water quality impacts of bioenergy crop scenarios in watersheds in the Midwest.

Some researchers have simulated bioenergy crop growth and its impacts on water quantity and quality at a watershed scale using SWAT globally (Boles, 2013; Cibin et al., 2012; Cibin et al., 2016; Gush, 2010; Liu et al., 2014; Love and Nejadhashemi, 2011; Valcu-Lisman et al., 2016; Yasarer et al., 2016), but few of them incorporated woody bioenergy crops, such as *Populus* into bioenergy crop scenarios, or under tile drainage systems. The objective of this study was to quantify biomass yields of bioenergy crops scenarios, including woody bioenergy crops, and their impacts on streamflow, tile drain flow and nutrient losses under consideration of tile drainage systems in a typical tile drained watershed. The results of this study can help determine optimal bioenergy scenarios with high biomass yields, and water quality benefits in the LVR watershed and even the Mississippi River system and Gulf of Mexico.

2. Materials and methods

2.1. Study area

The LVR watershed is a typical flat upland watershed in east-central Illinois and drains approximately 518 km^2, at the boundary of Champaign and Vermilion counties. The LVR watershed has an average slope about 1%, with elevation ranging from approximately 235 m in the headwaters to 174 m at the outlet of the watershed (Zanardo et al., 2012). About 90% of the LVR watershed is agricultural land used for corn and soybean production, and the remainder consists of grassland, forest land, roadways and farmsteads (Kalita et al., 2006). Based on agricultural statistical data for the LVR watershed, the cropland was equally subdivided between corn and soybeans (Algoazany et al., 2007). The dominant soil associations are Drummer silty clay loam (fine-silty, mixed, superactive, mesic Typic Endoaquolls) and Flanagan silt loam (fine, smectitic, mesic Aquic Argiudolls) (Keefer, 2003; Zanardo et al., 2012). Annual average precipitation at the watershed outlet was 1016 mm from 1985 to 2008. The LVR watershed has altered hydrology from an extensive subsurface drainage system network (Algoazany et al., 2007).

2.2. Bioenergy crop scenarios

In the current study, the primary goal was to estimate biofeedstock production of plausible bioenergy scenarios and their impacts on watershed hydrology and water quality. The purpose of scenario planning was to place bioenergy crops with high biomass yields on the LVR watershed and explore hydrologic and water quality impacts. Thus, there were several concerns about bioenergy scenario planning (Peterson et al., 2003):

1. It was significant to design bioenergy scenarios favoring the growth of high yielding bioenergy crops (switchgrass, *Miscanthus* and hybrid poplar), and also have minimal impacts on food production (grain production of corn and soybeans).

2. Marginal land with steep slopes, low soil productivity or not suited for corn and soybean growth, which has low crop productivity could be chosen for bioenergy crop placement.

3. Minimal nutrient or sediment export to the outlet of the LVR watershed should also be taken into consideration.

To meet the aforementioned goals of bioenergy crop scenario planning, biofuel crop scenarios were formulated and simulated on highly erodible areas, and marginal land in the LVR watershed (Fig. 1). The corn and soybean areas with >5% slope were considered as potential highly erodible areas. The areas with soil non-irrigated unit capability class of 3 and 4 (may be more profitable used for grasses or trees), 6 (excess or lack of water), 7 (soil damage) and 8 (soil and climatic limitations) were considered as marginal land (Table 1) (Klingebiel and Montgomery, 1961). Based on these criteria, areas for bioenergy crop scenarios were small (Table 1).

Eighteen bioenergy crop scenarios were formulated (Table 2) considering bioenergy crop production on highly erodible areas (Scenarios 1, 2 and 3), on marginal land (Scenarios 4, 5 and 6), with stover removal with various nutrient replacement amounts (Scenarios 7, 8 and 9), combination of stover removal and bioenergy crop production on highly erodible areas (Scenarios 10, 11 and 12), combination of stover removal and bioenergy crop production on marginal land (Scenarios 13, 14 and 15), and combination of stover removal and bioenergy crop production on highly erodible areas and marginal land (Scenarios 16, 17 and 18).

Shawnee switchgrass (*Panicum virgatum* L.), *Miscanthus* (*Miscanthus* × *giganteus*) and *Populus* 'Tristis #1' (*Populus balsamifera* L. × *P. tristis* Fisch) were included as high yielding bioenergy crops due to high productivity, availability and adaptability and corn stover as crop residue for biofuel production (Behrman et al., 2014; Boles, 2013; Casler, 2010; Cortese et al., 2010; Hansen, 1991; Kiniry et al., 2013; Schmer et al., 2010; Thomas et al., 2014; Thomas et al., 2011; Tilman et al., 2009; Trybula et al., 2015). The stover removal rate of 38% proposed by Brechbill and Tyner (2008) was used for the study, representing potential corn stover that can be collected from baling a windrow (Brechbill and Tyner, 2008), which has been widely used for agricultural land.

2.3. SWAT model setup

Guo et al. (2015) improved leaf area index and biomass yield simulation of *Populus* tree growth simulation in SWAT, and determined parameter sets for hybrid poplar growth, which can be used to accurately model biofeedstock production of hybrid poplar growth and its impacts on hydrology and water quality from planting to harvest. SWAT2012 (Revision 615) with the improved tree growth simulation (Guo et al., 2015) was used for modeling. The 30 m Digital Elevation Model (DEM) was used to create a clipped stream layer for the LVR watershed into the simulation and subbasins in LVR watershed were

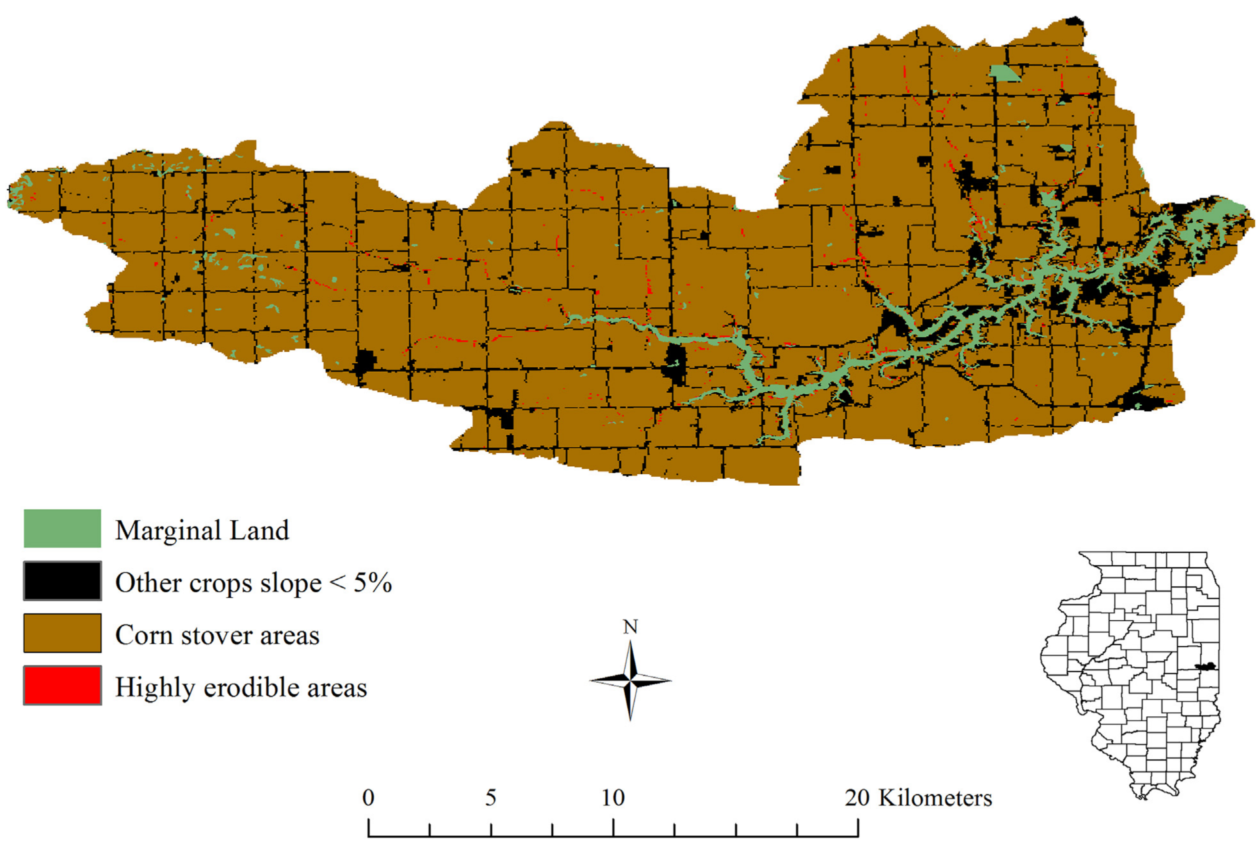


Fig. 1. Potential lands for bioenergy crop scenarios in the LVR watershed.

Table 1
Potential area for bioenergy crop scenarios[a].

Potential lands	Land use	Slope	Soil capability class (non-irrigated)	Area (km^2)	Percent of the watershed (%)
Corn stover areas	Corn/soybeans	<5%	–	177.53	43
Highly erodible areas	Corn/soybeans soybean	>5%	–	2.10	0.50
Marginal land[a]	–	–	3, 4, 6, 7, 8	8.78	2.11

[a] Klingebiel and Montgomery (1961).

delineated (Table 3). The National Map Viewer and SSURGO from USDA Web Soil Survey were also added into ArcSWAT (Table 3). Crop data layer (CDL 2014) for the study area was obtained from USDA National Agricultural Statistics Service (NASS) (Table 3). The delineated 17 subbasins yielded 990 total hydrologic response units (HRUs) based on the following thresholds: 0% land, 10% soil, and 0% slope. Daily maximum and minimum temperature, solar radiation, wind speed and relative humidity data were obtained from an Illinois State Water Survey (ISWS) station (Champaign Station, Latitude: 40.08°, Longitude: −88.24°, Elevation: 219 m) closest to the LVR watershed (Table 3). Daily precipitation data from 01/01/1985 to 12/31/2008 for the SIDELL 4 N IL US weather station (GHCND: USC00117952, Latitude: 39.98°, Longitude: −87.88°, Elevation: 206 m) in the watershed was downloaded from National Climatic Data Center (NCDC CDO) and added into ArcSWAT (Table 3).

Tile drainage was assumed in areas where corn or soybean were the current land use, slope was lower than 5%, and soil drainage was somewhat poorly drained, poorly drained, or very poorly drained (Boles et al., 2015; Sugg, 2007; Sui and Frankenberger, 2008), and 75% of the watershed was tile drained. The model ran for a total of 23 years (1985–2008) to allow for sufficient warm-up (1985–1989) before reaching the simulation years (1990–2008).

The SWAT2012 model (Revision615) was calibrated/validated for monthly tile flow and nitrate in tile flow at subsurface stations, for monthly surface runoff, sediment and nitrate in surface runoff at surface stations, and for monthly streamflow, and sediment and nitrate in streamflow at a river site in the LVR watershed in a previous study (Guo et al., 2017). Calibrated parameter sets can be used to model hydrology and water quality results reasonably at both field site and river basin levels in the LVR watershed (Table 4). Moreover, tile flow parameters, tile depth (DDRAIN), drainage coefficient (DRAIN_CO), the maximum depressional storage selection flag/code (ISAMX) and static maximum depressional storage (SSTMAXD) defined in previous DRAINMOD studies on simulation of daily tile flow at field sites in the LVR watershed (Singh et al., 2001) and on the selection of parameter set during calibration and validation of DRAINMOD (Skaggs et al., 2012), and SWAT study on parameterization of tile drainage simulation in an Indiana watershed using SWAT2012 (Boles et al., 2015) were also used. The calibrated/validated model representing the current land cover was considered the baseline scenario. The calibrated model parameter set for the baseline was also applied to bioenergy crop scenarios (Table 2).

SWAT simulated annual corn and soybean yields were compared with measured National Agricultural Statistics Service (NASS) county level yield data. County level annual corn and soybean yield data for Vermilion, Champaign and Edgar Counties in Illinois from NASS statistics were area weighted to obtain watershed average yield data. Moisture content for NASS corn and soybean yields were assumed as 15.5% and 13.0%, respectively (Schroeder, 2004). Nineteen-year average simulated streamflow, sediment, nitrate, total nitrogen, soluble nitrogen, organic nitrogen, total phosphorus, mineral phosphorus, and organic phosphorus results at the watershed outlet, and tile flow and nitrate in tile flow across the entire watershed from 1990 to 2008 were compared with the baseline scenario, and percentage changes were calculated to determine biofeedstock production of bioenergy crop scenarios and their hydrologic and water quality impacts.

2.4. Bioenergy crop scenarios representation in the model

The plant growth parameters for corn (*Zea mays* L.), soybean (*Glycine* max L. *Merril*), Shawnee switchgrass (*Panicum virgatum* L.), *Miscanthus* (*Miscanthus* × *giganteus*) and *Populus* 'Tristis #1' (*Populus balsamifera* L. × *P. tristis* Fisch) were adjusted in the model. The present study used SWAT version Revision 615, incorporating modification of corn and soybeans (Cibin et al., 2016), perennial grasses (Cibin et al., 2016; Trybula et al., 2015) and hybrid poplar tree growth (Guo et al., 2015) with calibrated growth parameter values (Table S1).

Planting and harvest date, rotation, tillage practice, and fertilization and pesticide application of corn, soybean, corn stover, Tall Fescue, switchgrass, *Miscanthus*, and hybrid poplar in the LVR watershed varied (Table 5). Rotation years for switchgrass, *Miscanthus*, and hybrid poplar were set as 10, 10 and 14 years, respectively, since perennial grasses

Table 2
Description of biofuel scenarios evaluated in this study.

Name	Corn stover areas	Highly erodible areas	Marginal land
Baseline	–	–	–
Scenario 1	–	*Miscanthus*	–
Scenario 2	–	Switchgrass	–
Scenario 3	–	*Populus*	–
Scenario 4	–	–	*Miscanthus*
Scenario 5	–	–	Switchgrass
Scenario 6	–	–	*Populus*
Scenario 7	38% stover (no nutrient replacement)	–	–
Scenario 8	38% stover (more nutrient replacement)	–	–
Scenario 9	38% stover (less nutrient replacement)	–	–
Scenario 10	38% stover	*Miscanthus*	–
Scenario 11	38% stover	Switchgrass	–
Scenario 12	38% stover	*Populus*	–
Scenario 13	38% stover	–	*Miscanthus*
Scenario 14	38% stover	–	Switchgrass
Scenario 15	38% stover	–	*Populus*
Scenario 16	38% stover	*Miscanthus*	*Miscanthus*
Scenario 17	38% stover	Switchgrass	Switchgrass
Scenario 18	38% stover	*Populus*	*Populus*

Note: Baseline scenario represents the current land use in the watershed and the developed scenarios changing corresponding land use from the baseline.

Table 3
Data for bioenergy crop scenario simulation by SWAT.

Data type	Source	Format	Date
Elevation	[a]USGS The National Map Viewer	30 m raster	
[b]SSURGO	[c]USDA Web Soil Survey	Polygon shapefile	
[d]CDL	[e]USDA NASS	Raster	2014
Maximum and minimum temperature, solar radiation, relative humidity and wind speed	[f]ISWS	Tabular data	1985–2008
Precipitation	[g]NCDC	Tabular data	1985–2008

[a] USGS: U.S. Geological Survey.
[b] SSURGO: Soil Survey Geographic Database.
[c] USDA: U.S. Department of Agriculture.
[d] CDL: Cropland Data Layer.
[e] USDA NASS: United States Department of Agriculture National Agricultural Statistics Service.
[f] ISWS: Illinois State Water Survey.
[g] NCDC: National Climatic Data Center.

would produce biomass yield once established with proper management, and poplar trees could resprout vigorously after harvest for a period longer than 10 years (Hansen, 1991; Pyter et al., 2007). Hybrid poplar with population of 500 trees/100 m^2 was selected as short-rotation woody crops (Riemenschneider et al., 2001; Zalesny et al., 2009; Zalesny et al., 2012), which could reach maturity at the 6th year since planting (Hansen, 1983). Corn stover removal was set as 38% stover biomass removal after corn grain harvest (Brechbill and Tyner, 2008) in the model, including no (218 kg/ha Anhydrous Ammonia and 67 kg/ha P_20_5) more (250 kg/ha Anhydrous Ammonia and 78 kg/ha P_20_5) and less (234 kg/ha Anhydrous Ammonia and 72 kg/ha P_20_5) additional fertilizer application to account for nutrient replacement associated with stover removal (Table 5). Tall Fescue (*Schedonorus arundinaceus* (Schreb.) Dumort) with hay cut and rotational gazing (Table 5) was selected for pasture areas. Consumed and trampled biomass were both considered as 37 kg/ha/day during grazing, and 60% of the consumed biomass was considered as the manure deposited back in these areas (Cibin et al., 2016). Kentucky bluegrass (*Poa pratensis*) was selected as the grass in urban areas for this study, and the details about management practice setup for its growth were described in Data S1.

3. Results and discussion

3.1. Biofeedstock production of bioenergy crop scenarios

Simulated corn and soybean yields were similar to observed county level values (Fig. 2), except that simulated values of corn and soybean yields for years 1996, 2002, 2005 and 2007 were lower than observed values. Precipitation was low during the growing seasons for corn and soybeans during these years, which caused higher water stress during the growing seasons and underestimated crop yields.

Simulated yields of *Miscanthus*, switchgrass, and hybrid poplar on highly erodible areas (corn and soybean areas with slope >5%) (Scenarios 1–3, and Scenarios 10–12) averaged 19.5, 9.4 and 8.2 Mg/ha/yr respectively (Table 6). Simulated *Miscanthus* and switchgrass yields on highly erodible areas were similar to measured yields at the Purdue Water Quality Field Station (WQFS) in the same region as the LVR watershed (Table 6) (Trybula et al., 2015). Simulated yields of *Miscanthus*, switchgrass, and hybrid poplar on marginal land (soil capability class as 3, 4, 6, 7 and 8) (Scenarios 4–6, and Scenarios 13–15) averaged 17.0, 8.1, and 7.2 Mg/ha/yr, respectively (Table 6). Simulated yields of *Miscanthus*, switchgrass, and hybrid poplar on highly erodible areas and marginal land (Scenario 16–18) averaged 17.5, 8.3 and 7.4 Mg/ha/yr, respectively (Table 6). Simulated *Miscanthus* and switchgrass yields on marginal land were lower than measured yields at the Purdue WQFS (Table 6) (Trybula et al., 2015). This could be expected given that soil properties of marginal land in the LVR watershed were less fertile and had higher ability to restrict plant growth than those from the WQFS. Simulated annual average *Miscanthus* and switchgrass yields on highly erodible areas and marginal land were within simulated ranges of *Miscanthus* (15–20 Mg/ha/yr) and switchgrass (8–11 Mg/ha/yr) yields by Feng (2016). Simulated hybrid poplar yields on highly erodible areas and marginal lands were lower than measured yield at the USDA Forest Service Harshaw Experimental Farm (HEF) near Rhinelander, Wisconsin

Table 4
Description of parameter values for water quantity and quality processes in the LVR watershed.

Parameter	Description	Values	Process
CN2	Soil moisture condition II curve number	[a,b]−0.20	Surface runoff
SURLAG	Surface runoff lag coefficient	[a]1.03	
DEP_IMP	Depth to impervious layer (mm)	[a]2700	Tile drain
Tile depth	DDRAIN (mm)	[c]1075	
DRAIN_CO	Drainage coefficient (mm/d)	[c,d]20	
ISAMX	Maximum depressional storage selection flag/code	[e]0	
SSTMAXD	static maximum depressional storage (mm)	[e]12	
LATKSATF	Multiplication factor to determine lateral saturated hydraulic conductivity	[a]1.05	
SDRAIN	Tile spacing (mm)	[a]38000	
ESCO	Soil evaporation compensation factor	[a]0.98	Evapotranspiration
ADJ_PKR	Peak rate adjustment factor for sediment routing in the subbasin (tributary channels)	[a]1.16	Sediment losses
SPEXP	Exponent parameter for calculating sediment re-entrained in channel sediment routing	[a]1.94	
CH_COV1	Channel erodibility factor	[a]0.31	
CMN	Rate factor for mineralization for the humus active organic nutrients (N)	[a]0.03	Nitrate losses
RCN	Concentration of nitrogen in rainfall (mg N/L)	[a]0.10	
NPERCO	Nitrogen concentration reduction coefficient	[a]0.99	
SDNCO	Denitrification threshold water content	[a]1.46	
CDN	Denitrification exponential rate coefficient	[a]0.00	

[a] The calibrated parameter set from Guo et al. (2017)'s research.
[b] The relative change to default value (Guo et al., 2017).
[c] Defined in Singh et al. (2001)'s research.
[d] Defined in Skaggs et al. (2012)'s research.
[e] Defined in Boles et al. (2015)'s research.

Table 5
SWAT management practices for corn, soybean, pasture, lawn grass, corn stover, switchgrass, *Miscanthus* and hybrid poplar in the LVR watershed.

Management operations	Corn (corn stover)	Soybean	Tall fescue (pasture)	Switchgrass (*Miscanthus*)	Hybrid poplar
Planting date	May 5	May 24	Mar 1	Apr 1	May 22
Harvesting date	Oct14	Oct 7	May 30 (Hay cut)	Oct 30	Dec 30 (7th, 14th years)
Rotation (year)	2	2	1	10	14
Tillage	Apr 15 Spring chisel plow May 5 Offset disk plow	Nov 1 Fall chisel plow	–	–	Apr1 Roto-Tiller (1st year)
Nitrogen fertilizer	Apr 22 Anhydrous Ammonia no (218 kg/ha), more (250 kg/ha) and less (234 kg/ha) nutrient replacement	–	May 1 & Aug 1 Urea 61 kg/ha	Apr 15 Urea 122 kg/ha	Apr1 Urea 110 kg/ha (every other year)
Phosphorus fertilizer	Apr 24 P_20_5 No (67 kg/ha), more (78 kg/ha) and less (72 kg/ha) nutrient replacement	May 10 P_20_5 56 kg/ha	May 1 P_20_5 11 kg/ha	–	
Pesticide application	May 2 Atrazine 2.2 kg/ha	–	–	–	Apr1 Linuron 2.2 kg/ha (1st year)
Grazing	–	–	July 15, 14 days 1 cow/acre Sep 1, 14 days 2 cows/acre	–	–

(Table 6) (Hansen, 1991). Given that the soil, slope and climate conditions at and the LVR watershed in Illinois were different from those at the HEF in Wisconsin, the simulated hybrid poplar yields were reasonable. Simulated yields of corn stover on highly erodible areas with no, more and less additional nutrient replacement (Scenarios 7–9) averaged 3.65, 3.81 and 3.74 Mg/ha/yr, respectively (Table 6). More nutrient replacement (Scenario 8) resulted in higher corn stover production (3.81 Mg/ha/yr) and corn grain production (8.38 Mg/ha/yr), and no nutrient replacement (Scenario 7) resulted in lower corn stover production (3.65 Mg/ha/yr) and corn grain production (8.04 Mg/ha/yr). Average annual biofeedstock production for bioenergy areas varied for different scenarios, and quantity of potential biofeedstock production was not large (Table 6) since bioenergy areas were small (Table 1). Corn stover (66,000 Mg/yr) with combination of *Miscanthus* both on highly erodible areas and marginal land (19,000 Mg/yr) provided the highest biofeedstock production (Scenario 16) (Table 6).

Only one NOAA station with usable precipitation data was located in the LVR watershed. Corn and soybean management practice data for the whole watershed were represented by management data from several field sites. Limited precipitation and corn and soybean growth management data may influence the accuracy of biomass yield simulation for corn and soybeans, as well as corn stover, switchgrass, *Miscanthus* and hybrid poplar.

3.2. Impacts of bioenergy crop scenarios on hydrology

Annual flow partitioning for the LVR watershed from 1990 to 2008 for the baseline was plotted (Fig. 3). Simulated annual tile flow values ranged from 163 mm to 257 mm with an average value as 209 mm over the period. Simulated tile flow fluctuated from 16% to 24% of total precipitation with an average of 20%. Percent of total precipitation as simulated average evapotranspiration values ranged from 41% to 62%, with an average of 51%. Simulated water yield ranged from 34% to 59% of precipitation, with an average of 48%. Flow partitioning was reasonable for simulated water quantity results for the LVR watershed for the baseline period, which was similar to that for simulated water balance results at the Matson Ditch watershed in Indiana (Boles et al., 2015).

Simulated annual average streamflow for the baseline and bioenergy crop scenarios at the LVR watershed outlet ranged from 3.79 to 3.82 m^3/s over the period from 1990 to 2008 (Table 7). Streamflow was slightly reduced under bioenergy crop scenarios relative to the baseline (Table 7). The percentage reduction in streamflow ranged from 0.05% (Scenario 3, hybrid poplar on highly erodible areas) to 0.76% (Scenario 16, stover with *Miscanthus* on highly erodible areas and marginal land) (Table 7). Generally, streamflow reduction was slightly more under scenarios with corn stover with a combination of bioenergy crops on marginal land (Scenarios 13–18) (Fig. 4(c)) than under scenarios with bioenergy crops on marginal land (Scenarios 4–6) (Fig. 4(a)). Scenarios with bioenergy crops on marginal land (Scenarios 4–6) (Fig. 4(a)) had more streamflow reduction than those on highly erodible areas (Scenarios 1–3) (Fig. 4 (a) and Table 7).

Simulated annual average tile flow for the baseline and bioenergy crop scenarios across the entire LVR watershed ranged from 204 to 206 mm over the period from 1990 to 2008 (Table 7). Tile flow was slightly reduced under bioenergy crop scenarios (Fig. 4 and Table 7). The percentage reduction in tile flow ranged from 0.01% (Scenario 3, hybrid poplar on highly erodible areas, and Scenario 6, hybrid poplar on marginal land) to 0.89% (Scenario 7, stover with no nutrient replacement) (Table 7). Generally, tile flow reduction was slightly more under scenarios with corn stover removal (Scenarios 7–18) (Fig. 4(b) and (c)) than under scenarios without corn stover removal (Scenarios 1–6) (Fig. 4(a) and Table 7).

Reduction of streamflow and tile flow under bioenergy crop scenarios occurred mainly because of higher infiltration, percolation, and evapotranspiration, and lower soil moisture under bioenergy crop scenarios (Fig. 3 and Table 7) (Hickman et al., 2010; McIsaac et al., 2010). Planting of bioenergy crops in riparian zones could yield high biomass and also help trap and filter concentrated flow (Meehan et al., 2013; Pankau et al., 2012). However, the impacts on trapping concentrated flow was small; since surface runoff rarely occurred in this extensively tile-drained watershed, flow in channels, streams and the river was largely due to tile flow, and the function as a buffer is minimal.

Reduction in streamflow and tile flow under the scenario with corn stover removal may be due to increased evaporation from soil cover loss and reduced soil water holding capacity caused by corn stover removal (Cibin et al., 2012; Donk et al., 2010). The impacts of corn stover removal, switchgrass, *Miscanthus*, and hybrid poplar scenarios on streamflow and tile flow were minimal, since potential areas for bioenergy crop scenarios were small (Table 1). Corn stover removal (43 km^2) had a larger potential area than marginal land (2.11 km^2), which was slightly higher than that of highly erodible areas (0.50 km^2) (Table 1). The difference in potential area for bioenergy scenarios caused the difference in ability to reduce streamflow and tile flow. The larger the potential area for

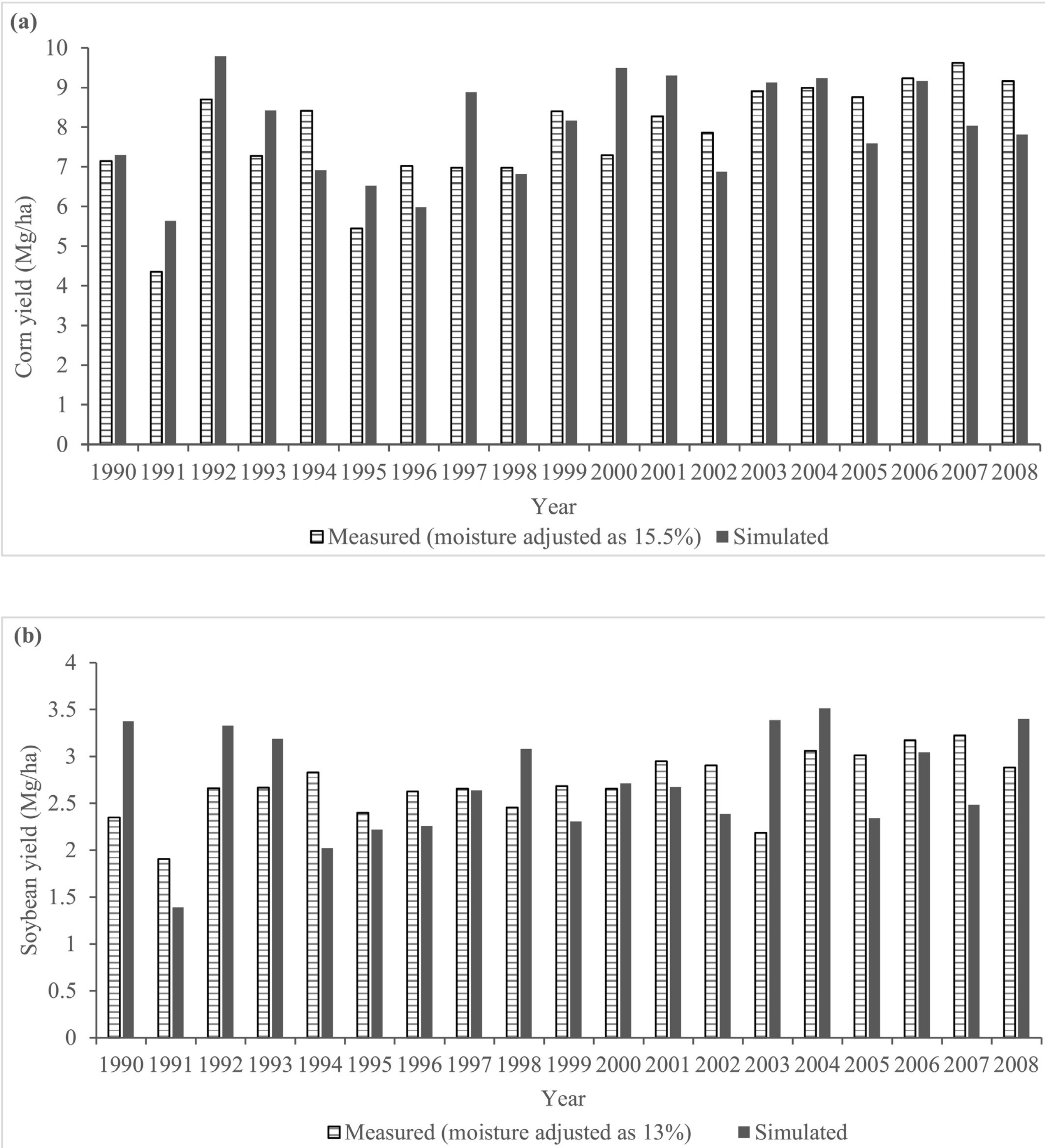


Fig. 2. Comparison of simulated corn (a) and soybean (b) yields with measured National Agricultural Statistics Service (NASS) yield data from Vermilion, Champaign and Edgar Counties in Illinois.

bioenergy scenarios, the higher the reduction in streamflow and tile flow. Thus, streamflow reduction was slightly more under scenarios with corn stover removal with combination of bioenergy crops on marginal land than under scenarios on marginal land, which had more streamflow reduction than scenarios on highly erodible areas. Streamflow reduction under scenarios with corn stover removal was slightly more than that for scenarios without corn stover removal. *Miscanthus* had the highest biomass yields and capability of water interception among three bioenergy crops, followed by switchgrass, and then hybrid poplar (Table 6). Reduction in streamflow under the scenario with *Miscanthus* on highly erodible areas (Scenario 1) was slightly higher than that with switchgrass on highly erodible arears (Scenario 2), which had a slightly higher reduction in streamflow than the scenario with hybrid poplar (Scenario 3) (Table 7 and Fig. 4(a)).

Table 6
Potential grain and biomass production for bioenergy crop scenarios in the LVR watershed[a].

Crop	Corn		Corn stover		*Miscanthus*		Switchgrass		Hybrid poplar		Area of bioenergy crops (ha)	Total biomass (Mg/yr)	Measured biomass yields
Yield	Mg/ha/yr	Mg/yr	Mg/ha/yr	Mg/yr	Mg/ha/yr	Mg/yr	Mg/ha/yr	Mg/yr	Mg/ha/yr	Mg/yr			
Baseline	7.95	141,000									0	189,000	*Miscanthus*[b]
Scenario 1	8.01	142,000			19.49	4000					210	194,000	25 Mg/ha/yr
Scenario 2	8.01	142,000					9.39	2000			210	192,000	(Trybula et al., 2015)
Scenario 3	8.01	142,000							8.17	2000	210	192,000	
Scenario 4	7.95	141,000			17.01	15,000					878	204,000	
Scenario 5	7.95	141,000					8.06	7000			878	196,000	
Scenario 6	7.95	141,000							7.16	6000	878	195,000	
Scenario 7	8.04	143,000	3.65	65,000							17,753	256,000	Switchgrass[b]
Scenario 8	8.38	149,900	3.81	68,000							17,753	265,900	10 Mg/ha/yr
Scenario 9	8.22	146,000	3.74	66,000							17,753	260,000	(Trybula et al., 2015)
Scenario 10	8.22	146,000	3.74	66,000	19.49	4000					210	264,000	
Scenario 11	8.22	146,000	3.74	66,000			9.39	2000			210	262,000	
Scenario 12	8.22	146,000	3.74	66,000					8.17	2000	210	262,000	
Scenario 13	8.22	146,000	3.74	66,000	17.01	15,000					878	275,000	Hybrid poplar[c]
Scenario 14	8.22	146,000	3.74	66,000			8.06	7000			878	267,000	10 Mg/ha/yr
Scenario 15	8.22	146,000	3.74	66,000					7.16	6000	878	266,000	(Hansen, 1991)
Scenario 16	8.22	146,000	3.74	66,000	17.49	19,000					1088	279,000	
Scenario 17	8.22	146,000	3.74	66,000			8.32	9000			1088	269,000	
Scenario 18	8.22	146,000	3.74	66,000					7.36	8000	1088	268,000	

[a] Annual average soybean yields were 2.72 Mg/ha/yr and 48,000 Mg/yr for baseline and all bioenergy crop scenarios.
[b] The measured yields for *Miscanthus* and Switchgrass were at the Purdue Water Quality Field Station (WQFS).
[c] The measured yield for hybrid poplar was at the USDA Forest Service Harshaw Experimental Farm (HEF) near Rhinelander, Wisconsin.

3.3. Impacts of bioenergy crop scenarios on erosion

Simulated annual average sediment load for baseline and bioenergy crop scenarios for the LVR watershed outlet ranged from 39,613 to 43,783 Mg/yr over the period from 1990 to 2008 (Table 7). Sediment was reduced under bioenergy crop scenarios of *Miscanthus*, switchgrass, and hybrid poplar on highly erodible areas and marginal land (Scenarios 1–6) (Fig. 4(a) and Table 7), with the percentage reduction in sediment load ranging from 2.69% (Scenarios 4 and 5, *Miscanthus* and Switchgrass on marginal land) to 4.76% (Scenario 3, hybrid poplar on high erodible land). Sediment load reduction was slightly more under bioenergy crop scenarios on highly erodible areas than scenarios on marginal land, and *Miscanthus* and switchgrass were equivalent in reducing sediment load (Fig. 4(a) and Table 7). Sediment load reduction from scenarios with hybrid poplar on highly erodible areas (Scenario 3) or marginal land (Scenario 6) was higher than these areas with *Miscanthus* and switchgrass. Soil erosion and sediment loss were more severe on highly erodible areas, and bioenergy crops had the potential to reduce sediment load.

Corn stover removal scenarios increased sediment load and ranged from 5.34% for stover removal with more nutrient replacement (Scenario 8) to 5.65% for stover removal without nutrient replacement

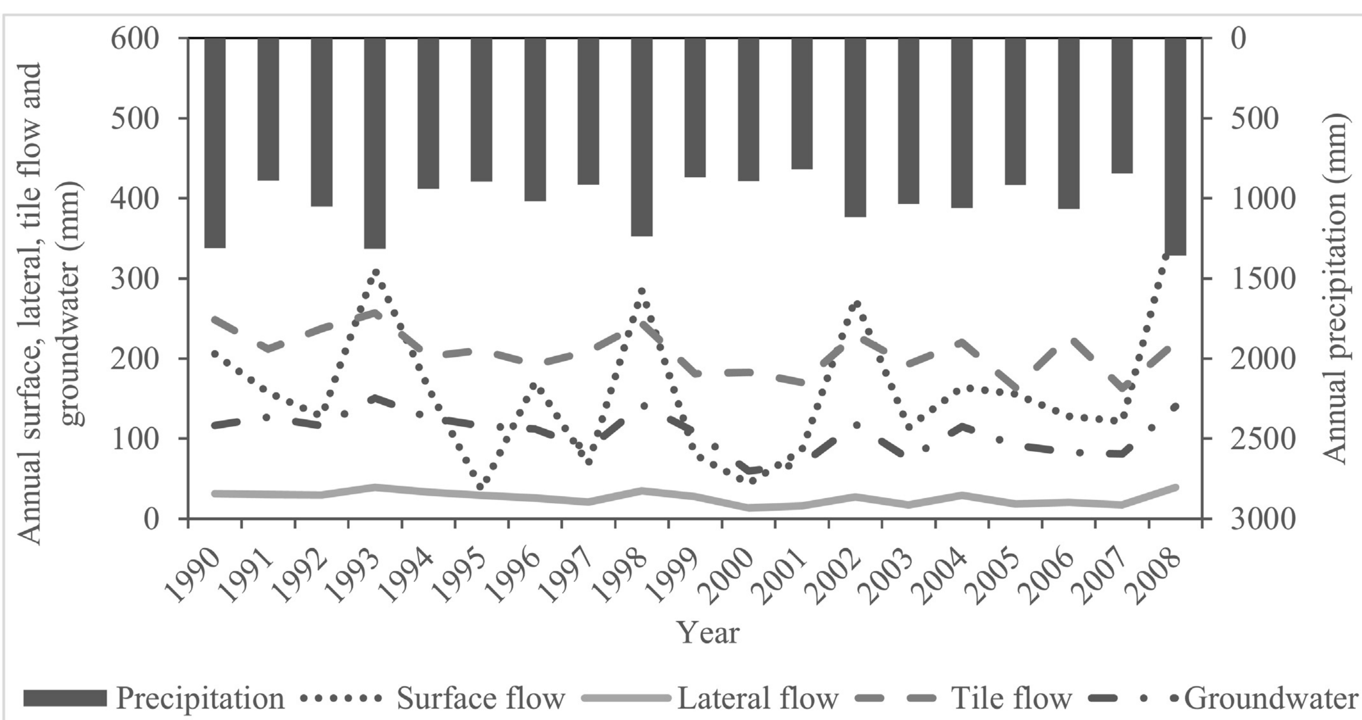


Fig. 3. Simulated annual flow partitioning for the baseline case for the LVR watershed.

Table 7
Average annual impact of bioenergy crop scenarios on streamflow, sediment losses, total nitrogen, nitrate losses, and total phosphorus losses at the LVR watershed outlet and evapotranspiration (ET), water yield, tile flow and nitrate losses in tile flow in the LVR watershed.

Scenario	Streamflow (m^3/s)	Tile flow (mm)	ET (mm)	Water yield (mm)	Sediment (Mg/yr)	Total nitrogen (kg/yr)	Nitrate (kg/yr)	Total phosphorus (kg/yr)	Nitrate in tile flow (kg/yr)
Baseline	3.818	206.26	518.90	503.40	41,573	281,502	266,115	46,576	191,310
Scenario 1	3.813	206.18	519.05	503.25	39,655	275,497	261,195	45,242	189,308
Scenario 2	3.815	206.19	519.04	503.26	39,696	274,080	259,902	45,284	189,391
Scenario 3	3.816	206.23	519.02	503.28	39,571	274,997	260,695	45,326	189,725
Scenario 4	3.802	206.19	519.22	503.09	40,447	275,497	260,903	45,826	189,475
Scenario 5	3.805	206.19	519.19	503.12	40,447	273,996	259,485	45,784	189,350
Scenario 6	3.805	206.23	519.19	503.12	40,363	275,706	260,987	45,868	189,725
Scenario 7	3.806	206.23	519.22	503.09	43,908	256,191	242,097	47,244	180,051
Scenario 8	3.807	204.43	519.17	503.14	43,783	272,787	257,984	48,161	191,935
Scenario 9	3.807	204.52	519.15	503.15	43,824	264,406	250,020	47,619	185,930
Scenario 10	3.802	204.49	519.15	503.15	41,906	263,488	250,020	46,285	185,472
Scenario 11	3.804	204.44	519.22	503.09	41,948	262,112	248,602	46,326	185,555
Scenario 12	3.805	204.44	519.20	503.11	41,823	263,113	249,395	46,368	185,930
Scenario 13	3.791	204.49	519.19	503.12	42,699	263,405	249,686	46,827	185,597
Scenario 14	3.793	204.45	519.34	502.97	42,699	261,987	248,310	46,827	185,514
Scenario 15	3.794	204.44	519.32	503.00	42,615	263,780	249,812	46,910	185,930
Scenario 16	3.789	204.45	519.30	503.01	40,697	262,696	249,686	45,617	185,597
Scenario 17	3.791	204.44	519.37	502.95	40,739	261,112	248,102	45,617	185,514
Scenario 18	3.792	204.49	519.34	502.97	40,614	262,404	249,311	45,659	185,930

(Scenario 7) (Fig. 4(b) and Table 7). Corn stover removal may accelerate soil nutrient losses and intensify wind and water soil erosion (Kenney et al., 2015). The increase in sediment load by corn stover removal could be offset under scenarios with corn stover removal with combination of *Miscanthus*, switchgrass and hybrid poplar (Scenarios 10–18) (Fig. 4(b) and (c), and Table 7). Corn stover removal combined with *Miscanthus*, switchgrass and hybrid poplar both on highly erodible areas and marginal land, could reduce sediment load (Scenarios 16–18) (Fig. 4(c) and Table 7). Corn stover removal had the potential to increase soil erosion but not by a considerable amount, since soil erosion was small given the watershed is mildly-sloped (Table 7). Perennial grasses and hybrid poplar trees in highly erodible areas and marginal land can reduce erosion slightly, since the areas for bioenergy crops were small.

3.4. Impacts of bioenergy crop scenarios on nutrient losses

Simulated annual average nutrient load for baseline and bioenergy crop scenarios at the LVR watershed outlet ranged from 256,024 to 281,460 kg/yr for total nitrogen, from 242,264 to 266,031 kg/yr for nitrate load, from 180,134 to 191,810 kg/yr for nitrate in tile flow, and from 45,451 to 47,952 kg/yr for total phosphorus over the period from 1990 to 2008 (Table 7). Simulated nitrate load at the watershed outlet is reasonable when compared to nitrate load (10 kg/ha) at the outlet of the county line river station (69 km^2) inside the watershed (Zanardo et al., 2012). Generally, nitrate load, nitrate in tile flow, and total nitrogen were reduced under bioenergy crop scenarios (Scenarios 1–18) (Fig. 4), except that nitrate in tile flow was increased by 0.33% under corn stover removal with more nutrient replacement (Scenario 8) (Fig. 4(b)). The percentage reduction ranged from 1.84% (Scenario 1, *Miscanthus* on highly erodible areas) to 9.02% (Scenario 7) for nitrate load, and from 2.06% (Scenario 6) to 8.99% (Scenario 7) for total nitrogen (Fig. 4 and Table 7). *Miscanthus*, switchgrass and hybrid poplar yielded more biomass than corn and soybeans, and amount of below ground biomass of bioenergy crops are higher than that of corn and soybeans, thus bioenergy crops are able to conserve nutrients from shoots to roots (Trybula et al., 2015).

Total phosphorus load was reduced under bioenergy crop scenarios of *Miscanthus*, switchgrass, and hybrid poplar on highly erodible land and marginal land (Scenarios 1–6) (Fig. 4(a) and Table 7), and the percentage reduction ranged from 1.59% (Scenario 6) to 2.85% (Scenario 1) (Fig. 4(a)). Reduction in total phosphorus load was slightly more under bioenergy crop scenarios on highly erodible areas than scenarios on marginal land (Fig. 4(a) and Table 7), since more phosphorus may move with sediment loss on highly erodible areas with steeper slopes (slope > 5%).

Generally, corn stover removal scenarios increased total phosphorus load (Fig. 4(b)). Increase in total phosphorus load was slightly more under corn stover removal with more nutrient replacement than less nutrient replacement, which had more phosphorus increase than stover removal without nutrient replacement (Fig. 4(a)). The increase in total phosphorus for corn stover removal could be offset under scenarios with corn stover removal with the combination of *Miscanthus*, switchgrass and hybrid poplar (Scenarios 10–18) (Fig. 4(b) and (c)). With the combination of *Miscanthus*, switchgrass and hybrid poplar both on highly erodible areas and marginal land, corn stover removal scenarios reduced total phosphorus load (Scenarios 16–18) (Fig. 4(c) and Table 7). Corn stover removal with nutrient replacement had the potential to increase nutrient loss (Fig. 4(b)), and perennial grasses and hybrid poplar trees on highly erodible areas and marginal land could reduce nutrient losses slightly (Fig. 4(b) and (c)). *Miscanthus*, switchgrass, and hybrid poplar yielded higher biomass yields than corn and soybeans and they can store nutrients in below ground biomass, and nutrient requirements for bioenergy crops were lower than those for corn and soybeans. Additionally, less nutrient mass was applied to bioenergy crops than those for corn and soybeans. Thus, bioenergy crop scenarios can reduce nutrient losses in subsurface drainage systems and at watershed outlets generally (Cibin et al., 2016; Heaton et al., 2009). Corn stover removal could reduce soil cover, increase sediment and nutrient losses, and with the combination of more nutrient replacement, it could increase nitrate losses in subsurface drainage systems (Cibin et al., 2012; Delgado, 2010). Switchgrass had the highest reduction in total nitrogen and phosphorous on marginal land (Scenario 5) among the three bioenergy crops (Table 7 and Fig. 4(a)), possibly because switchgrass could yield high below ground biomass during the early growing period and could store more nutrients than *Miscanthus* and hybrid poplar on marginal land (Scenarios 4 and 6). Reduction of nutrient losses by bioenergy crop scenarios at the watershed scale in this study was lower than reported values in previous studies (Boles, 2013; Cibin et al., 2016), since the potential areas for bioenergy crop scenarios were very small. In terms of reduction of nutrient losses per unit of changed area, reduction of nitrate load under scenario 16, 17 and 18 for the changed area for bioenergy crop scenarios (10.88 km^2) were 15.1, 16.6 and 15.4 kg/ha, respectively.

Limited observed precipitation data and crop management practices data, such as planting and harvest date and fertilizer application

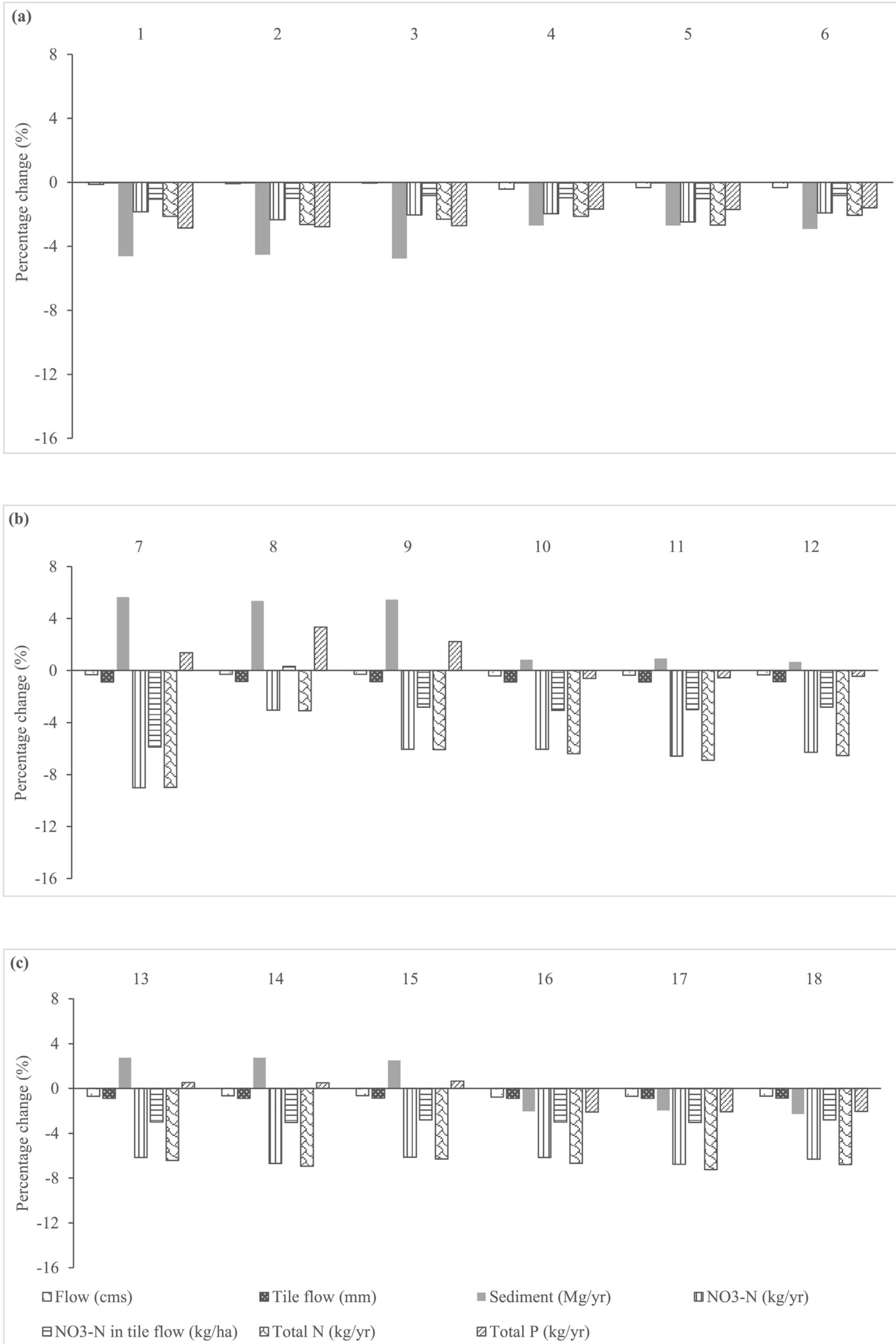


Fig. 4. Average annual impacts of bioenergy crop scenarios on hydrology and water quality for the LVR watershed. Numbers 1 to 18 represent Scenarios 1 to 18 (Table 2).

amount, could be used in the watershed, which may impact accuracy of crop growth, hydrology and water quality simulation. Potential areas for bioenergy crop scenarios were small, thus the ability to produce biomass, and to improve water quantity and quality was limited. Corn stover removal with bioenergy crops both on highly erodible areas and marginal land could yield high biofeedstock production, and could be beneficial to water quality in the watershed. The research results provide guidance for further research on assessment of bioenergy crop scenarios at a large scale in the Mississippi River system in the U.S. and other countries or regions, such as China with large areas of marginal land.

4. Conclusions

SWAT2012 (Revision 615) with improved perennial grass and tree growth and the new tile drainage routine (DRAINMOD routine) was used to simulate annual biomass yields, streamflow, sediment, nitrate, total nitrogen, soluble nitrogen, organic nitrogen, total phosphorus, mineral phosphorus, and organic phosphorus results at the watershed outlet, and tile flow and nitrate in tile flow across the entire watershed under various bioenergy scenarios from 1990 to 2008. Simulated annual average results from different bioenergy crop scenarios were compared with those from the baseline.

The results showed that simulated annual corn and soybean yields for the baseline were similar to observed values. Simulated annual average yields for *Miscanthus*, switchgrass and hybrid poplar were reasonable compared to simulated results in the same region from previous studies. Annual average biofeedstock production for bioenergy areas varied for different bioenergy crop scenarios. Thirty eight percent of corn stover removal (66,000 Mg/yr) with a combination of *Miscanthus* both on highly erodible areas and marginal land (19,000 Mg/yr) provided the highest biofeedstock production. Biofeedstock production was not considerable, since the potential areas of bioenergy crop scenarios were small.

Sediment load was reduced under bioenergy crop scenarios of *Miscanthus*, switchgrass, and hybrid poplar on highly erodible land, and marginal land. Corn stover removal scenarios (as high as 38%) increased sediment load, and the increase in sediment load for corn stover removal could be offset under scenarios with corn stover removal with a combination of *Miscanthus*, switchgrass and hybrid poplar.

Generally, streamflow, tile flow, sediment load, and nutrient losses were slightly reduced by switchgrass, *Miscanthus* and hybrid poplar for scenarios on highly erodible areas and marginal land. Corn stover removal did not result in significant water quality alterations. Adverse impacts of corn stover removal on sediment load and nutrient losses could be offset by bioenergy crop production in the watershed on highly erodible areas and marginal land. Corn stover removal with a combination of perennial grasses and hybrid poplar both on highly erodible areas and marginal land could slightly reduce streamflow and tile flow and improve water quality. Bioenergy crops could produce more biofeedstock than corn and soybeans, and store more nutrients in below ground biomass, and reduce sediment and nutrient losses in soil and drainage systems. Potential areas for bioenergy crop scenarios were very small, and thus the ability to improve water quantity and quality in the LVR watershed was small and lower than reported values in previous studies.

Corn stover removal with bioenergy crops both on highly erodible areas and marginal land could provide more biofuel production relative to the baseline, and could improve water quality at the watershed scale. Further research on quantification of biofeedstock production of bioenergy crop growth and its impacts on water quantity and quality from larger areas can be considered in mildly-sloped watersheds. It is also important to investigate the loss of pasture during bioenergy crop planting and its impacts on biomass production and water quality in further study. Additionally, field experiments can be performed to quantify water quality impacts of bioenergy crop scenarios. Moreover, there is need to monitor nutrient reduction efficiencies, and assess the cost and economic benefits of bioenergy crop scenarios at a large scale in the Mississippi River system to alleviate hypoxia in the Gulf of Mexico.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2017.09.148.

References

Algoazany, A.S., Kalita, P.K., Czapar, G.F., Mitchell, J.K., 2007. Phosphorus transport through subsurface drainage and surface runoff from a flat watershed in East Central Illinois, USA. J. Environ. Qual. 36 (3), 681–693.

Basu, N.B., Rao, P.S.C., Winzeler, H.E., Kumar, S., Owens, P., Merwade, V., 2010. Parsimonious modeling of hydrologic responses in engineered watersheds: structural heterogeneity versus functional homogeneity. Water Resour. Res. 46(4).

Behrman, K.D., Keitt, T.H., Kiniry, J.R., 2014. Modeling differential growth in switchgrass cultivars across the Central and Southern Great Plains. BioEnergy Res. 7 (4), 1165–1173.

Boles, C.M.W., 2013. SWAT Model Simulation of Bioenergy Crop Impacts in a Tile-drained Watershed. Purdue University, West Lafayette, Indiana.

Boles, C.M.W., Frankenberger, J.R., Moriasi, D.N., 2015. Tile drainage simulation in SWAT2012: parameterization and evaluation in an Indiana watershed. Trans. ASABE 58 (5), 1201–1213.

Borah, D.K., Bera, M., Shaw, S., 2003. Water, sediment, nutrient, and pesticide measurements in an agricultural watershed in Illinois during storm events. Trans. ASABE 46 (3), 657–674.

Brechbill, S., Tyner, W.E., 2008. The Economics of Renewable Energy: Corn Stover and Switchgrass: Purdue University Cooperative Extension Service.

Buhler, D.D., Randall, G.W., Koskinen, W.C., Wyse, D.L., 1993. Atrazine and alachlor losses from subsurface tile drainage of a clay loam soil. J. Environ. Qual. 22 (3), 583–588.

Casler, M.D., 2010. Changes in mean and genetic variance during two cycles of within-family selection in switchgrass. BioEnergy Res. 3 (1), 47–54.

Cibin, R., Chaubey, I., Engel, B., 2012. Simulated watershed scale impacts of corn stover removal for biofuel on hydrology and water quality. Hydrol. Process. 26 (11), 1629–1641.

Cibin, R., Trybula, E., Chaubey, I., Brouder, S.M., Volenec, J.J., 2016. Watershed-scale impacts of bioenergy crops on hydrology and water quality using improved SWAT model. GCB Bioenergy 8 (4), 837–848.

Cortese, L.M., Honig, J., Miller, C., Bonos, S.A., 2010. Genetic diversity of twelve switchgrass populations using molecular and morphological markers. BioEnergy Res. 3 (3), 262–271.

Delgado, J.A., 2010. Crop residue is a key for sustaining maximum food production and for conservation of our biosphere. J. Soil Water Conserv. 65 (5), 111A–116A.

Donk, S.J.v., Martin, D.L., Irmak, S., Melvin, S.R., Petersen, J.L., Davison, D.R., 2010. Crop residue cover effects on evaporation, soil water content, and yield of deficit-irrigated corn in West-Central Nebraska. Trans. ASABE 53 (6), 1787–1797.

Evans, R.O., Fausey, N.R., Skaggs, R., Schilfgaarde, J.V., 1999. Effects of inadequate drainage on crop growth and yield. Agric. Drain. 13–54.

Feng, Q., 2016. Hydrologic and Water Quality Impacts from Perennial Crop Production on Marginal Lands. Purdue University, West Lafayette, Indiana.

Gamalero, E., Cesaro, P., Cicatelli, A., Todeschini, V., Musso, C., Castiglione, S., Fabiani, A., Lingua, G., 2012. Poplar clones of different sizes, grown on a heavy metal polluted site, are associated with microbial populations of varying composition. Sci. Total Environ. 425, 262–270.

Graham, R.L., Nelson, R., Sheehan, J., Perlack, R.D., Wright, L.L., 2007. Current and potential U.S. corn stover supplies. Agron. J. 99 (1), 1–11.

Guo, T., He, B., Jiang, X., Ma, Y., Wu, Y., Xiang, M., Chen, Y., Tang, C., 2012a. Effect of *Leucaena leucocephala* on soil organic carbon conservation on slope in the purple soil area. Acta Ecol. Sin. 32 (1), 190–197.

Guo, T., He, B.H., Chen, J.J., 2012b. Study on SOC forecast model in regions of hilly purple soil by water erosion. Adv. Mater. Res. 391, 982–987 (Trans Tech Publ).

Guo, T., Engel, B.A., Shao, G., Arnold, J.G., Srinivasan, R., Kiniry, J.R., 2015. Functional approach to simulating short-rotation woody crops in process-based models. BioEnergy Res. 8 (4), 1598–1613.

Guo, T., Gitau, M., Merwade, V., Arnold, J., Srinivasan, R., Hirschi, M., Engel, B., 2017. Comparison of performance of tile drainage routines in SWAT 2009 and 2012 in an extensively tile-drained watershed in the Midwest. Hydrol. Earth Syst. Sci. Discuss. 2017, 1–33.

Gush, M.B., 2010. Assessing Hydrological Impacts of Tree-based Bioenergy Feedstock. University of Newcastle.

Hansen, E.A., 1983. Intensive plantation culture: 12 years research. General Technical Report, North Central Forest Experiment Station, USDA Forest Service (NC-91).

Hansen, E.A., 1991. Poplar woody biomass yields: a look to the future. Biomass Bioenergy 1 (1), 1–7.

He, B., Guo, T., 2012. Impact of Agricultural Contaminants in Surface Water Quality: A Case Study from SW China: INTECH Open Access Publisher.

He, B., Guo, T., Huang, H., Xi, W., Chen, X., 2017. Physiological responses of *Scaevola aemula* seedlings under high temperature stress. S. Afr. J. Bot. 112, 203–209.

Heaton, E.A., Dohleman, F.G., Long, S.P., 2009. Seasonal nitrogen dynamics of *Miscanthus* × *giganteus* and *Panicum virgatum*. GCB Bioenergy 1 (4), 297–307.

Hickman, G.C., Vanloocke, A., Dohleman, F.G., Bernacchi, C.J., 2010. A comparison of canopy evapotranspiration for maize and two perennial grasses identified as potential bioenergy crops. GCB Bioenergy 2 (4), 157–168.

Hoskinson, R.L., Karlen, D.L., Birrell, S.J., Radtke, C.W., Wilhelm, W.W., 2007. Engineering, nutrient removal, and feedstock conversion evaluations of four corn stover harvest scenarios. Biomass Bioenergy 31 (2–3), 126–136.

Jaynes, D., James, D., 2007. The extent of farm drainage in the United States. Annual Meeting of the Soil and Water Conservation Society, Tampa, Florida.

Kalita, P.K., Ward, A.D., Kanwar, R.S., McCool, D.K., 1998. Simulation of pesticide concentrations in groundwater using Agricultural Drainage and Pesticide Transport (ADAPT) model1. Agric. Water Manag. 36 (1), 23–44.

Kalita, P.K., Algoazany, A.S., Mitchell, J.K., Cooke, R.A.C., Hirschi, M.C., 2006. Subsurface water quality from a flat tile-drained watershed in Illinois, USA. Agric. Ecosyst. Environ. 115 (1–4), 183–193.

Kalita, P.K., Cooke, R.A.C., Anderson, S.M., Hirschi, M.C., Mitchell, J.K., 2007. Subsurface drainage and water quality: the Illinois experience. Trans. ASABE 50 (5), 1651–1656.

Keefer, L., 2003. Sediment and water quality monitoring for the Vermilion River and Little Vermilion River watersheds. Illinois State Water Survey Contract Report 2003–06, Champaign, IL.

Kenney, I., Blanco-Canqui, H., Presley, D.R., Rice, C.W., Janssen, K., Olson, B., 2015. Soil and crop response to stover removal from rainfed and irrigated corn. GCB Bioenergy 7 (2), 219–230.

Khanal, S., Parajuli, P.B., 2013. Evaluating the impacts of forest clear cutting on water and sediment yields using SWAT in Mississippi. J. Water Resour. Prot. 5 (4), 474–483.

Kim, S., Dale, B.E., 2004. Global potential bioethanol production from wasted crops and crop residues. Biomass Bioenergy 26 (4), 361–375.

Kiniry, J.R., Johnson, M.-V.V., Bruckerhoff, S.B., Kaiser, J.U., Cordsiemon, R.L., Harmel, R.D., 2012. Clash of the titans: comparing productivity via radiation use efficiency for two grass giants of the biofuel field. BioEnergy Res. 5 (1), 41–48.

Kiniry, J.R., Anderson, L.C., Johnson, M.-V.V., Behrman, K.D., Brakie, M., Burner, D., Cordsiemon, R.L., Fay, P.A., Fritschi, F.B., Houx, J.H., Hawkes, C., Juenger, T., Kaiser, J., Keitt, T.H., Lloyd-Reilley, J., Maher, S., Raper, R., Scott, A., Shadow, A., West, C., Wu, Y., Zibilske, L., 2013. Perennial biomass grasses and the Mason–Dixon line: comparative productivity across latitudes in the Southern Great Plains. BioEnergy Res. 6 (1), 276–291.

Kladivko, E.J., Brown, L.C., Baker, J.L., 2001. Pesticide transport to subsurface tile drains in humid regions of North America. Crit. Rev. Environ. Sci. Technol. 31 (1), 1–62.

Klingebiel, A., Montgomery, P., 1961. Land-capability classification. Agricultural Handbook. No. 210. Soil Conservation Service. US Department of Agriculture, Washington DC.

Kuzmanovski, V., Trajanov, A., Leprince, F., Džeroski, S., Debeljak, M., 2015. Modeling water outflow from tile-drained agricultural fields. Sci. Total Environ. 505, 390–401.

Lindstrom, M.J., 1986. Effects of residue harvesting on water runoff, soil erosion and nutrient loss. Agric. Ecosyst. Environ. 16 (2), 103–112.

Liu, W., Mi, J., Song, Z., Yan, J., Li, J., Sang, T., 2014. Long-term water balance and sustainable production of *Miscanthus* energy crops in the Loess Plateau of China. Biomass Bioenergy 62, 47–57.

Liu, Y., Bralts, V.F., Engel, B.A., 2015. Evaluating the effectiveness of management practices on hydrology and water quality at watershed scale with a rainfall-runoff model. Sci. Total Environ. 511, 298–308.

Love, B.J., Nejadhashemi, A.P., 2011. Water quality impact assessment of large-scale biofuel crops expansion in agricultural regions of Michigan. Biomass Bioenergy 35 (5), 2200–2216.

McIsaac, G.F., David, M.B., Mitchell, C.A., 2010. *Miscanthus* and switchgrass production in Central Illinois: impacts on hydrology and inorganic nitrogen leaching. J. Environ. Qual. 39 (5), 1790–1799.

Meehan, T.D., Gratton, C., Diehl, E., Hunt, N.D., Mooney, D.F., Ventura, S.J., Barham, B.L., Jackson, R.D., 2013. Ecosystem-service tradeoffs associated with switching from annual to perennial energy crops in riparian zones of the US Midwest. PLoS One 8 (11), e80093.

Mitchell, J.K., McIsaac, G.F., Walker, S.E., Hirschi, M.C., 2000. Nitrate in river and subsurface drainage flows from an east central Illinois watershed. Trans. ASABE 43 (2), 337–342.

Ng, T.L., Eheart, J.W., Cai, X., Miguez, F., 2010. Modeling *Miscanthus* in the soil and water assessment tool (SWAT) to simulate its water quality effects as a bioenergy crop. Environ. Sci. Technol. 44 (18), 7138–7144.

Pankau, R.C., Schoonover, J.E., Williard, K.W.J., Edwards, P.J., 2012. Concentrated flow paths in riparian buffer zones of southern Illinois. Agrofor. Syst. 84 (2), 191–205.

Parajuli, P.B., Duffy, S.E., 2013. Quantifying hydrologic and water quality responses to bioenergy crops in Town Creek watershed in Mississippi. J. Sustain. Bioenergy Syst. 3 (3), 202–208.

Parajuli, R., Knudsen, M.T., Djomo, S.N., Corona, A., Birkved, M., Dalgaard, T., 2017. Environmental life cycle assessment of producing willow, alfalfa and straw from spring barley as feedstocks for bioenergy or biorefinery systems. Sci. Total Environ. 586, 226–240.

Peterson, G.D., Cumming, G.S., Carpenter, S.R., 2003. Scenario planning: a tool for conservation in an uncertain world. Conserv. Biol. 17 (2), 358–366.

Pyter, R., Voigt, T., Heaton, E., Dohleman, F., Long, S., 2007. Giant Miscanthus: biomass crop for Illinois. In: Janick, J., Whipkey, A. (Eds.), Proc. Sixth National Symposium. Issues in New Crops and New Uses. ASHS Press, VA.

Rabalais, N., Turner, R., Justic, D., Dortch, Q., Wiseman, W., 1999. Characterization of hypoxia. Topic 1 report for the integrated assessment of hypoxia in the northern Gulf of Mexico. NOAA Coastal Ocean Program Decision Analysis Series Report No. 15.

Randall, G.W., Iragavarapu, T.K., 1995. Impact of long-term tillage systems for continuous corn on nitrate leaching to tile drainage. J. Environ. Qual. 24 (2), 360–366.

Riemenschneider, D.E., Isebrands, J.G., Berguson, W.E., Dickmann, D.I., Hall, R.B., Mohn, C.A., Stanosz, G.R., Tuskan, G.A., 2001. Poplar breeding and testing strategies in the north-central U.S.: demonstration of potential yield and consideration of future research needs. For. Chron. 77 (2), 245–253.

Schmer, M.R., Mitchell, R.B., Vogel, K.P., Schacht, W.H., Marx, D.B., 2010. Spatial and temporal effects on switchgrass stands and yield in the Great Plains. BioEnergy Res. 3 (2), 159–171.

Schroeder, J.W., 2004. Silage Fermentation and Preservation: NDSU Extension Service Fargo, North Dakota.

Singh, J., Kalita, P.K., Mitchell, J.K., Cooke, R.A.C., Hirschi, M.C., 2001. Simulation of tile flow for a flat tile drained watershed in East Central Illinois. 2001 ASAE Annual Meeting.

Skaggs, R.W., Youssef, M.A., Chescheir, G.M., 2012. DRAINMOD: model use, calibration, and validation. Trans. ASABE 55 (4), 1509–1522.

Sood, A., Ritter, W.F., 2010. Evaluation of best management practices in Millsboro pond watershed using soil and water assessment tool (SWAT) model. J. Water Resour. Prot. 2 (5), 10.

Srinivasan, R., Zhang, X., Arnold, J., 2010. SWAT ungauged: hydrological budget and crop yield predictions in the Upper Mississippi River Basin. Trans. ASABE 53 (5), 1533–1546.

Sugg, Z., 2007. Assessing US Farm Drainage: Can GIS Lead to Better Estimates of Subsurface Drainage Extent. World Resources Institute, Washington, DC 20002.

Sui, Y., Frankenberger, J.R., 2008. Nitrate loss from subsurface drains in an agricultural watershed using SWAT2005. Trans. ASABE 51 (4), 1263–1272.

Thomas, M.A., Engel, B.A., Chaubey, I., 2011. Multiple corn stover removal rates for cellulosic biofuels and long-term water quality impacts. J. Soil Water Conserv. 66 (6), 431–444.

Thomas, M.A., Ahiablame, L.M., Engel, B.A., Chaubey, I., 2014. Modeling water quality impacts of growing corn, switchgrass, and *Miscanthus* on marginal soils. J. Water Resour. Prot. 6 (14), 1352–1368.

Thornton, F.C., Dev, Joslin J., Bock, B.R., Houston, A., Green, T.H., Schoenholtz, S., Pettry, D., Tyler, D.D., 1998. Environmental effects of growing woody crops on agricultural land: first year effects on erosion, and water quality. Biomass Bioenergy 15 (1), 57–69.

Tilman, D., Socolow, R., Foley, J.A., Hill, J., Larson, E., Lynd, L., Pacala, S., Reilly, J., Searchinger, T., Somerville, C., Williams, R., 2009. Beneficial biofuels—the food, energy, and environment trilemma. Science 325 (5938), 270–271.

Tolbert, V.R., Lindberg, J., Green, T., 1997. Soil and Water Quality Implications of Production of Herbaceous and Woody Energy Crops. Oak Ridge National Lab, TN (United States).

Trybula, E.M., Cibin, R., Burks, J.L., Chaubey, I., Brouder, S.M., Volenec, J.J., 2015. Perennial rhizomatous grasses as bioenergy feedstock in SWAT: parameter development and model improvement. GCB Bioenergy 7 (6), 1185–1202.

Valcu-Lisman, A.M., Kling, C.L., Gassman, P.W., 2016. The optimality of using marginal land for bioenergy crops: tradeoffs between food, fuel, and environmental services. Agric. Resour. Econ. Rev. 45 (02), 217–245.

Yan, L., Penttinen, P., Simojoki, A., Stoddard, F.L., Lindström, K., 2015. Perennial crop growth in oil-contaminated soil in a boreal climate. Sci. Total Environ. 532, 752–761.

Yasarer, L.M., Sinnathamby, S., Sturm, B.S., 2016. Impacts of biofuel-based land-use change on water quality and sustainability in a Kansas watershed. Agric. Water Manag. 175, 4–14.

Zalesny, R., Hall, R., Zalesny, J., McMahon, B., Berguson, W., Stanosz, G., 2009. Biomass and genotype × environment interactions of *Populus* energy crops in the Midwestern United States. BioEnergy Res. 2 (2), 106–122.

Zalesny, R.S., Donner, D.M., Coyle, D.R., Headlee, W.L., 2012. An approach for siting poplar energy production systems to increase productivity and associated ecosystem services. For. Ecol. Manag. 284, 45–58.

Zanardo, S., Basu, N.B., Botter, G., Rinaldo, A., Rao, P.S.C., 2012. Dominant controls on pesticide transport from tile to catchment scale: lessons from a minimalist model. Water Resour. Res. 48 (4).

Zhuang, J., Gentry, R.W., Yu, G.-R., Sayler, G.S., Bickham, J.W., 2010. Bioenergy sustainability in China: potential and impacts. Environ. Manag. 46 (4), 525–530.

View publication stats