05 Water Quality Responses to Simulated Management Practices on Agricultural Lands Producing Biomass Feedstocks in Two Tributary Basins of the Mississippi River

Henriette I. Jager,[1] May Wu,[2] Miae Ha,[2]
Latha Baskaran,[1] and Jasmine Kreig[1]

[1] Oak Ridge National Laboratory
[2] Argonne National Laboratory

5.1 Introduction

Water quality is a legitimate concern for any proposed shift in the nation's energy portfolio. Of the total length of wadeable U.S. streams, 42% are in poor condition (Paulsen et al. 2008). Increasing human exposure to nitrates in drinking water is a significant health concern in the Midwest because of its increasing trend in groundwater (Stets, Kelly, and Crawford 2015). In addition, nitrogen enrichment has played a role in the imperilment of aquatic species (Hernandez et al. 2016). Decomposition of algal blooms during summer periodically depletes water of oxygen in a significant number of rivers, lakes, and reservoirs. Downstream nutrient excesses have degraded more than 60% of coastal rivers and bays in the United States (Simpson et al. 2008). Furthermore, climate warming is likely to exacerbate problems and increase the potential for harmful algal blooms and the incidence of hypoxic conditions in rivers, lakes, and estuaries.

Given the state of the nation's waters, it is important to understand the water quality implications of future biomass feedstock production systems. Will future production have positive or negative impacts on water quality? The answer likely depends on the choice of crop (feedstock) and how the energy crop is managed relative to the previous non-energy crop. At one end of the spectrum, expansion of corn acreage to support grain-based ethanol production might be expected to degrade water quality in the same way that corn grown for food and animal feed would. This is because corn is inefficient in nitrogen uptake (Simpson et al. 2008). Under this 'worst-case' scenario, increasing grain (corn) production might put the goal of reducing the hypoxic 'dead' zone in the Gulf of Mexico farther out of reach (Donner and Kucharik 2008). Assuming an 80% increase in corn acreage, the estimates of nutrient losses from the Mississippi-Atchafalaya River Basin (MARB) using the SPARROW model were 37% nitrogen and 25% phosphorus, respectively (Simpson et al. 2008). This highlights the potential water quality benefits of growing cellulosic and perennial biomass feedstocks, combined with targeted best management practices applied to areas planted in corn.

5.1.1 Cellulosic and Perennial Feedstocks

The outlook for water quality has changed with the prospect of growing and using cellulosic and perennial feedstocks. Compared with corn, cellulosic and, especially, perennial feedstocks, including short-rotation woody crops (SRWCs), have considerable benefits for improving water quality (Simpson et al. 2008) by potentially reducing nutrient loadings by half (Alshawaf, Douglas, and Ricciardi 2016, Evans et al. 2009). Research is showing that regional-scale production of feedstocks consistent with the Energy Independence and Security Act of 2007 and/or the Billion-Ton Update (DOE 2011) could improve water quality (Costello et al. 2009; Jager et al. 2015), particularly when perennial biomass feedstocks replace more intensively managed crops (Love and Nejadhashemi 2011).

5.1.2 Conservation Practices

In this chapter, the question posed is, "How can future biomass feedstocks be managed to protect water quality with minimal decrease in feedstock supply?" Thus, our emphasis is on identifying the 'swing potential' of different management practices (Davis et al. 2013). In other words, which practices have the highest potential for protecting water quality? We ask whether water quality can be protected by choosing perennial feedstocks and/or incorporating suitable combinations of best management practices into biomass-feedstock production. Practices evaluated in the past have included more precise application of fertilizer; use of cover crops, filter strips, and riparian buffers; no-till management; and mitigation of agricultural drainage. Although most studies focused on the watershed scale, water quality benefits of such practices have also been demonstrated at the scale of a large river basin, using models, for example, in the Upper Mississippi River Basin (UMRB) (Wu, Demissie, and Yan 2012; Demissie, Yan, and Wu 2012).

From a crop-management perspective, reduced or targeted fertilizer management can enhance the efficiency of nitrogen application and, thereby, provide farmers with flexible options for maintaining high-yielding production systems (Nelson, Motavalli, and Nathan 2014; Noellsch et al. 2009) and reducing nitrogen runoff. Using cover crops with corn and interplanting SRWCs have been shown to prevent excess nutrients from flowing into adjacent water bodies (Nyakatawa et al. 2006). In a comparison of management practices, nitrate leaching from Midwest fields growing annual crops (wheat, corn, and soy) was highest under conventional management, followed by no-till, reduced-input (20% to 50% fertilizer with leguminous cover crop), and organic production with no fertilizer inputs (Syswerda et al. 2012).

Planting perennial crops has been shown to reduce nitrate leaching more than the conservation practices applied to corn-based production systems (Syswerda et al. 2012). One of the most effective strategies—implementing a conservation buffer in riparian areas—can significantly decrease losses of nitrogen, phosphorus, and soil by trapping overland flow (Blanco et al. 2004; Dosskey et al. 2010; Balestrini et al. 2011). A review of widths of riparian buffers and filter strips by Fischer and Fischenich (2000) recommends a 5 meter (m) to 30 m width for water quality protection. Zhang et al. (2010) found that a 30-m buffer was required to remove 85% of nutrients on slopes up to 10%. Similarly, Gharabaghi, Rudra, and Goel (2006) found that more than 95% of sediment aggregates were removed by the initial 5 m of the vegetative filter's width.

The above practices might be rendered completely ineffective by artificial drainage (Petrolia and Gowda 2006; Petrolia, Gowda, and Mulla 2005). Excess nutrients (especially nitrate) bypass surface improvements, such as conservation tillage or riparian buffers, and flow through the soil into tile lines (Lemke et al. 2011). In addition, mitigation efforts that target drainage can be very effective—for example, controlled drainage (permitting water on fields during the fallow season). Filter strips can still be effective if they are located where they intercept shallow flow paths (Ssegane et al. 2015). Similarly, placement of filters at the inlet of tile-drain systems and placement of filter strips or wetlands at outlets can reduce nutrient losses. Addressing nutrient pathways through tile drains is critical to the success of nutrient-management efforts in the Midwest, where tile drains prevent waterlogging of crops and permit access by farm equipment.

5.1.3 Co-Optimizing Production and Water Quality

Is it possible to have the best of both worlds—high yields of biomass feedstocks and high water quality? Previous research at the watershed scale has found that balancing economic and environmental objectives using a spatially optimized landscape of biomass plantings can help move toward sustainable biomass-production systems (Parish et al. 2012). In a recent study of a typical Corn Belt watershed in the Iowa River Basin (IRB), Ha and Wu (2015) demonstrated the ability to harvest adequate levels of corn stover without adverse effects on water quality by implementing beneficial practices. Other studies have demonstrated that the use of cover crops can reduce water quality impacts of farming operations (Graham et al. 2007; Mann, Tolbert, and Cushman 2002), while reducing soil erosion, maintaining land productivity (Kaspar, Radke, and Laflen 2001; Snapp et al. 2005; Wyland et al. 1996), and reducing nutrient loadings.

In this chapter, we present research investigating the benefits of conservation practices that co-optimize the production of cellulosic energy feedstock and water quality improvements. Specifically, we look at landscapes produced that are consistent with a future 2040 economic scenario with $60/dry ton (dt) and 1% annual yield increases (BC1 2040; see chapter 2). Our central hypothesis is that the use of conservation practices and better management protocols can reduce the environmental effects of biomass production, without a significant sacrifice in production. Two goals of this chapter are to identify conservation practices that minimize water quality impacts and maximize feedstock yields. Thus, for watersheds located in different regions, we ask how can we apply conservation practices to lands producing biomass feedstocks that improve water quality with the least possible reduction in feedstock supply?

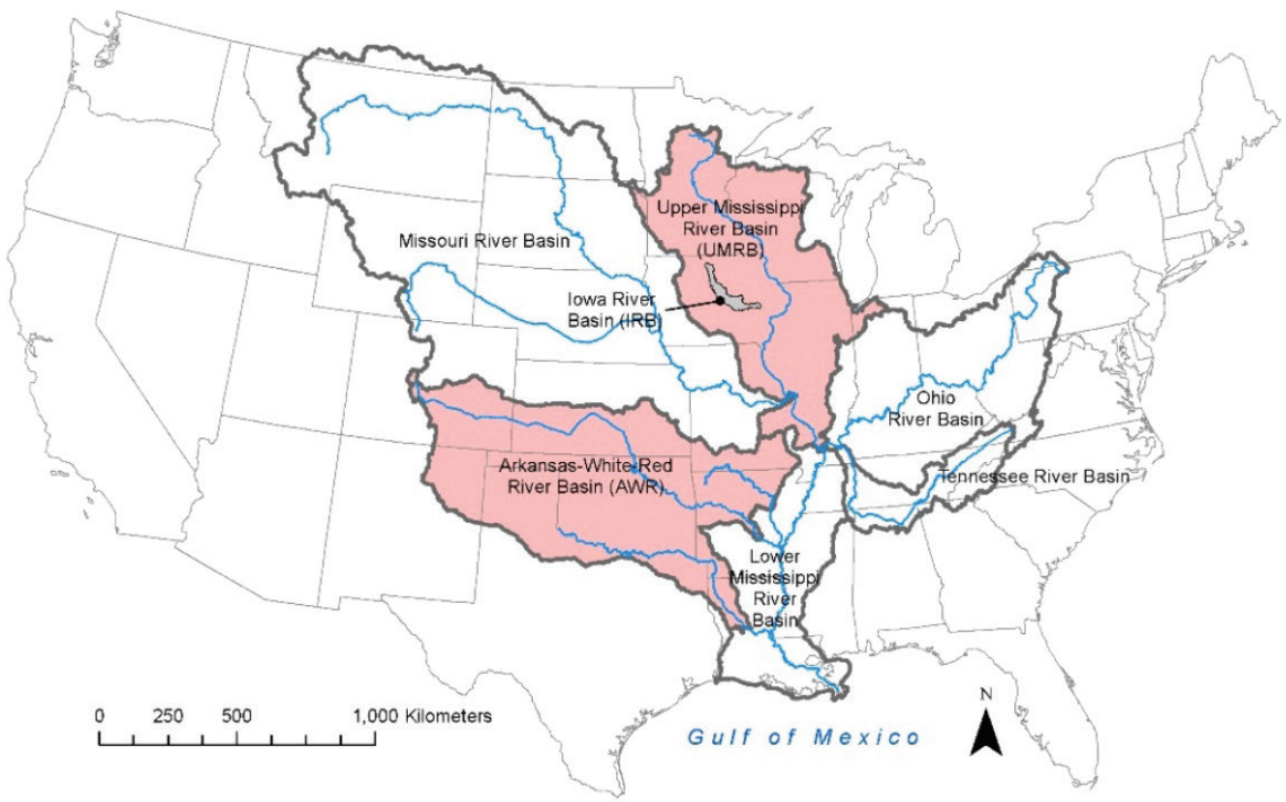
Our assessment seeks to understand how allocating conservation practices across future landscapes can help to achieve increases both in water quality and in biomass feedstock supply. Furthermore, we seek to understand general patterns that can be transferred to other locations to guide the management of cellulosic feedstocks. Implementing beneficial practices in a context-specific way is consistent with the conservation strategies devised by the U.S. Environmental Protection Agency's Hypoxia Task Force to reduce nutrient loadings from the Mississippi River Basin to the Gulf of Mexico by 20% by 2025 (EPA 2015).

In this study, we simulated conservation-practices relevant to feedstock cultivation for two dominant feedstock systems located in different regions within the Mississippi River Basin. Simulated results revealed relationships (tradeoffs and complementarities) among environmental indicators including (1) productivity, (2) nitrate loadings, (3) phosphorus loadings, (4) suspended sediment loadings, and (5) water yield.

5.2 Scope of Assessment

Unlike other assessments in this report, this analysis focuses on two areas with unique cellulosic feedstocks: the switchgrass-dominated Arkansas White and Red (AWR) River basin in the southern Great Plains and the corn stover-dominated IRB in the upper midwestern United States (fig. 5.1). *BT16* projections suggest that the potential for cellulosic feedstock production is high both in the AWR and in the UMRB, where the IRB lies.

Figure 5.1 | Two major river basins with different projected cellulosic biomass-production profiles



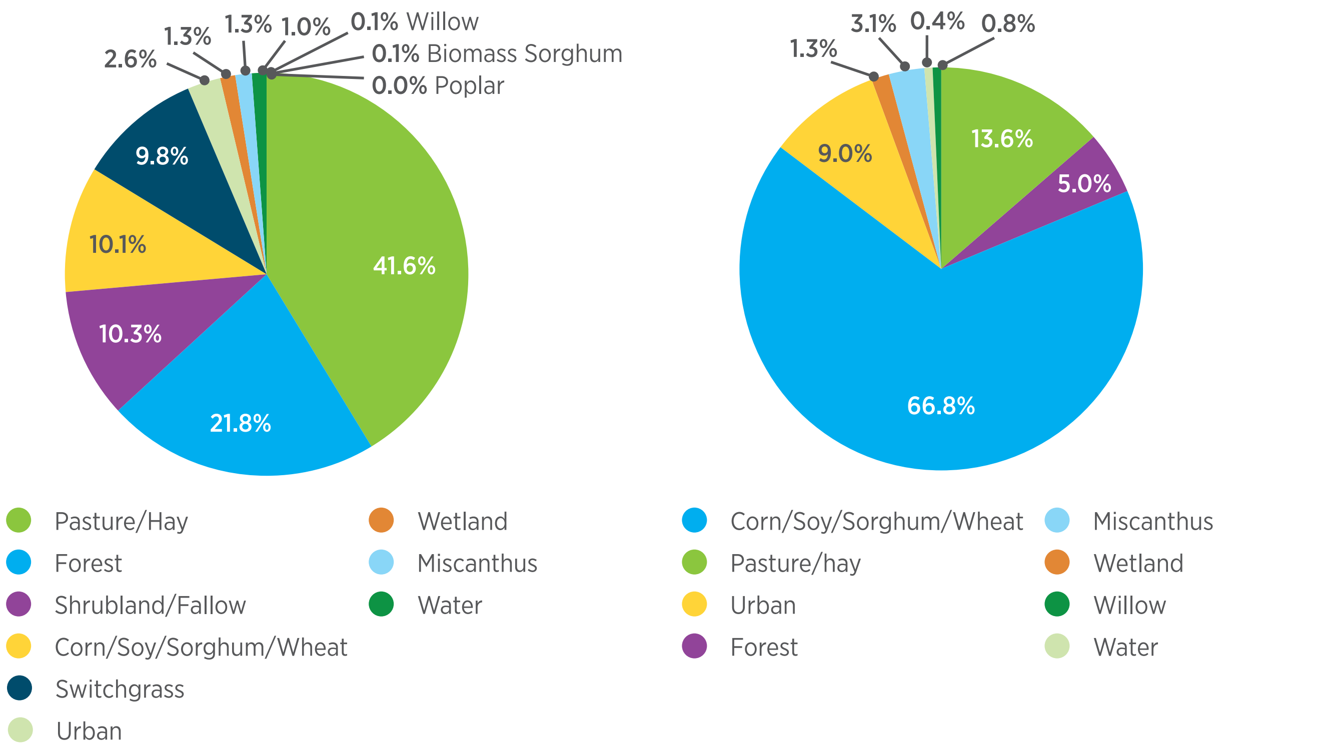
These basins are representative of two main agricultural systems that, according to *BT16* scenarios, would be dominated by distinct cellulosic feedstocks (chapter 3). In the UMRB, residue from corn stover is a promising near-term cellulosic feedstock (Graham et al. 2007). Located in the heart of the UMRB, the corn grain- and soybean-production systems of the IRB are representative of agriculture in the UMRB. The BC1 2040 scenario estimates that farms growing corn and soybeans will continue to dominate the IRB (67% of the land area in the IRB) (fig. 5.2).

Further south, the AWR is a promising region for sustainable biomass production and has potential for reducing nutrient loadings into the Gulf of Mexico (Jager et al. 2015). The AWR is a large river basin with diverse land uses (fig. 5.2). Under the BC1 2040 scenario, the region will remain diverse, dominated by pasture (42%) and forest (22%). The dominant feedstock in the region, switchgrass, produces yields of 8 to 14 Mg/ha (~4 tons/acre) (Jager et al. 2010; Wullschleger et al. 2010).

5.3 Methods

Our assessment involved five steps. First, for each river basin, we developed a Soil and Water Assessment Tool (SWAT) base model for the simulation area with at least 20 years of historical hydrology. Second, we downscaled the BC1 2040 scenario for each basin to produce a landscape for analysis. Third, we implemented SWAT with nominal conservation practices appropriate for respective production systems and with region-specific future energy crops and residues represented. Fourth, we simulated results for different conservation practices in SWAT. In our final step, we compared different conservation practices to understand tradeoffs and complementarities among

Figure 5.2 | Distribution of land use/land cover categories in landscapes consistent with the BC1 2040 scenario in the (a) Arkansas-White-Red and (b) Iowa River Basins



water quality and quantity indicators and biomass yields. This was done to promote the generalization of findings from these two regions to others with similar biomass feedstock profiles.

5.3.1 Environmental Indicators

Our analysis was designed to quantify environmental indicators (Dale et al. 2015) for different management practices associated with the BC1 2040-projected future landscape, which includes energy crops. To do this, we simulated a subset of the environmental indicators proposed by McBride et al. (2011). Our analysis focused on water quality and productivity indicators (table 5.1). Here, simulated annual values were averaged across years for the outlets of river basins.

Table 5.1 | Environmental Indicators of Water Quality, Quantity, and Productivity are Average Annual Values over 20 Simulated Years.

Environmental Indicator	Units
Nitrate loadings	kg/ha
Total nitrogen loadings	kg/ha
Total phosphorus loadings	kg/ha
Total suspended sediment	t/ha
Productivity (biomass yield)	t/ha

Acronyms: kg/ha – kilograms per hectare; t/ha – tons per hectare.

5.3.2 SWAT Implementation

We implemented SWAT for a large river basin (AWR) dominated by switchgrass and a smaller watershed (IRB) dominated by production of cellulosic residues in a predominantly corn/soybean-growing region in the BC1 2040 scenario. SWAT is a physically based, semi-distributed hydrologic model to simulate changes in land management and the resulting changes in the hydrologic cycle and water quality (Gassman et al. 2007). We relied on models that have already been described in previous publications. The analyses reported here use SWAT to explore the effects of conservation practices on three classes of environmental indicators: feedstock production, water quality, and water quantity.

We used spatial data layers describing soils, slope (from elevation), and land cover to partition each sub-basin into areas with similar hydrologic response units (HRUs) to climate. Input data sources for SWAT include soil properties, stream network topology, land topography via a digital elevation model, meteorological data, and stream-monitoring data. Soil properties were obtained from the Soil Survey Geographic Database, using the State Soil Geographic dataset in the larger basin and the Soil Survey Geographic Database in the smaller one. Historical calibrations were performed independently for the two basins. For the IRB, climate data were obtained over a historical period from 1994 to 2013 from the National Oceanic and Atmospheric Administration's National Climatic Data Center. For the AWR, daily climate variables were obtained over the historical period from 1980 to 2011 from Daymet (Thornton, Running, and White 1997). Other climate variables, including wind speed, relative humidity, and potential evaporation, were simulated by SWAT's climate generator. Land cover data for 2014 were obtained from the Crop Data Layer generated by the U.S. Department of Agriculture's (USDA's) National Agricultural Statistics Service (NASS 2013). Simulations reported here were performed by using SWAT model version 2012, revision 622.

Soil units that comprised more than 10% of a sub-basin were represented as separate HRUs in SWAT. Maloney and Feminella (2006) showed that disturbances had greater impacts on sediment loadings in streams for watersheds with slopes greater than 5%. Therefore, we discretized slope into four categories: <1%; 1%–2%; 2%–5%; and >5%. Because a small amount of steep land can have large effects on sediment losses, we included all slope categories, regardless of area.

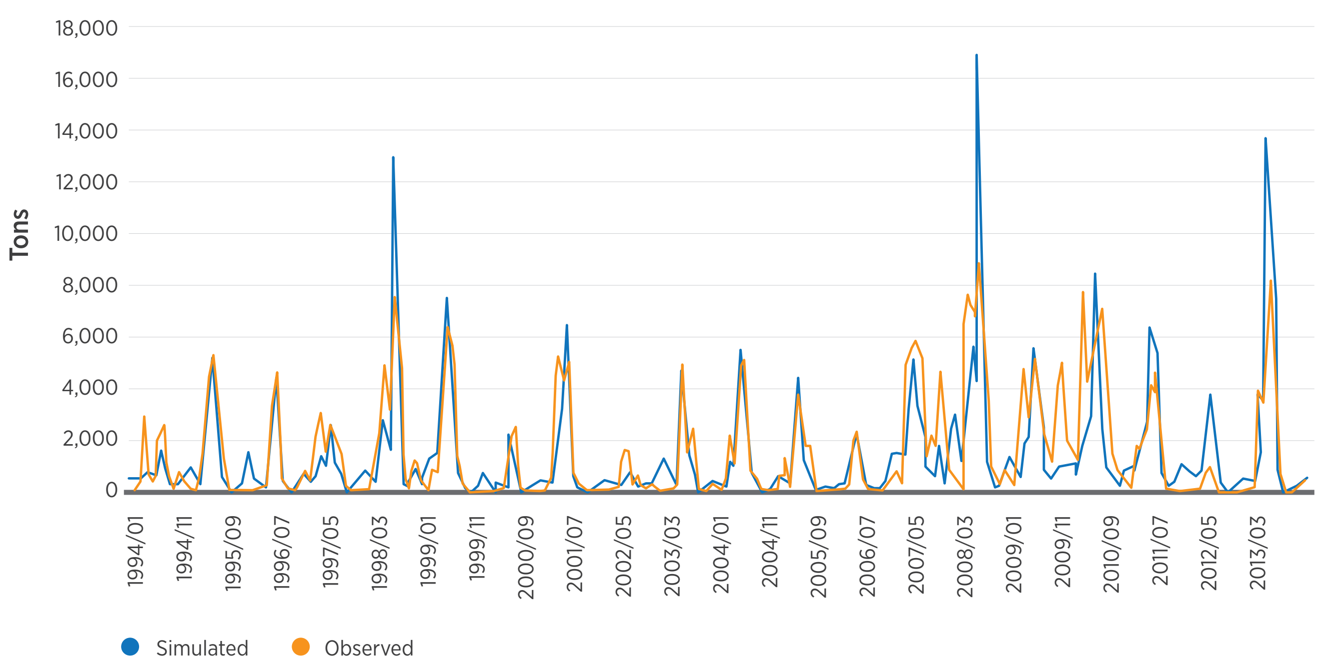
Defining land-management categories for HRU construction required that we cross-reference SWAT land-use classes with Crop Data Layer classes and manage agricultural classes modeled by the Policy Analysis System, the economic model. Land management in the BC1 2040 landscape was downscaled to USDA Common Land Unit parcels from county-level categories simulated by the Policy Analysis System as described in the biodiversity chapter (chapter 10). In the AWR, we retained land-use classes that comprised more than 5% of the sub-basin. However, HRUs planted in dedicated energy crops were included, regardless of area. We represented a total of 15,437 HRUs across the AWR region and 3,346 HRUs in the IRB.

5.3.2.1 Sensitivity Analysis, Calibration, and Validation

Validation is more feasible in smaller, rather than larger, river basins. To illustrate, the IRB model was calibrated and validated for stream flow, sediment, nitrate, organic nitrogen, and total phosphorus at the U.S. Geological Survey's (USGS's) gauging station #05453100, which is located on the Iowa River at Marengo, Iowa, by using 20 years (1994–2013) of meteorological and monitoring data from the USDA Conservation Effects Assessment Project. The model calibration period is 1994–2003, and the validation period is 2004–2013. The calibrated parameters include the Soil Conservation Service runoff curve number; Universal Soil Loss Equation support practice factor; tile-drainage parameters; soil evaporation-compensation factor; plant uptake-compensation factor; surface-runoff coefficient; and parameters for channel flows, calculating sediment, nitrogen, and groundwater parameters, among others. Nash-Sutcliffe efficiencies (NSE) are commonly used for hydrologic modeling to explain its performance (∞ to 1; 1 is perfect matching). NSE values were 0.89, 0.69, 0.62, 0.40, and 0.85 (calibration) and 0.85, 0.73, 0.41, 0.66, and 0.86 (validation) for flow, suspended sediment, nitrate, organic nitrogen, and phosphorus, respectively. Coefficients of determination, R^2, ranged from 0.52 to 0.90 for flow, suspended sediment, nitrate, organic nitrogen, and phosphorus. Figure 5.3 presents calibration results for nitrate for the IRB model. SWAT-model calibration/validation evaluation values for monthly water quantity and quality parameters for IRB were well above the acceptable ranges reported by other researchers (Engel et al. 2007; Moriasi et al. 2007).

In the AWR basin, we used historical data in sensitivity analysis, calibration, and validation at two scales as described by Baskaran et al. (2010). We conducted parameter-sensitivity analysis and calibration for two smaller basins, the Current River watershed (Hydrologic Unit Code [HUC] #11010008) and Southern Beaver watershed (HUC #11130207). These produced NSE values of 0.74 and 0.78 (calibration, 1985–1996) and 0.75 and 0.65 (validation, 1997–2003). For the larger AWR region, we compared predictions for outlet gauges at 86 of the 173 sub-basins with long-term data. A strong relationship was observed between area-weighted USGS- and SWAT-predicted flow (adjusted $R^2 = 0.83$; root-mean-square-error = 90.48 cubic meters per second, 16,589 degrees of freedom), with a slope near 1 (0.91). In addition, we conducted sensitivity analysis focused on tradeoffs between switchgrass yield, nitrate export, and nitrogen fertilizer across the region (Baskaran et al. 2013). Because pasture was managed as switchgrass in the earlier Billion-Ton Update scenario, assumptions about fertilization or cattle density were important. This analysis sought to understand geographic patterns in the relationship between pas-

Figure 5.3 | Results of SWAT nitrate calibration for the IRB



ture intensification and to avoid densities that might lead to “breakthrough” of nitrate.

5.3.2.2 Biomass Crop / Residue Management

BC1 2040 future landscapes included several feedstocks, such as miscanthus and willow, that were not simulated in earlier resource assessments. Below, we summarize our implementation of these energy crops in the landscape. We also describe shared elements of crop management between the two basins, with individual refinements described in sections for each of the two basins.

A spin-up period is typically simulated before reporting results. This allows simulations to equilibrate away from the influence of initial conditions, and should be at least as long as the shortest crop rotation (4–10 years spin-up). The range of fertilizer values simulated for each crop bracketed those specified in the *BT16* volume 1 assessment.

Perennial grasses: Perennial grasses include multiyear crop rotations with planting in the first year and harvesting every year after planting. We assumed that new cultivars would be planted after 10 years for switchgrass or 15 years for miscanthus. Switchgrass and miscanthus were planted with no tillage. Results represent average yields over harvest years in the rotation. Perennial grasses require several years to become fully established, and no fertilizer was applied during the first 2 years of establishment to suppress weeds. In subsequent years, we compared simulations with different amounts of nitrogen fertilizer in the AWR. Miscanthus management in the AWR was based on the approach used by Cibin et al. (2016). In the IRB, region-specific crop-management practices and crop-growth parameters for miscanthus and switchgrass were derived from the Purdue Water Quality Field Station in Indiana (Trybula et al. 2015). The annual amount of nitrogen fertilizer applied in the Indiana study was 56 kilograms per hectare (kg/ha).

SRWCs: For willow, we assigned a 22-year rotation (Volk et al. 2006; Abrahamson et al. 2010). The plant is coppiced after the first year. Coppicing was simulated as a harvest-only operation with harvest index of 96% (Abrahamson et al. 2010). We simulated application of nitrogen after coppicing and applied a specified amount after every subsequent 3-year harvest cycle. For poplar, we simulated an 8-year rotation with growth parameters calibrated to match leaf area index and plant biomass (Guo et al. 2015). We varied the amounts of nitrogen depending on the conservation practice in the third and sixth years, as described in Section 5.3.3, and applied 17 kg/ha phosphorus in the third year.

Energy sorghum: High-yield sorghum is an annual cellulosic feedstock (Venuto et al. 2008). We applied 67 kg/ha phosphorus each year and varied the amount of nitrogen applied. Our growth parameters for energy sorghum were derived from USDA values (White 2006).

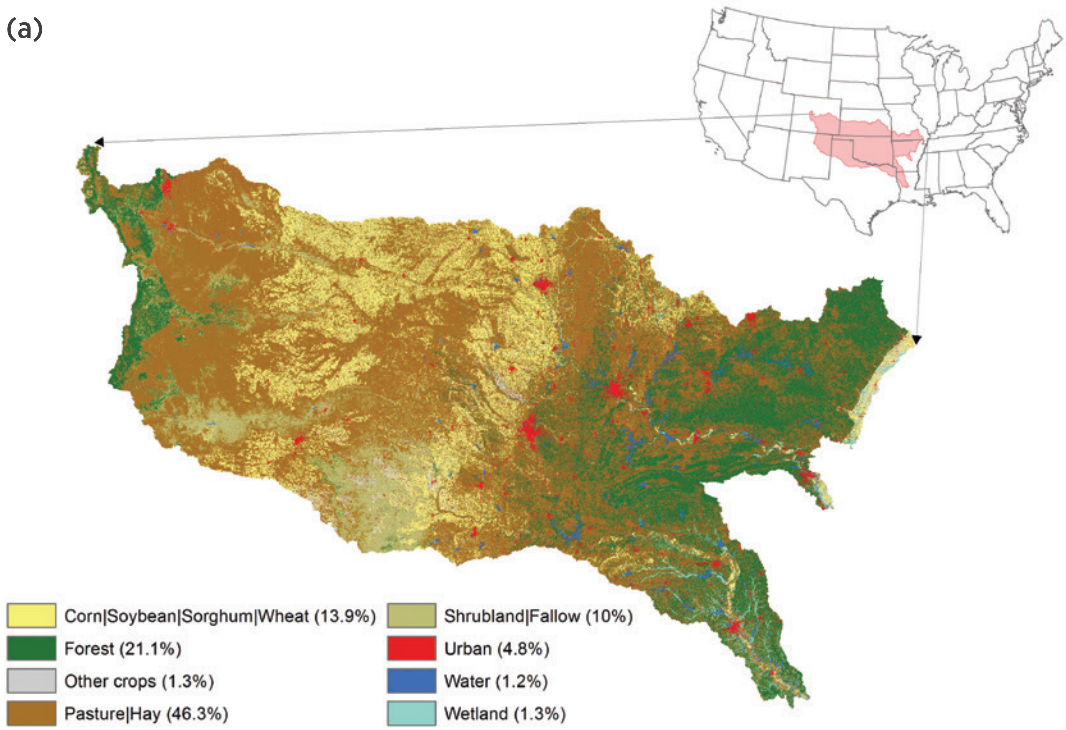
Crop residues: We represented stover removal from annual crops in both regions. However, the IRB has a feedstock profile dominated by harvest of residues from corn. In both regions, we simulated split fertilizer application. In the IRB, fertilizer applications of nitrogen and phosphorus for corn, corn stover, and soybeans are consistent with BC1 2040 scenario presented in *BT16* volume I (table 5.3). Nitrogen fertilizer for corn grain was 142 kg/ha followed by 51 kg/ha after stover removal to account for nitrogen removed in the stover. In the AWR, we varied the application in fall for annual crops, corn, and sorghum.

5.3.2.3 AWR River Basin

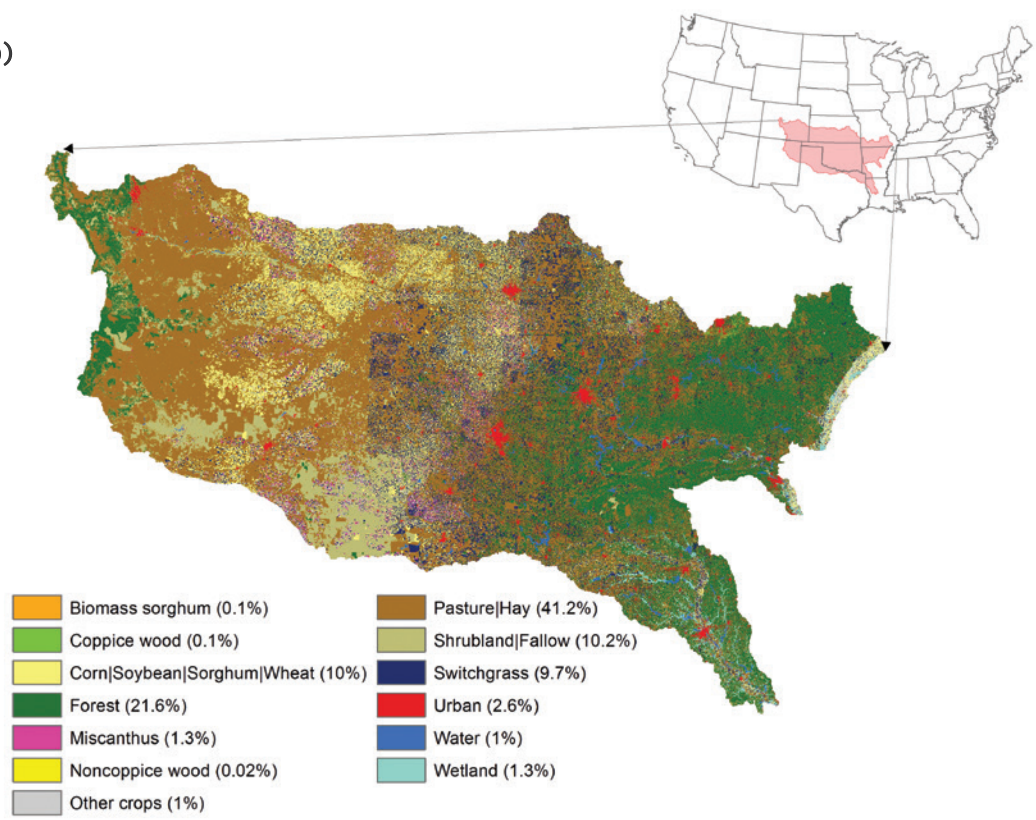
We implemented SWAT for 173 sub-basins (USGS eight-digit HUCs) within the AWR drainage (fig. 5.4) (Jager et al. 2015). Details regarding the delineation of watersheds and hydrography is described in Baskaran et al. (2010) for the AWR.

Figure 5.4 | The (a) 2014 landscape based on cropland data layer and (b) spatial distribution of energy crops consistent with the BC1 2040 economic scenario

(a)



(b)



5.3.2.4 IRB

The location of the IRB in the UMRB and its cropland features are shown in figure 5.5. A SWAT base model was first constructed for the 2013 landscape. The terrain in the modeling area is relatively flat; 39.0% of the basin is <2% slope and 32.5% of the basin is with 2% to 5% slope. The model represented 90 sub-basins and 3,346 HRUs. Four-year corn and soybean rotations were simulated from 2010 to 2013. Sequences of the 4-year rotations were classified into 10 different rotation types. Land balance was conducted for each year of the rotation, with 99.6% accuracy in land accounting. The rotation sequence was applied to all 20 years of simulation. The model includes simulation of tile drainage.

Projected crop locations in the BC1 2040 scenario at the spatial resolution of counties were downscaled and simulated by using the IRB SWAT model. In the scenario, the watershed remains predominantly agricultural, with 66.9% corn and soybean rotation, 3.1% miscanthus, 0.8% willow, 13.6% pasture, 9.0% urban areas, 5.0% forest, 1.3% wetlands, and 0.4% water (fig. 5.2). In addition, its acreages for perennial grasses and SRWCs increase. We omitted poplar harvest, which represents a minimal resource (less than 0.01%).

Three different tillage operations were applied to corn and soybean areas in the IRB—for corn, operations included 9.5% conventional tillage, 27.4% no-tillage, and 63.1% reduced tillage, and for soybeans, operations included 4.2% conventional tillage, 40.8% no-tillage, and 55% reduced tillage. A land use/land cover map was created for the current year (2013) and for the future BC1 2040 scenario (fig. 5.6).

Figure 5.5 | The Iowa River Basin (IRB), a region dominated by annual agricultural crops (corn and soybean) located in the Upper Mississippi River Basin. Point sources of nitrogen (N) include waste-water treatment (WWT) and industrial discharges.

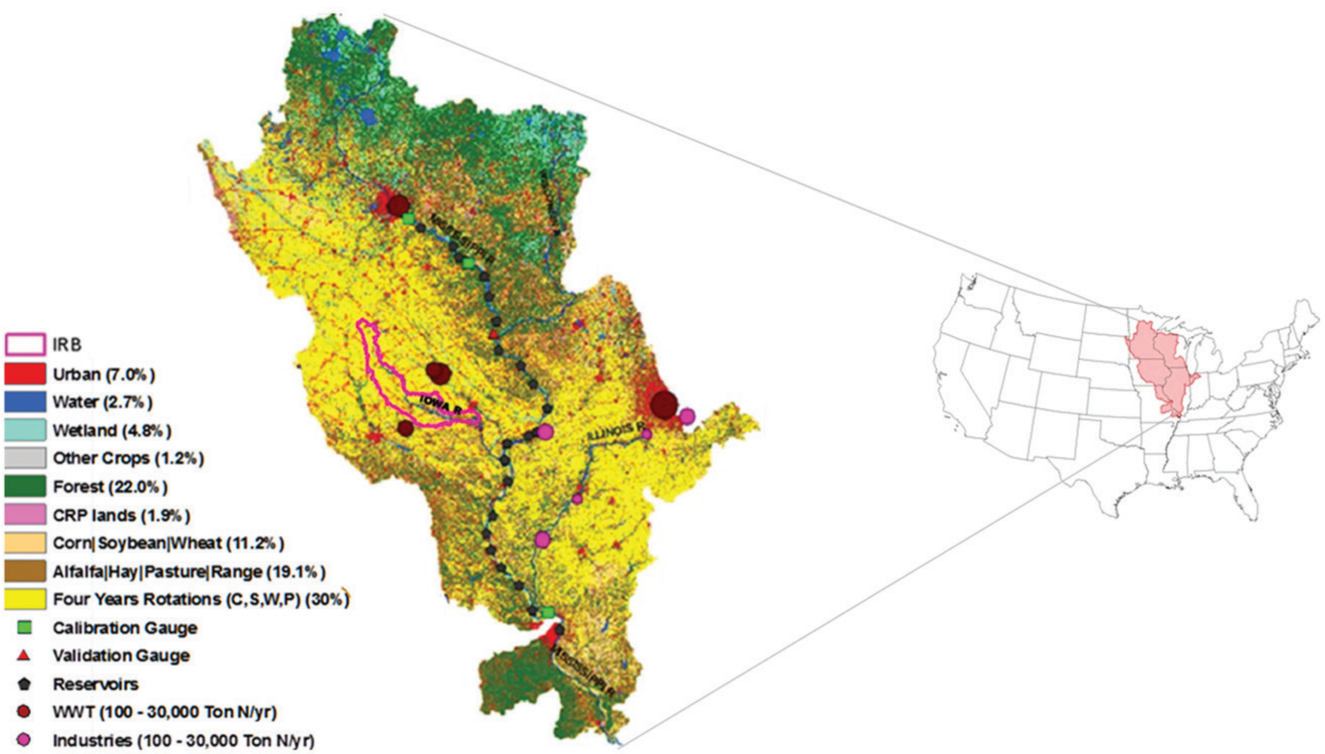
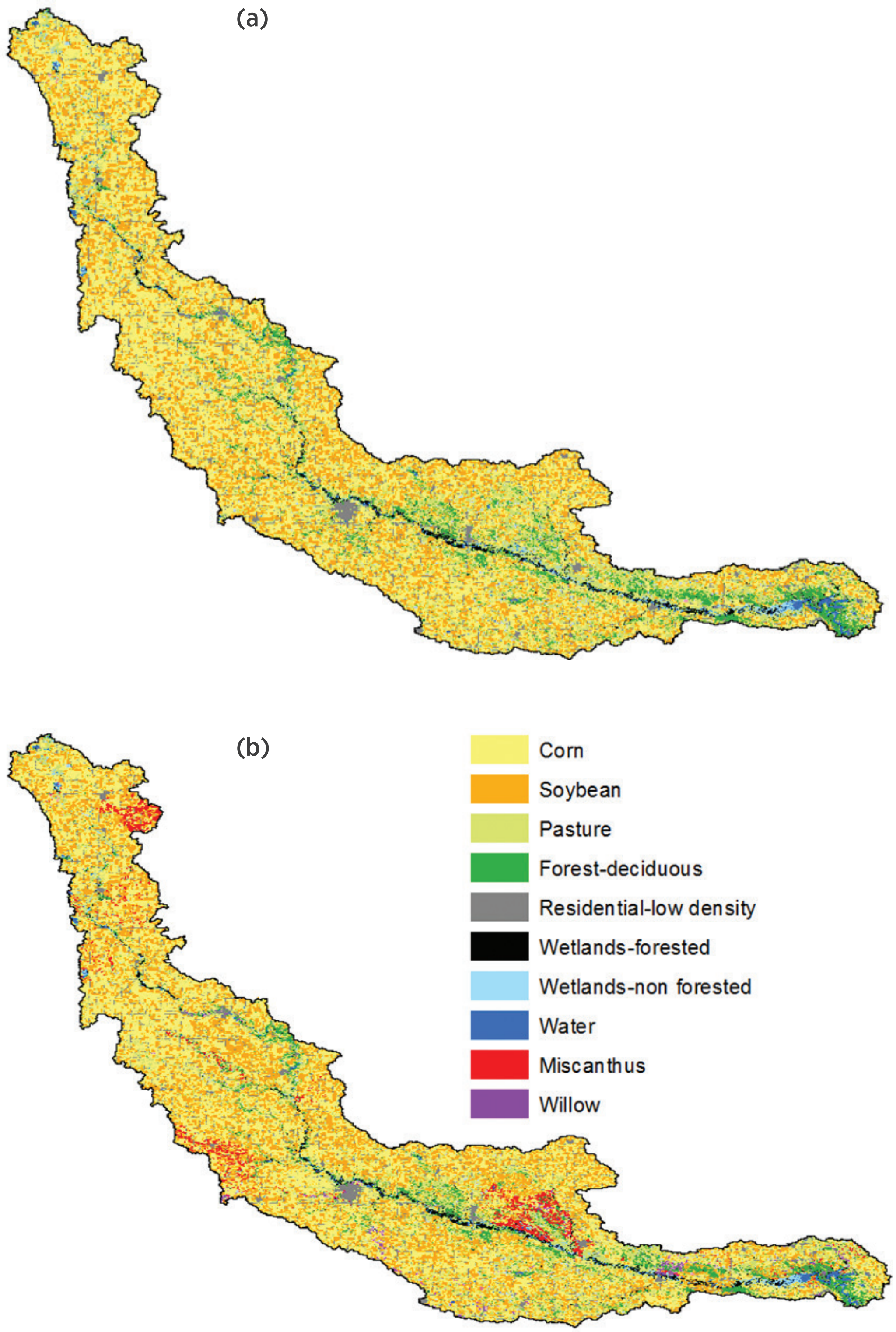


Figure 5.6 | Distribution of crops and other land use//land cover classes in the Iowa River Basin in (a) 2013 and (b) the future scenario BC1 2040



5.3.3 Conservation Practices

The primary objective of this research was to compare management practices and evaluate feedstock yields and water quality indicators. Below, we describe how this was done for the larger river basin and the smaller corn-soy-dominated watershed.

5.3.3.1 AWR Basin

After producing a SWAT setup for the BC1 2040 landscape using the ESRI© ArcGIS interface for SWAT, we used scripts to generate SWAT input files for simulations with different practices shown in table 5.2. We present results for all combinations of practices and what we refer to as "superlative" practices (i.e., those with the highest feedstock yield, those with the lowest nitrate loadings, those with the lowest total phosphorus (TP) loadings, and those the lowest total suspended sediment (TSS) loadings, respectively). Each set is optimized for a different indicator. In addition, we developed a visualization that allows stakeholders to set limits on water quality and yield indicator values. Stakeholders can evaluate the consequences of conservation practices capable of producing outcomes within specified limits, and the correlated responses of other indicators listed in table 5.1.

Filter strips: Filter strips were simulated by setting the ratio of the field area to the filter strip area to 40 to achieve 2.5% of the field area. It was assumed that 50% of the HRU drained to the most concentrated 10% of the filter strip. None of the concentrated flow was fully channelized such that it would bypass filtering effects of the filter strips (Kalcic, Frankenberger, and Chaubey 2015).

Fertilizer: Fertilization practices are described in section 5.3.3.2 for each feedstock. We varied these practices for each crop as described in table 5.2. In general, fertilizer was applied once in spring for perennial grasses. For residues, we varied only the second fertilizer application, which occurred in fall. Fertilizer amounts apply to the whole crop and not just residues.

Tile drainage: For annual crops, we simulated two alternative implementations of tile drainage controls to evaluate the potential for improving water quality outcomes. In one set of simulations, tile drains were simulated only for HRUs with low slopes <1% in all HRUs; in another, tile drains were simulated only for HRUs with slopes <2% (table 5.3). We assumed that perennial root systems can be used without tile drainage and that such drainage would be plugged.

Table 5.2 | Simulated Levels of Each Conservation Practice Applied in the AWR River Basin

Biomass feedstock	Filter strip	N fertilizer (kg/ha)	Tillage practice	Tile drainage
Switchgrass	None	0, 20, 60, 100	No-till	None
Poplar	With and without	0, 20, 60, 100	No-till	None
Miscanthus	Without	0, 20, 70, 120	No-till	None
Willow	With and without	0, 30, 70, 110	No-till	None
High-yield sorghum	None	101, 135, 168, 202, 235	No-till Conventional	Lands (HRUs) with <1% slope Lands (HRUs) with <2% slope
Sorghum stubble	None	105, 120, 135	No-till Conventional	Lands (HRUs) with <1% slope Lands (HRUs) with <2% slope
Corn stover	None	60, 85, 110	No-till Conventional	Lands (HRUs) with <1% slope Lands (HRUs) with <2% slope

5.3.3.2 IRB

Four different conservation practices were simulated and compared to the BC1 2040 scenario (table 5.3). They include cover crop, a riparian buffer of 30 m and 50 m, controlled-release nitrogen fertilizer, and controlled tile drainage. Neither buffers nor cover crops were harvested.

Riparian buffers: Riparian buffer installation is not mandatory in this region and is therefore rare. In simulations with a riparian buffer, the buffer was installed in sub-basins along the main stem of the Iowa River, in accordance with National Resources Conservation Service's guidelines for Iowa. The riparian buffer was planted in switchgrass. We compared two buffer widths: a 30-m (RB30) and 50-m (RB50) riparian buffer (table 5.3).

Cover crops: Rye is a common choice of cover crop in this region. For this scenario (CC in table 5.3), we assumed that the cover crop was killed in the spring but that residue remained on the soil.

Fertilizer: Corn grain, stover, and miscanthus receive nitrogen fertilizer. Nitrogen fertilizer is applied to corn at 142 kg/ha. When stover is harvested, a supplemental nitrogen fertilizer of 51 kg/ha is applied to compensate nitrogen loss due to removal of stover from the field. Miscanthus requires minimal nitrogen of 56kg/ha. Willow does not receive nitrogen fertilizer. Fertilizer is applied after harvest in fall and in the spring. In a controlled-release nitrogen fertilizer scenario (CR in table 5.3), the nitrogen fertilizer is applied after harvesting residue in fall and at spring planting. Simulated nitrogen release occurred within two months.

Tile drainage: Much cropland in the Midwest is tile drained, and this drainage aggravates downstream water quality problems by creating a bypass around potential nutrient uptake and conversion pathways within soils. Therefore, closing tiles when they are not needed could be an important practice. Three tile drainage options were simulated: no tile control (all tile drains are open [Open]), no tile (all tile drains

Table 5.3 | Simulated Conservation Practice Scenarios in the IRB. Conservation Practices Added to the BC1 2040 Scenario (BC40) Included a 30-m Riparian Buffer (RB30), a 50-m Riparian Buffer (RB50), a Cover Crop (CC), Controlled-Release of N Fertilizer (N CR), Closing of All Tile Drains (Tile), and Tile Drains Open for Land with <2% Slopes (Tile2%).

IRB conservation practice	Riparian buffer	Cover crop	N fertilizer	Tile drainage
BC40	No	No	Corn: 142 kg/ha Stover: 51 kg/ha Miscanthus: 56 kg/ha	Open
RB30	30 m, switchgrass	No	Same as above	Open
RB50	50 m, switchgrass	No	Same as above	Open
CC	No	Rye	Same as above	Open
N CR	No	No	Controlled release for corn: spring and fall, 2 months	Open
Tile	No	No	Corn: 142.3 kg/ha Stover: 51.1 kg/ha Miscanthus: 56 kg/ha	All plugged
Tile2%	No	No	Same as above	≥ 2% slope plugged

plugged [Tile]), and partial mitigation control (tile closed in areas where land slope is greater than 2% [Tile2%]) (table 5.3).

Historical climate data (1994–2013) were used to predict the long-term hydrology and the impact of the BC1 2040 scenario and conservation practices (case studies) on water quality. Modeled results are presented for water yield, TSS, nitrate, total nitrogen, organic phosphorus, and mineral phosphorus, and are compared among scenarios with different conservation practices.

5.4 Results

The two river basins differ in feedstock profiles. Below, we present and discuss the responses of feedstock yield and water quality indicators to conservation-management practices deemed most relevant to improve water quality in each river basin. In the AWR and IRB, we present results for three classes of feedstock: (1) perennial grasses, (2) SRWCs, and (3) crop residues, each with relevant conservation practices. Simulated conservation practices include (1) riparian buffers, (2) planting a cover crop, (3) tile-drainage control, and (4) use of slow-release nitrogen fertilizer.

5.4.1 Arkansas-White-Red River Basin

We represented the effects of conservation practices for each of three classes of feedstock in the AWR. All combinations of practices in table 5.2 were simulated, and our primary dataset includes the following information: 1) crop, 2) the HRU ID, 3) the value of each of the practices in table 5.2 (depending on crop), and 4) each of the simulated indicator values.

For each crop-HRU, we identified which combination of practices produced the best results in terms of each indicator (i.e., minimum nutrient and TSS or maximum biomass yield). We refer to these as 'superlative practices'. Thus, for a given crop, there is one practice with maximum yield for each HRU (i.e., slope-soil combination managed for the crop of interest within a subbasin). For each indicator, the total number of superlative practices associated with a given crop would be the number of HRUs in the crop. The set of superlative practices excludes combinations of practices that did not do best with respect to any indicator.

For each crop, we present two types of plots summarizing superlative practices. First, we produced a frequency histogram of HRU counts by practice combination. If we evaluated more than one practice, facet plots are used to display frequencies across multiple dimensions (practices). Second, the distribution of values for each of the four indicators is presented for the superlative subset of simulated data.

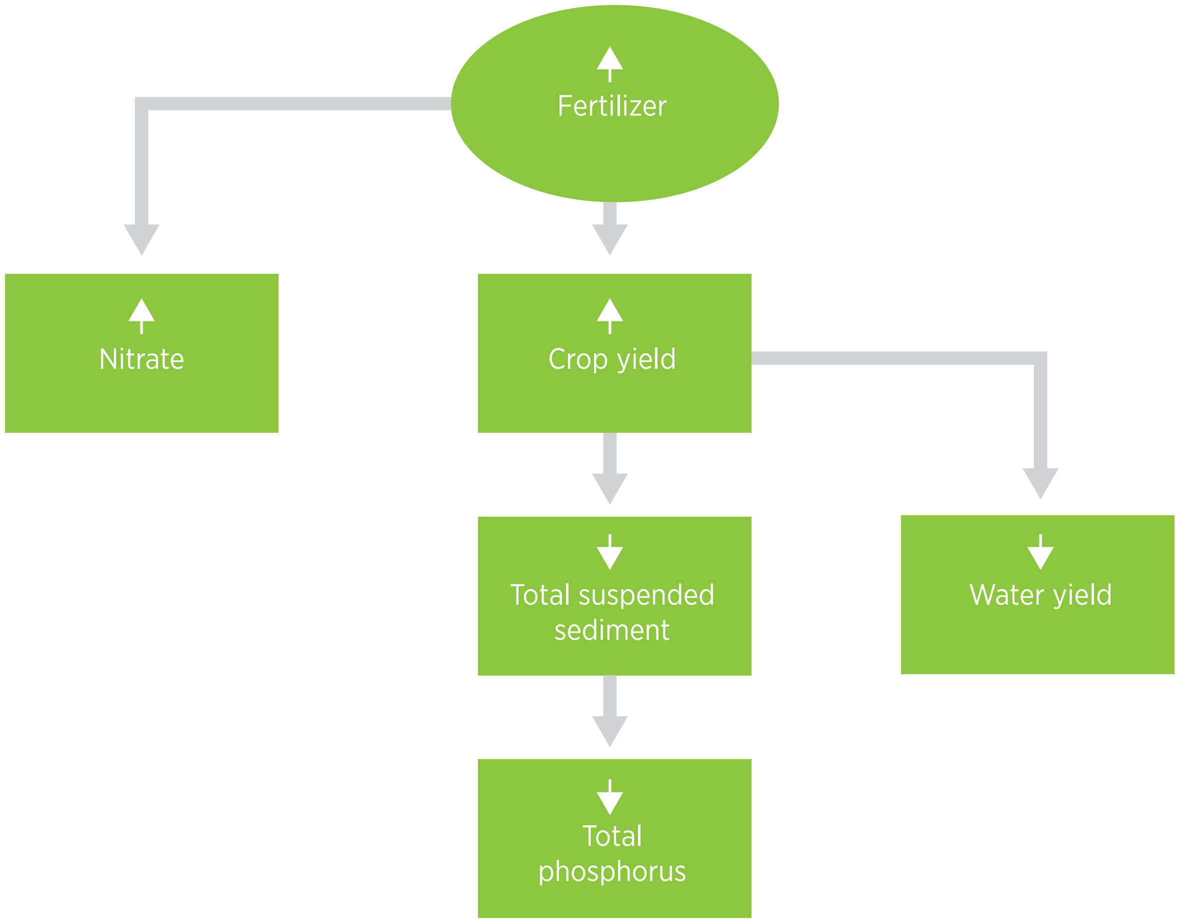
Generally, the associations observed for perennial grasses and SRWCs were described by the path diagram in figure 5.7. However, we did not observe this pattern for crop residues.

5.4.1.1 Perennial Grasses

SWAT-modeled responses of water quality and yield to switchgrass fertilizer were correlated in expected ways (fig. 5.8). For switchgrass, we observed a positive relationship between TSS and TP because TP is primarily bound to sediment. We observed negative relationships between TSS and switchgrass yield, and higher fertilizer amounts resulted in higher switchgrass yields and lower TSS.

For the grasses, the practices resulting in the highest yields were those with the highest levels of nitrogen fertilizer (fig. 5.8). For example, the light green bar shows that all HRUs with a maximum yield were managed by applying the highest fertilizer level. This was generally true for miscanthus as well. For both switchgrass and miscanthus, the practice resulting in the lowest nitrate level was the one with the lowest level of fertilizer. Patterns for TSS and TP were weaker, but both tended to be lower where yields were high (i.e., in the high-fertilizer scenario) (fig. 5.8).

Figure 5.7 | Path diagram describing the expected effects of nitrogen fertilizer on biomass yield and indicators of water quality and quantity



In general, miscanthus yields (fig. 5.9b) were significantly higher than for switchgrass (fig. 5.9a). Scenarios with minimum nitrate (no fertilizer) had very low yields. Yields in scenarios with minimum TP and TSS were not impacted as much as those in minimum nitrate scenarios (fig. 5.9). Practices that minimized nitrate (no fertilizer) produced much higher TP and TSS (fig. 5.9). This is consistent with the idea that more vegetative growth prevents runoff of sediment and sediment-bound nutrients. Counter to our initial intuition, this suggests that adding sufficient nitrogen fertilizer to grasses can help to lower export of sediment and sediment-bound TP by increasing vegetative cover. Nitrate loadings were considerably higher in scenarios with maximum yield. Fertilizer amounts that minimized TP and TSS were intermediate both in yield and nitrate (fig. 5.9).

For SRWCs, we compared scenarios with and without filter strips, in addition to the four levels of fertilizer. Figure 5.10 shows these results. HRUs with minimum nutrient and sediment loadings appeared with higher frequency when filter strips were simulated than when they were not. The majority of HRUs with maximum yield and minimum TSS were produced in simulations with high fertilizer amounts. Nearly all HRUs with minimum nitrate loadings occurred in simulations with no fertilizer and a filter strip. Because no practices without filter strips appeared among superlative practices for willow, we did not include this plot in figure 5.10. Note that SWAT-simulated yield may be lower with a filter strip if the filter strip is not harvested, as it is not here.

Figure 5.8 | Distribution of superlative practices (fertilizer amount) with respect to each indicator for (a) switchgrass and (b) miscanthus. The maximum possible frequency for a given fertilizer level is the number of HRUs with the crop.

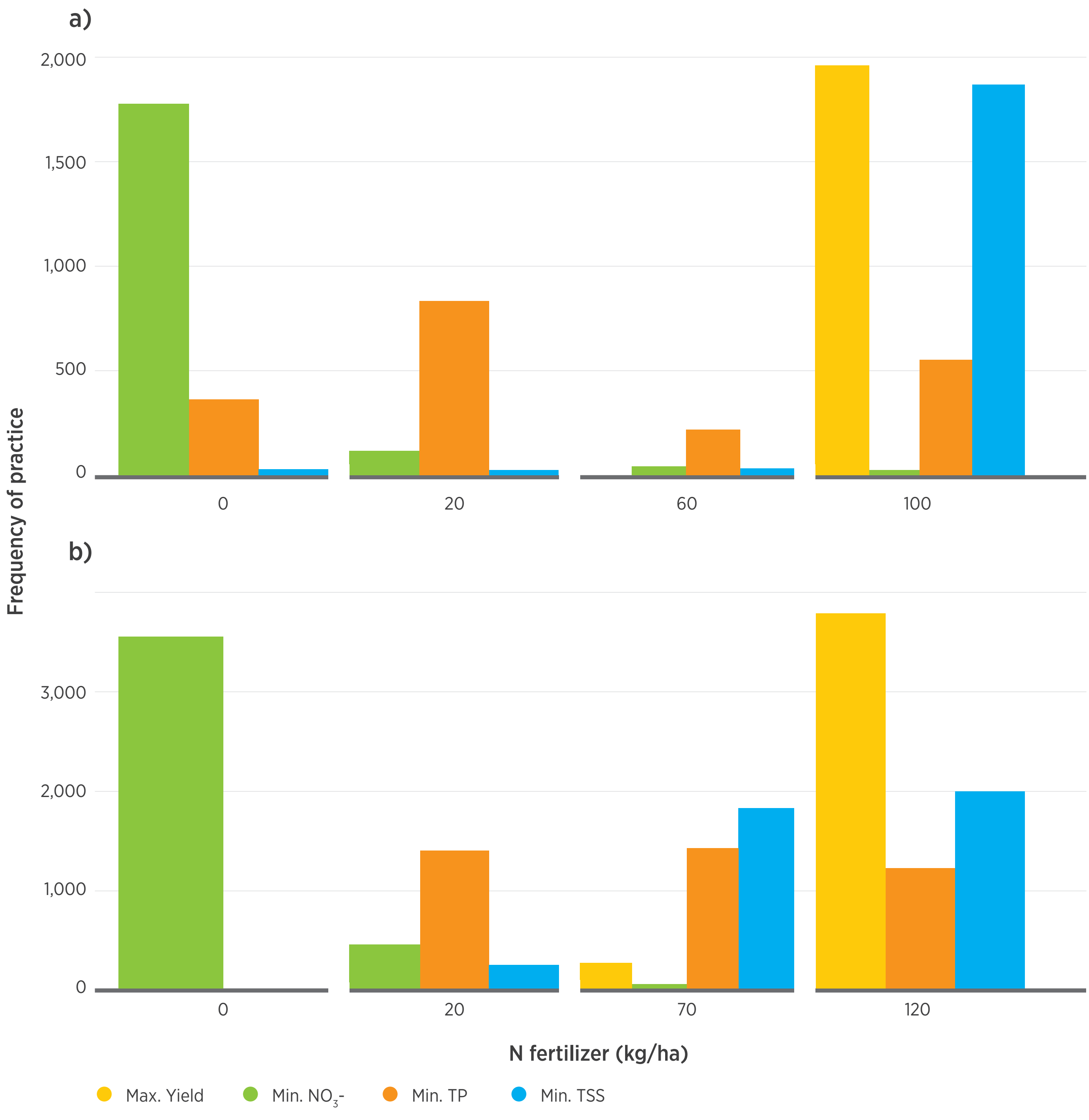


Figure 5.9 | Indicator values for the combination of practices (i.e., superlative practices) best able to meet the objective described by the x-axis for (a) switchgrass and (b) miscanthus. Indicators (y-axes) include feedstock yield, nitrate (NO_3^-), total phosphorus (TP), and total suspended sediment (TSS). Units for indicators are given in table 5.1.

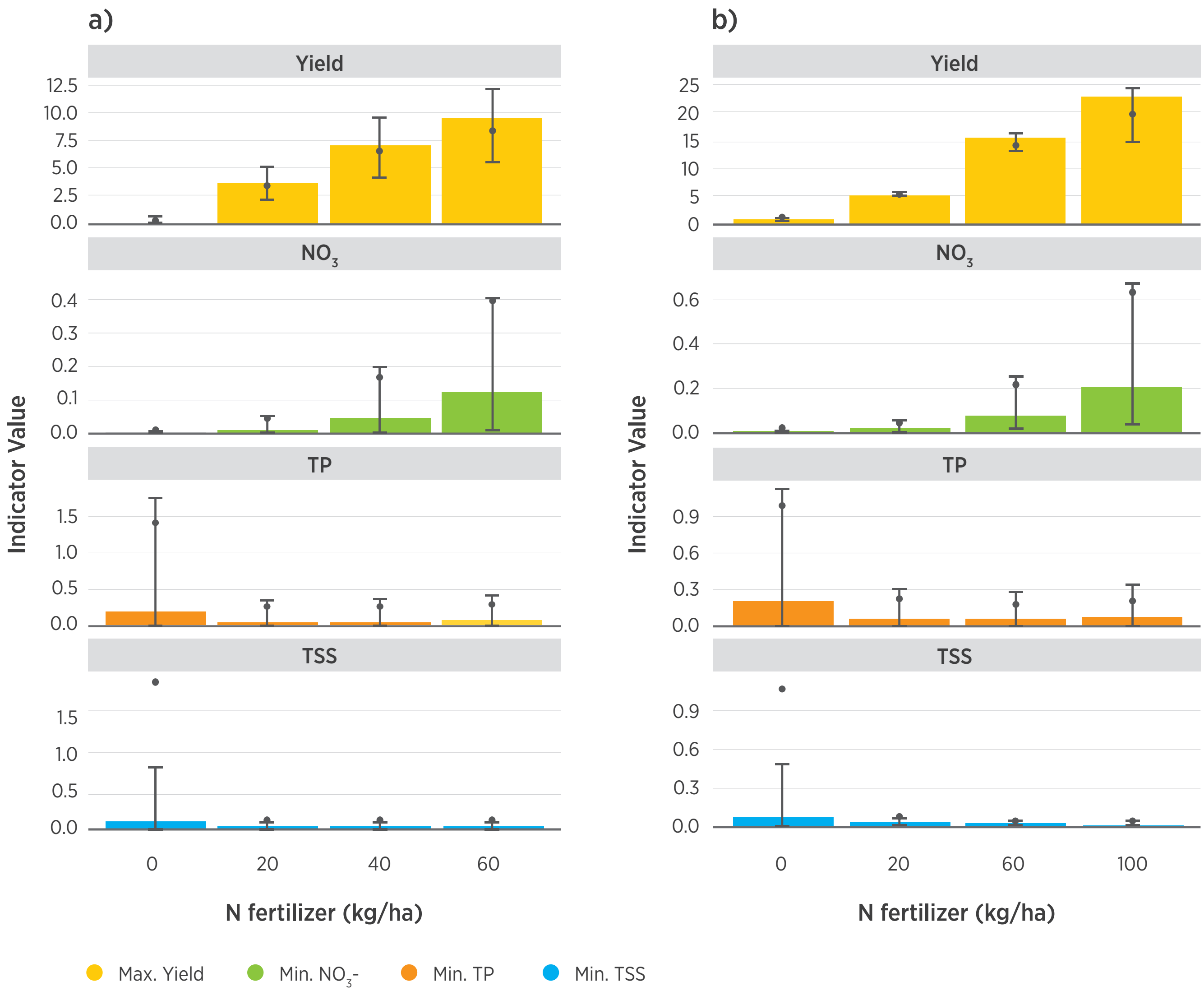
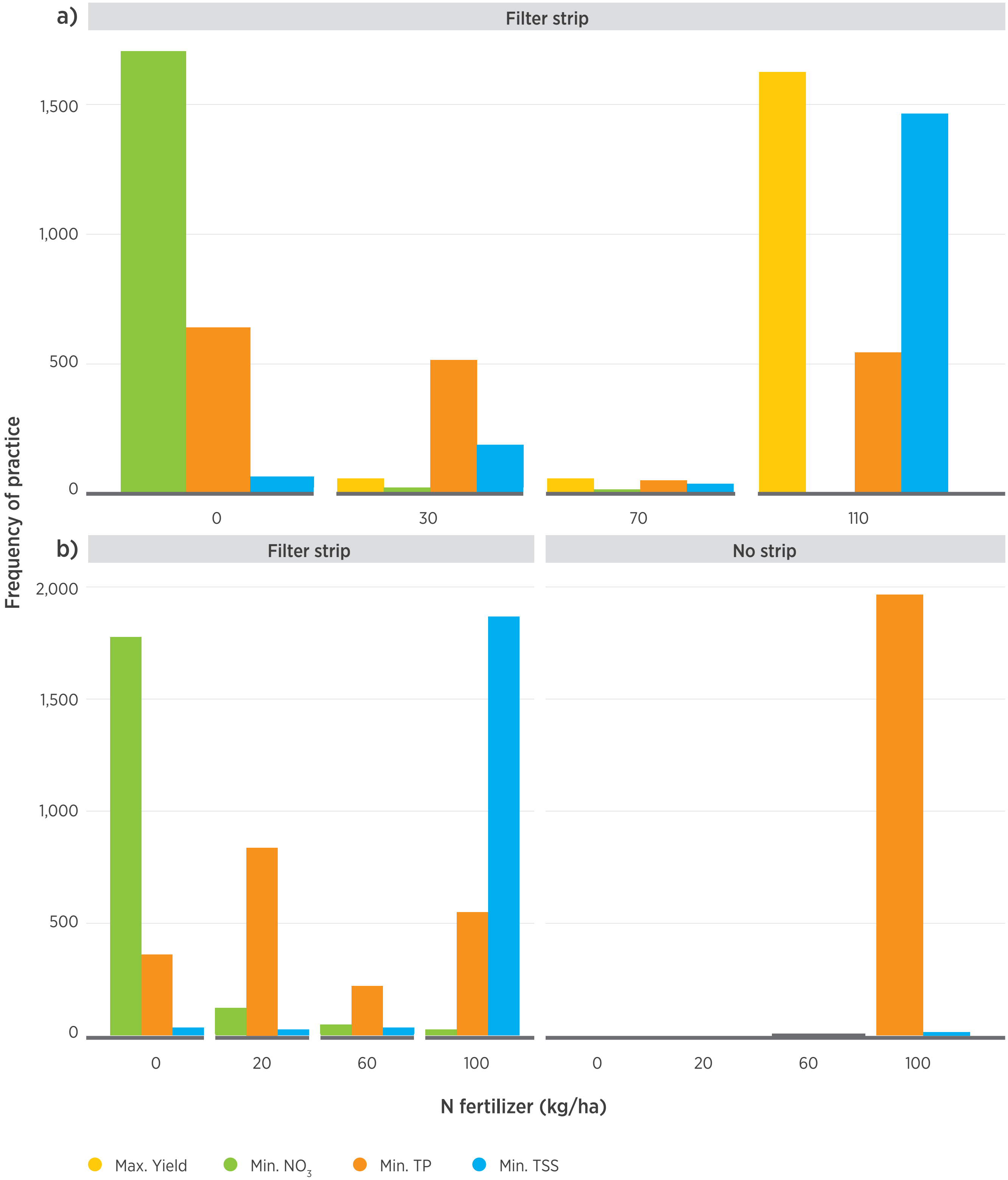
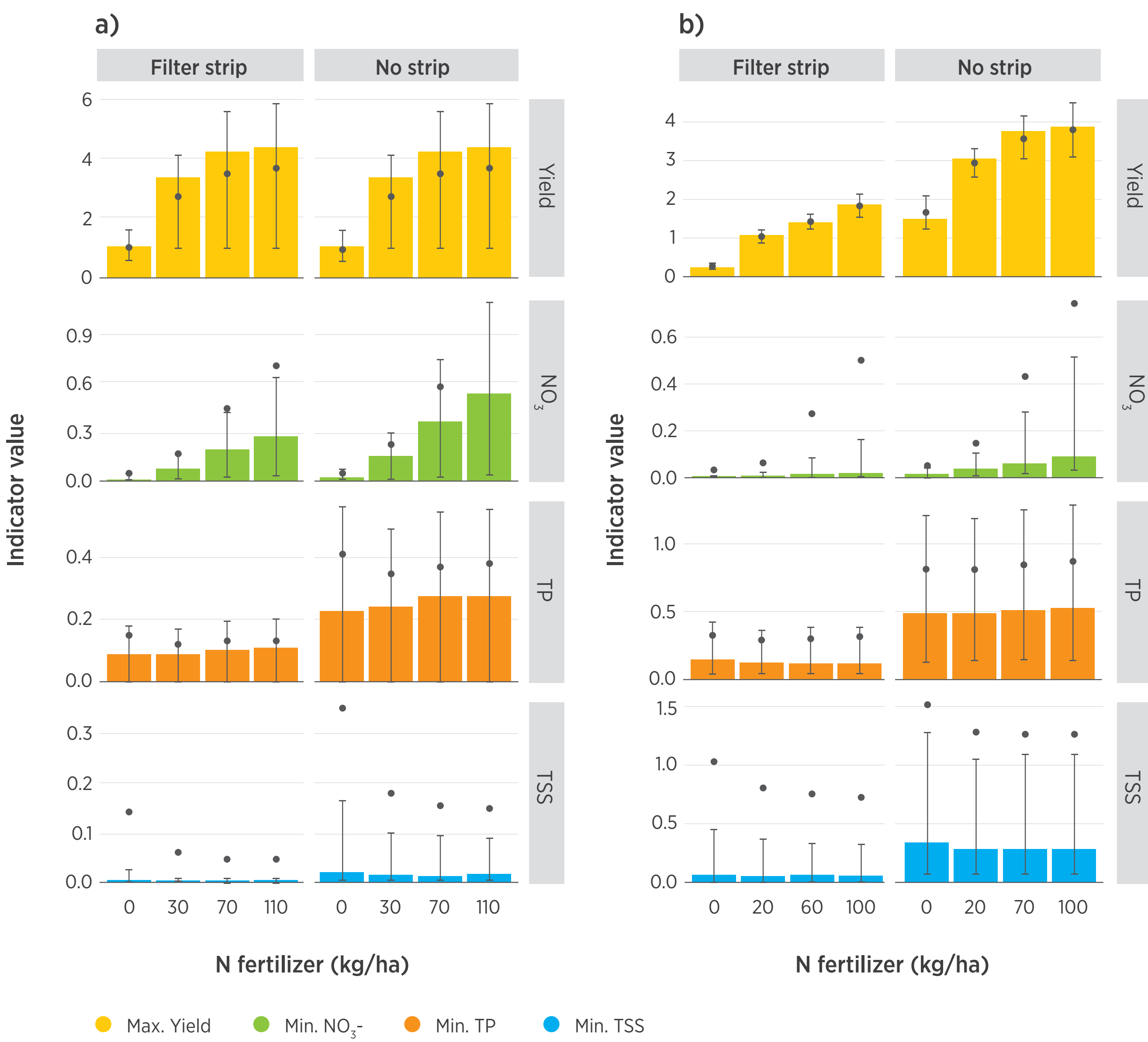


Figure 5.10 | Representation of superlative practices (filter strip versus none, fertilizer amount) with respect to each indicator for (a) willow and (b) poplar. The maximum possible frequency for a given combination of practices is the number of HRUs with the crop.



Simulated filter strips were very effective at reducing nutrients and sediment for both willow (fig. 5.11a) and poplar (fig. 5.11b). However, there was a larger cost in terms of reduced yield for poplar. Likely, this is because we simulated willow as a coppice SRWC, and therefore did not harvest the whole tree, producing better water quality outcomes. However, simulated TP and TSS loadings were higher for willow than for poplar for each combination of practices (fig. 5.11).

Figure 5.11 | Indicator values for the best combination of practices per the objective described by the x-axis (i.e., "superlative practices") for (a) willow and (b) poplar. Indicators (y-axes) include feedstock yield, nitrate (NO_3^-), total phosphorus (TP), and total suspended sediment (TSS). Units for indicators are given in table 5.1.



5.4.1.2 Annual Energy Crops and Residues

Below, we present results comparing practices for annual crops and residues, including high-yield sorghum, corn stover, and sorghum stubble. As for perennial crops, we analyzed superlative practices (i.e., practices that are best with respect to each indicator).

High-yield energy sorghum: High-yield energy sorghum was the only dedicated annual crop that occurred in the AWR in BC1 2040. Frequencies for superlative practices with respect to each indicator are displayed in figure 5.12. Most maximum yields occurred in no-till scenarios and at the highest level of fertilizer simulated. No-till practice is well represented among minimum TP and TSS scenarios as well. However, nitrate followed a different pattern, with the lowest values under conventional tillage and low nitrogen fertilizer. Average nutrient and sediment values follow similar patterns, with no-till scenarios having lower average TP (fig. 5.13).

Corn stover: We simulated corn with tile drains implemented for slopes <1% and slopes <2%, each with conventional tillage and no-till and with three different levels of fall-applied nitrogen fertilizer. Results are shown in figure 5.14. Simulations with tile drains on lands with <2% slope were rarely among the superlative scenarios. Among scenarios with tile drains on lands <1% slope, simulations with the highest fertilizer consistently produced the highest yields. Conventional tillage produced maximum yields and minimum nitrate for more HRUs than did no-till. Minimum TSS values occurred most frequently for HRUs managed with no-till and less fertilizer. Minimum TP also occurred more frequently at low levels of fertilizer, but more often in simulations with conventional till (fig. 5.14 and 5.15).

Grain sorghum stubble: We simulated grain sorghum with tile drains implemented for slopes <1% and slopes <2%, each with conventional tillage and no-till and with three different levels of fall-applied nitrogen fertilizer. We observed better outcomes with tile drainage on lands with <1% slope (fig. 5.16 and 5.17). Frequencies (HRUs) for superlative practices with respect to each indicator are displayed in figure 5.16. We consistently observed the highest yields in HRUs with high fertilizer and no-till management. TSS was minimized most frequently for HRUs managed with no-till. Minimum TP included HRUs managed with either no till and high fertilizer or conventional till with low fertilizer.

5.4.1.3 AWR Summary of TradeOffs and Complementarities

The AWR analysis was designed to quantify tradeoffs among indicators, especially between feedstock yield and water quality indicators. First, we calculated the percentage improvement between the best and worst conservation practices for each crop. In general, conservation practices (reduced fertilizer) produced large decreases in sediment and nutrients for perennial grasses and for the two SRWCs (fig. 5.18). The smallest improvements were realized for TSS and TP loadings by sorghum stubble. Note that these differences may simply reflect the range of practices simulated, rather than potential for growing each of these crops with more environmentally favorable outcomes.

Tradeoffs and complementarities differed among the four perennial crops (fig. 5.19 a–d). For poplar (fig. 5.19c), practices showed strong tradeoffs that maximized yield (yellow bar) and produced the highest nutrient and sediment loadings. Conversely, practices with the lowest nitrate produced the lowest yield as well. One commonality across perennials (fig. 5.19 a–d) is that the practice that minimized TSS (blue in fig. 5.19c) performed reasonably well in maximizing yields and minimizing nitrate and TP, suggesting a complementarity between TSS and other indicators. Tradeoffs were strongest between nitrate and yield, with very low yields in simulations with practices that resulted in low nitrate, probably due to low fertilizer levels (fig. 5.19 a–d).

Figure 5.12 | Superlative practices for high-yield energy sorghum managed under all combinations of three practices: (1) conventional tillage and no-till; (2) tile drainage for two slope classes; and (3) five levels of fertilizer application. The maximum possible frequency for a given combination of practices is the number of HRUs with the crop

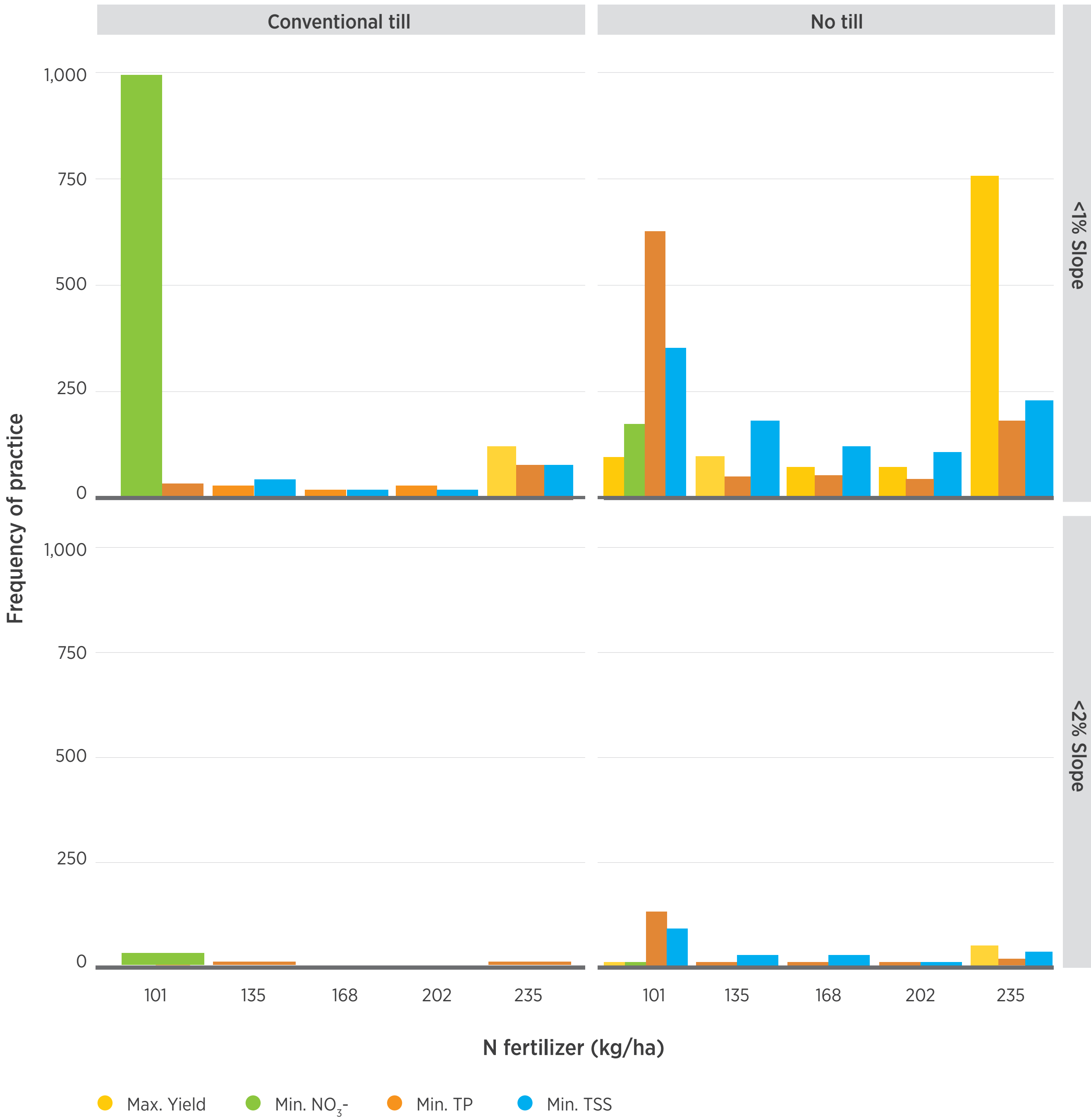


Figure 5.13 | Distributions of indicator values for high-yield sorghum scenarios. Whiskers indicate minimum and maximum values and the box encloses the 25th and 75th percentile with a horizontal line at the median. Indicators (y-axes) include log_{10}-transformed nitrate (NO_3^-), total phosphorus (TP), total suspended sediment (TSS), and feed-stock (grain) yield. Units for indicators are given in table 5.1.

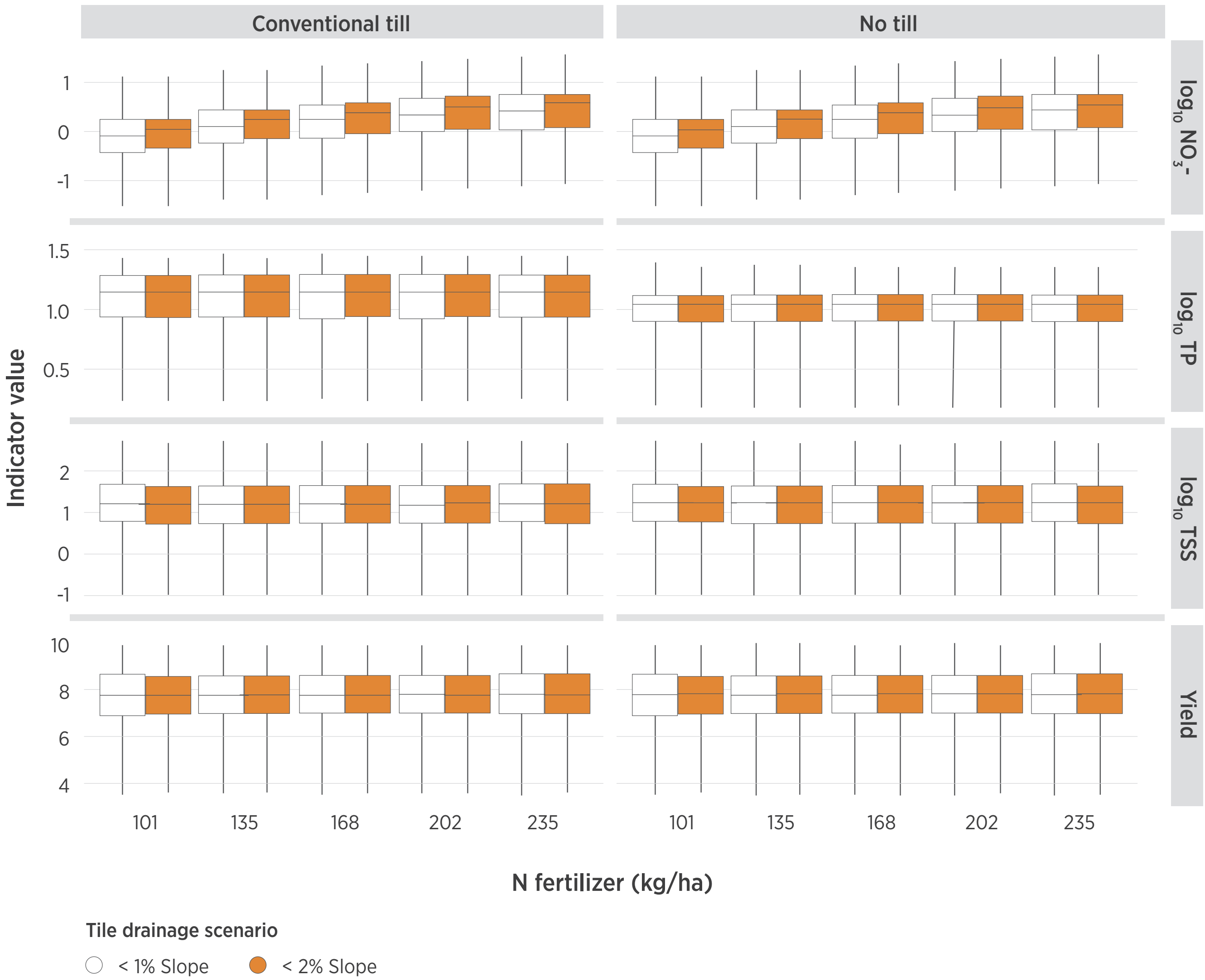


Figure 5.14 | Superlative scenarios for corn stover managed under all combinations of three practices: (1) conventional tillage and no-till; (2) tile drainage for two slope classes; and (3) three levels of fertilizer application. The maximum possible frequency for a given combination of practices is the number of HRUs with the crop.

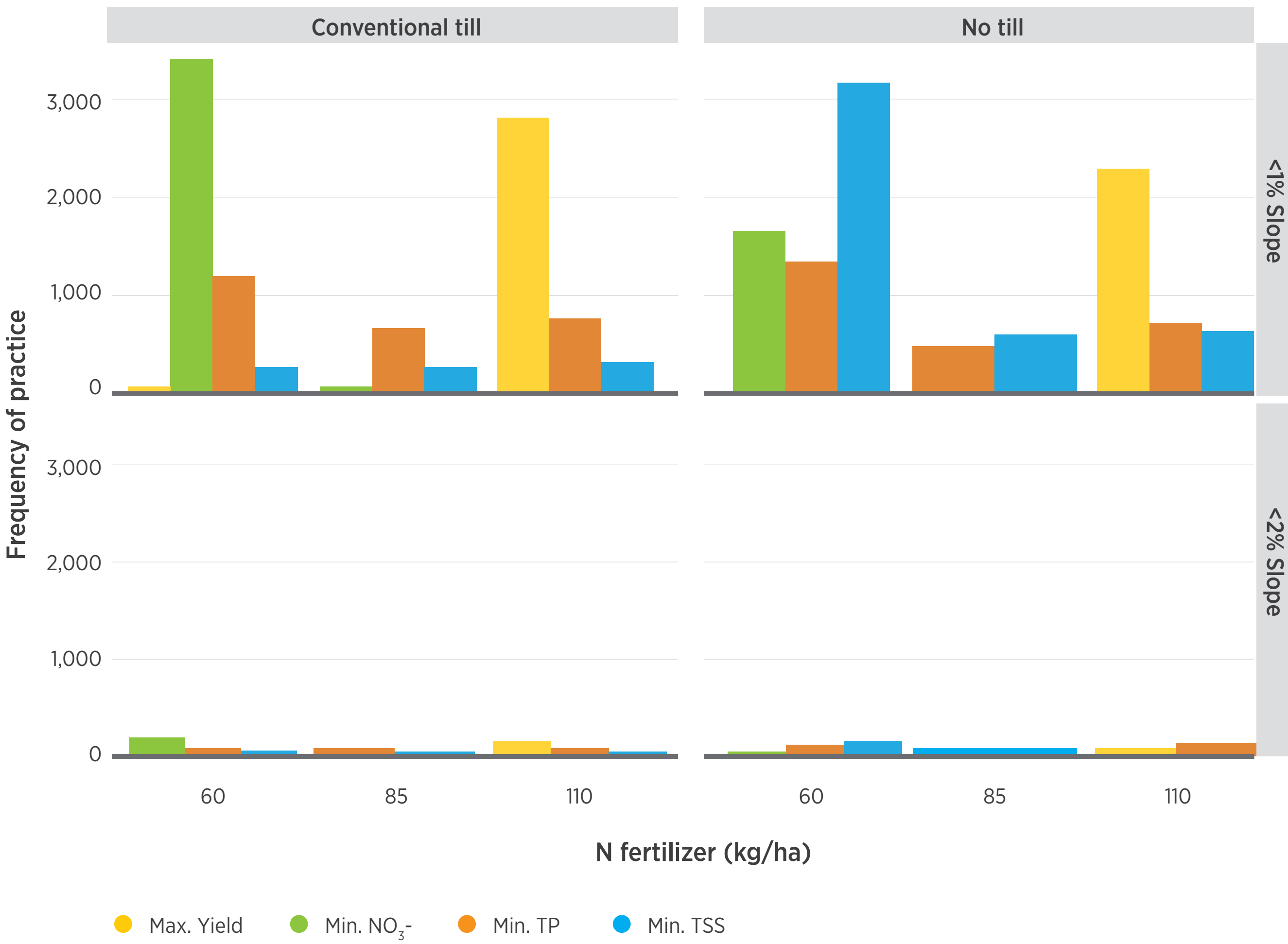


Figure 5.15 | Distributions of indicator values for corn-stover scenarios. Whiskers indicate minimum and maximum values and the box encloses the 25th and 75th percentile with a horizontal line at the median. Indicators (y-axes) include log_{10}-transformed nitrate (NO_3^-), total phosphorus (TP), total suspended sediment (TSS), and feedstock (residue) yield. Units for indicators are given in table 5.1.

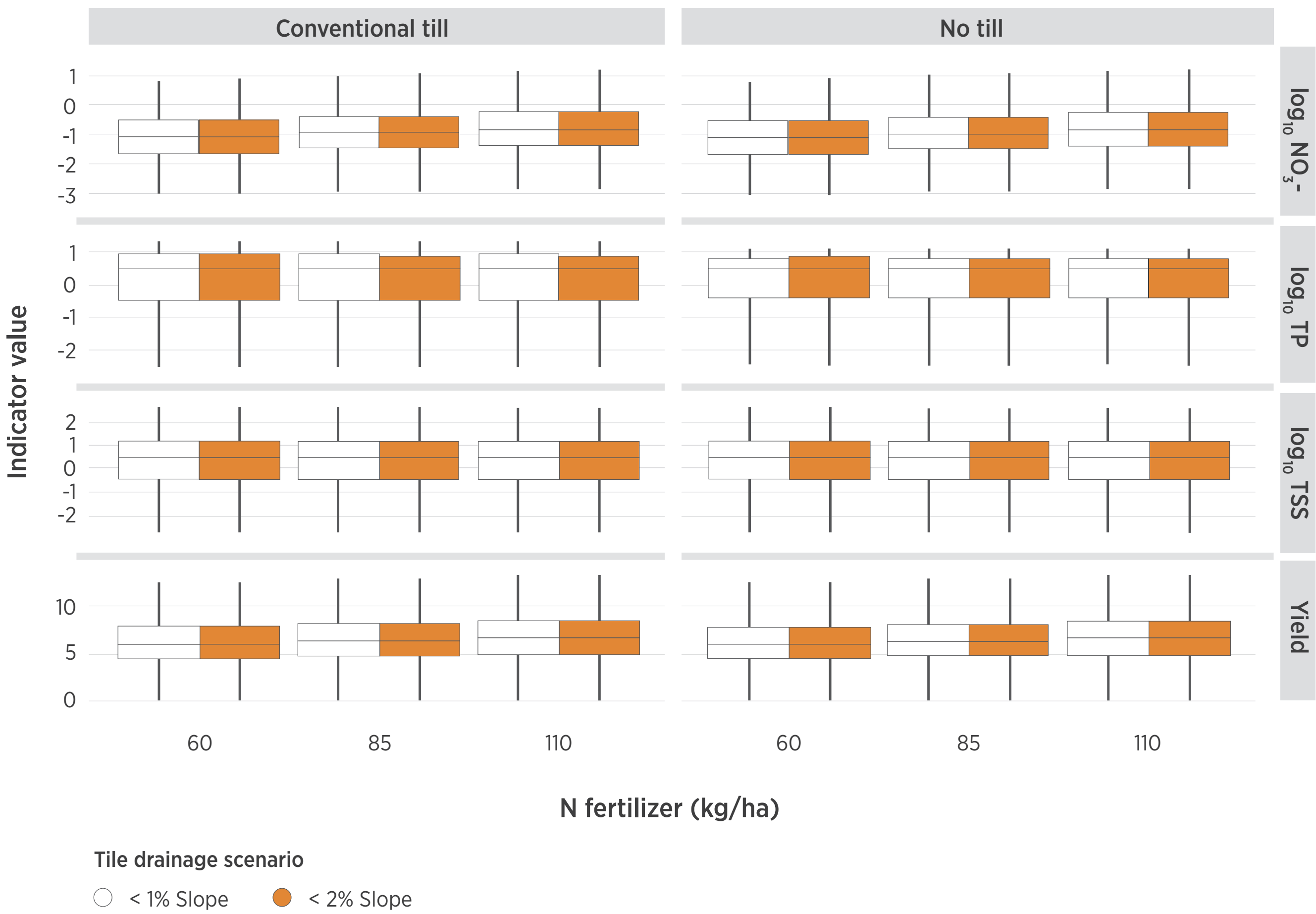


Figure 5.16 | Superlative scenarios for grain sorghum stubble managed under all combinations of three practices: (1) conventional tillage and no-till; (2) tile drainage for two slope classes, and (3) three levels of fertilizer application. The maximum possible frequency for a given combination of practices is the number of HRUs with the crop.

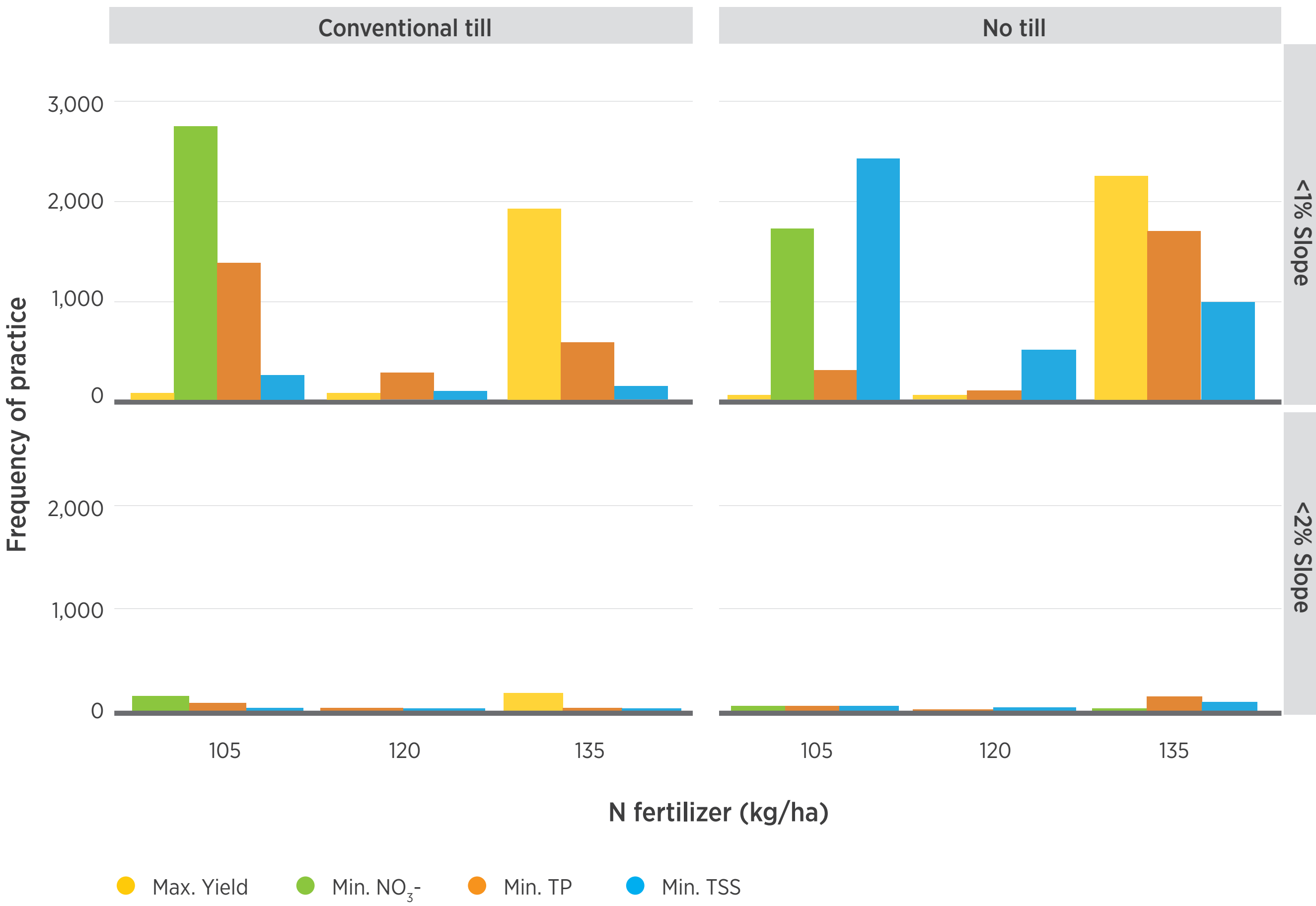


Figure 5.17 | Distributions of indicator values for grain sorghum scenarios. Whiskers indicate minimum and maximum values and the box encloses the 25th and 75th percentile with a horizontal line at the median. Indicators (y-axes) include log_{10}-transformed nitrate (NO_3^-), total phosphorus (TP), total suspended sediment (TSS), and feedstock (grain) yield. Units for indicators are given in table 5.1.

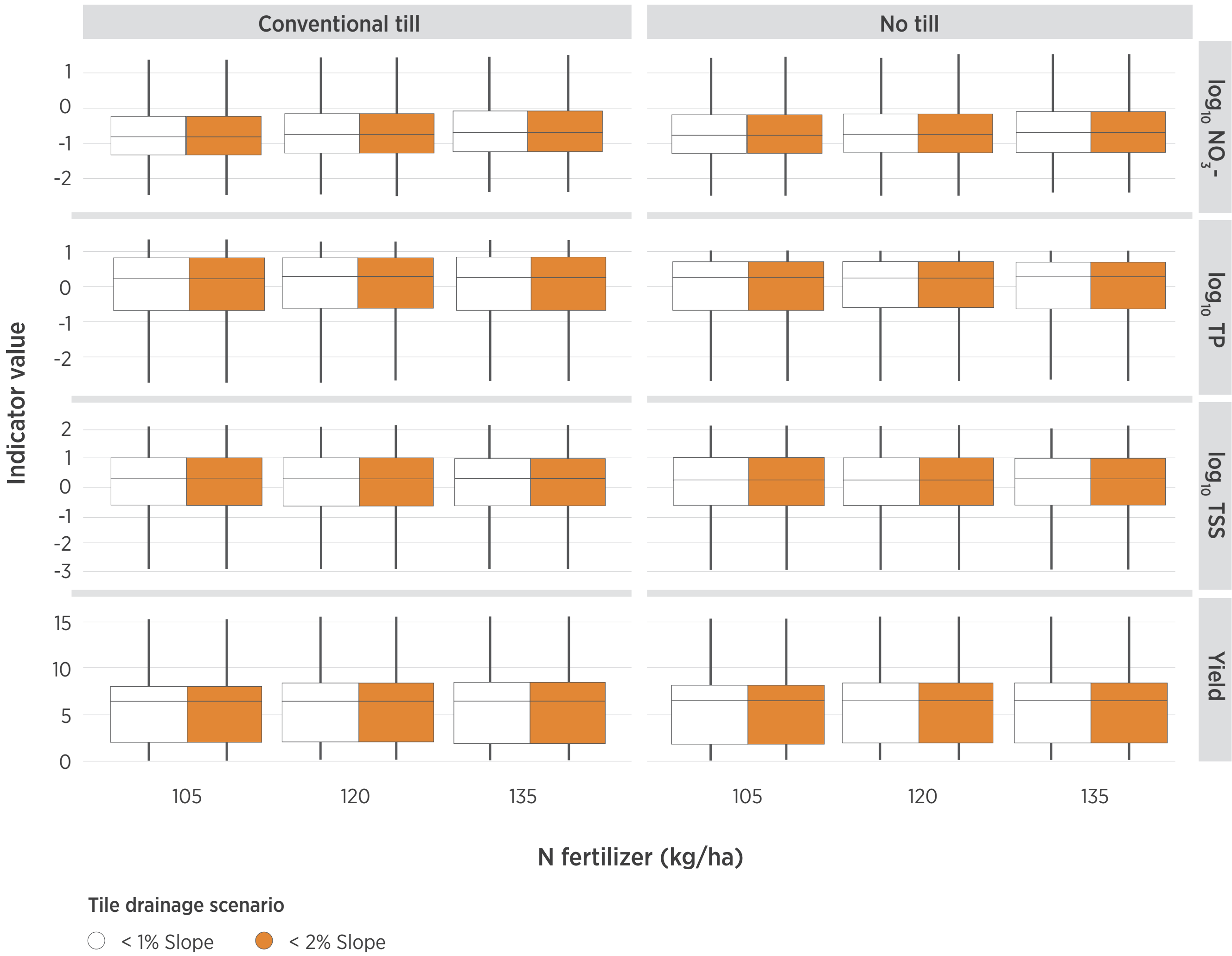


Figure 5.18 | Change in indicators among practices leading to best outcomes for each of four indicators: total suspended sediment (TSS), total phosphorus (TP), nitrate (NO_3^-), and feedstock yield

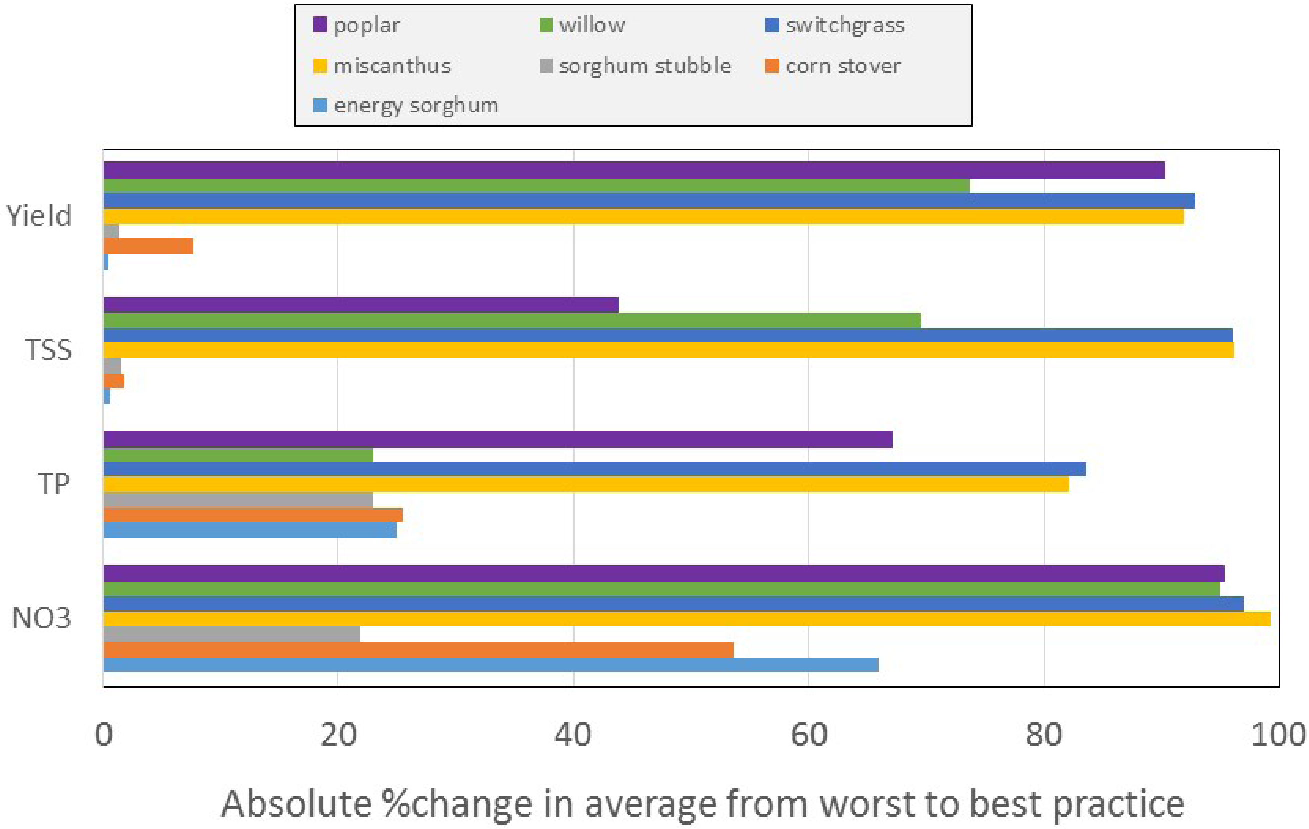


Figure 5.19 | Indicator values for practices leading to best outcomes for each of four indicators: total suspended sediment (TSS), total phosphorus (TP), nitrate (NO_3^-), and feedstock yield. Units for indicators are given in table 5.1.

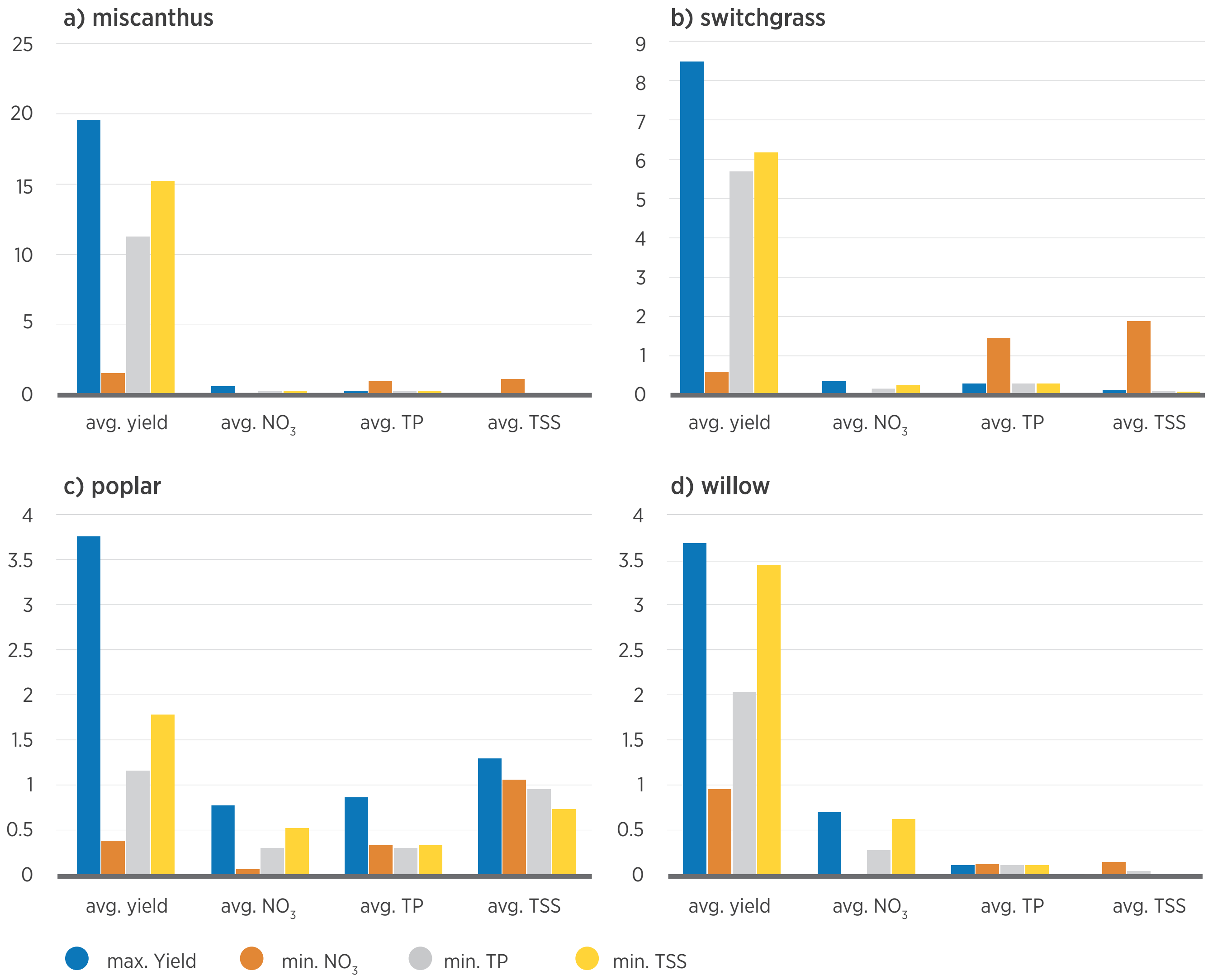
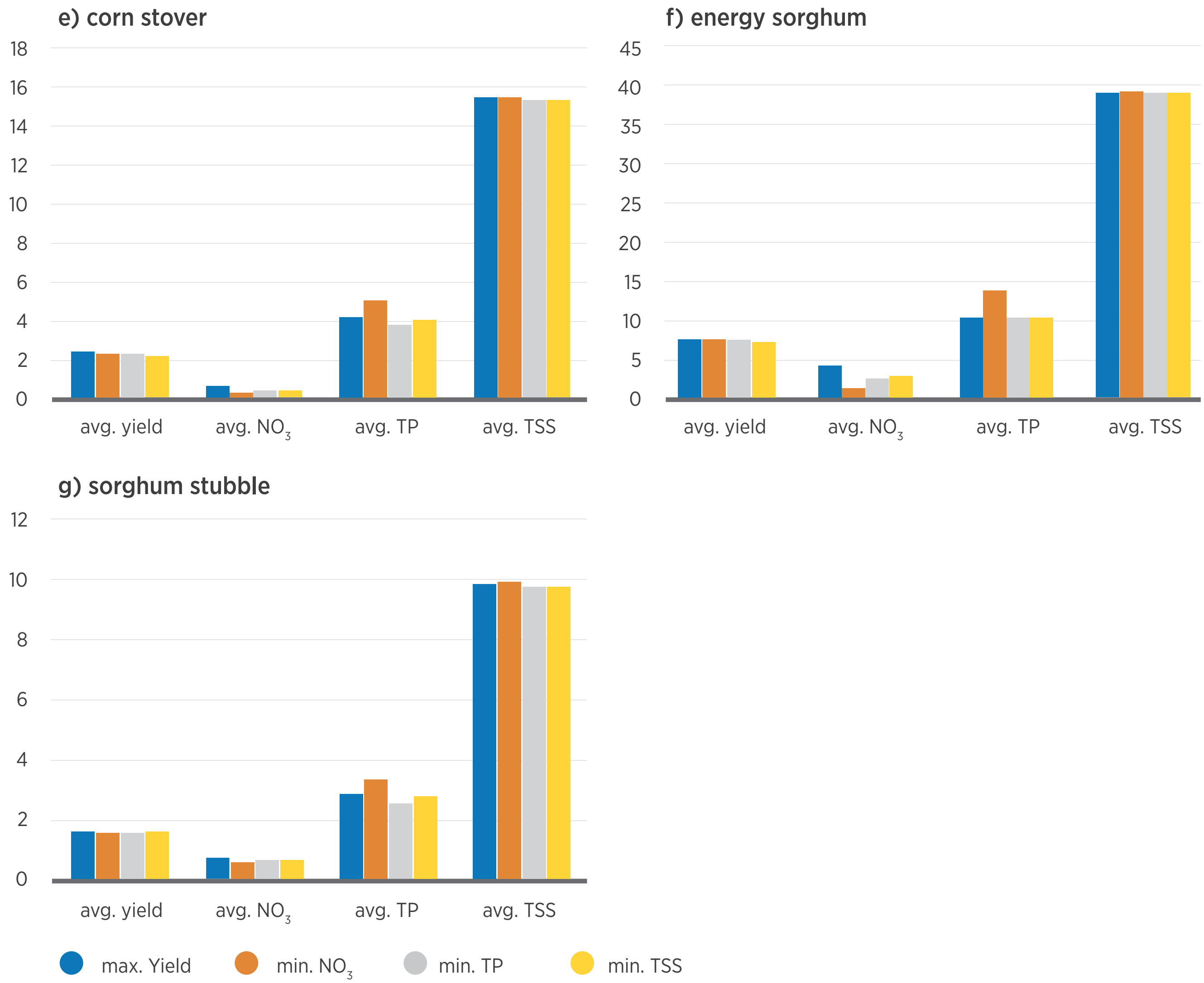


Figure 5.19 | *continued*



For annuals, adding tile drainage only on lands with <1% slope improved all indicators including yield. A tradeoff is evident between nitrate and TP (i.e., the practice leading to minimum nitrate generated high TP), but tradeoffs between yield and TSS were less apparent for residues (fig. 5.19e, g) and energy sorghum (fig. 5.19f). As expected, tillage generally produced lower TSS and TP for all annual crops. Whereas energy sorghum yield was consistently higher under no-till (fig. 5.12), the annuals produced higher whole-crop yields under conventional tillage in some sub-basins (fig. 5.14, 5.16).

As expected, yields were generally higher for the highest fertilizer application for all annuals. A positive yield response to fertilizer was most evident for energy sorghum (fig. 5.13). Therefore, it is unclear why lower fertilizer levels produced lower TSS loadings (and to a lesser extent TP) from lands growing annual crops under no-till management (fig. 5.12, 5.14, and 5.16). This differs from the pattern observed in simulations for perennial crops and illustrated by the conceptual diagram in figure 5.7.

Simulated nutrient and sediment loadings (fig. 5.19e, g) are attributed to the whole crop and not just the effect of residue removal. To attribute indicator values to residue removal, we subtracted nutrient and sediment loadings for simulations without residue removed from the values shown in figure 5.19. Interestingly, residue removal decreased nitrate and TP but increased TSS. This is because we simulated fixed fertilizer inputs rather than restoring the amount removed in residue. For example, harvest of sorghum stubble decreased average nitrate loadings by 15% to 20% and average TP loadings by 6% to 16%. However, harvesting residues increased average TSS by around 13%. For corn stover, decreases in nutrient loadings were quite variable (nitrate ranged from 13% to 40%; TP from 0.16% to 10%), whereas increases in TSS were similar among sub-basins (between 10% and 12.5%). The practice associated with the highest yield also produced the lowest (i.e., largest negative) "residual" contribution to nutrient loadings. Presumably, this is because more residue was harvested (i.e., a constant 80% percentage of yield).

5.4.2 Iowa River Basin

In the IRB study, we simulated seven conservation practice scenarios under BC1 2040 scenario: Riparian buffer 30m main stem, riparian buffer 50m main stem, cover crop, slow-release nitrogen, no tile, no tile at 2% slop and above, and open tile (Table 5.3). In addition, a scenario with riparian buffer 50m for the entire stream network in IRB was modeled to see the extend of the effect. The nutrient (nitrogen and phosphorus) and sediment loadings simulated at the IRB outlet and sub-basins are discussed in this section.

Implementing the conservation practices evaluated in this study—riparian buffer, controlled release, slow-release nitrogen fertilizer, and tile-drain control—substantially reduced watershed nitrogen loading (fig. 5.20). The reduction in total nitrogen because of these practices (compared with that from the baseline BC1 2040 scenario) ranged from 8% to 28%. Nitrate decreased from 6% to 29%. Tile-drain control and cover crops appeared most effective at reducing nitrate, at 28.6% and 19% respectively, followed by slow-release fertilizer (11.4%) (table 5.4).

Several conservation practices resulted in a significant reduction of phosphorus and sediments (fig. 5.21 - 5.22). Most noticeably, suspended sediments in the surface stream decreased by 70%, or 466,000 metric tons, when riparian buffers were installed in the main stem of the Iowa River. Cover crop ranked second with 37% reduction. These values are consistent with literature (Fischer and Fischenich 2000). For scenarios with a cover crop grown after stover is harvested, phosphorus loadings decreased by 27% (fig. 5.22) in the outlet of the basin.

Sensitivity of the annual crops to the nitrogen fertilizer-input rate in this region has been reported elsewhere (Demissie, Yan, and Wu 2012). Nitrate is

Figure 5.20 | Export of total nitrogen (TN) and nitrate (NO_3^-) loadings at the outlet of the IRB under various conservation practice scenarios for the BC1 2040 scenario

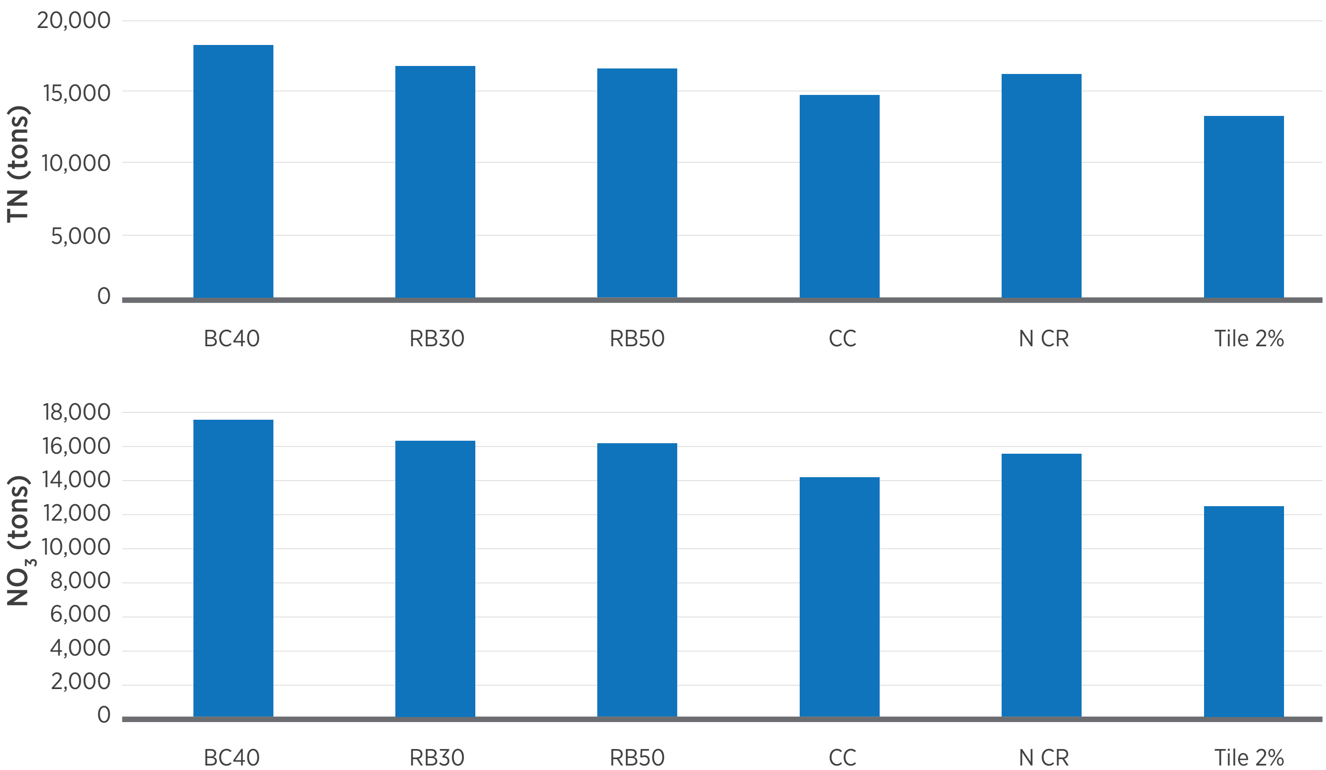


Table 5.4 | Comparison of Suspended Sediments, Phosphorus, and Nitrogen Removal under Conservation Practice Scenarios in the IRB

	Removals Relative to BC1 2040 Scenario (%)			
Conservation Practice Scenarios	Suspended sediment	Total phosphorus	Total nitrogen	Nitrate
RB30, main stem Iowa River	70.5%	7.9%	8.2%	6.2%
RB50, main stem Iowa River	70.8%	8.6%	8.9%	6.9%
RB50, entire Iowa River stream network	80.3%	22.7%	12.9 %	10.8%
CC	37.0%	27.4%	18.5%	19.0%
N CR	5.6%	9.9%	10.9%	11.4%
Tile2%	1.8%	1.7%	27.5%	28.6%

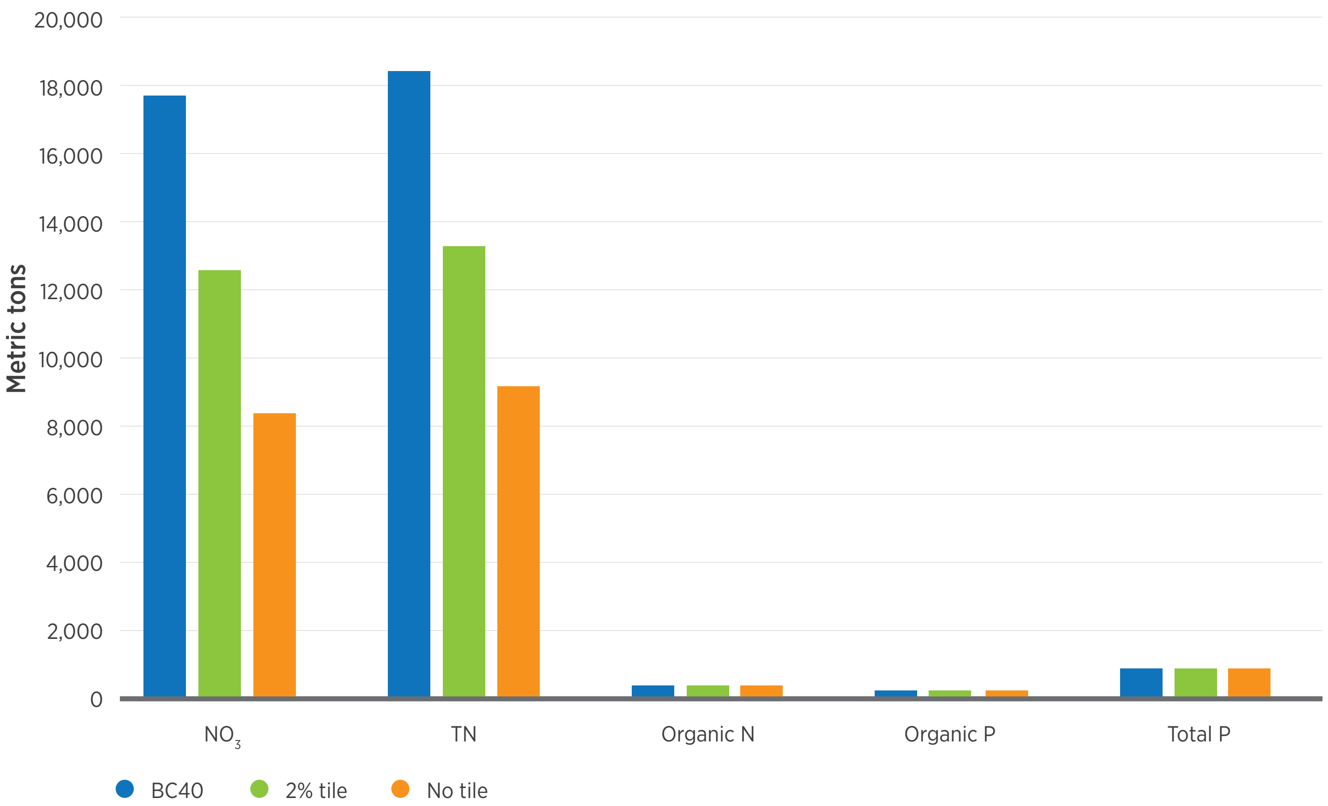
the main component (>90%) of total nitrogen in this region. Consequently, a decrease in nitrate leads to a comparable reduction in total nitrogen in the watershed.

5.4.2.1 Tile Drains

The Iowa agriculture region is one of the most intensively tile-drained regions in the United States. Nitrate is water-soluble and is often transported with water through soil. Drainage tiles create pipelines to carry nitrate from crop root zones to the surface water by short-circuiting the natural flow and, thus, speeding up conveyance of nitrate from the landscape to surface streams (Dinnes et al. 2002).

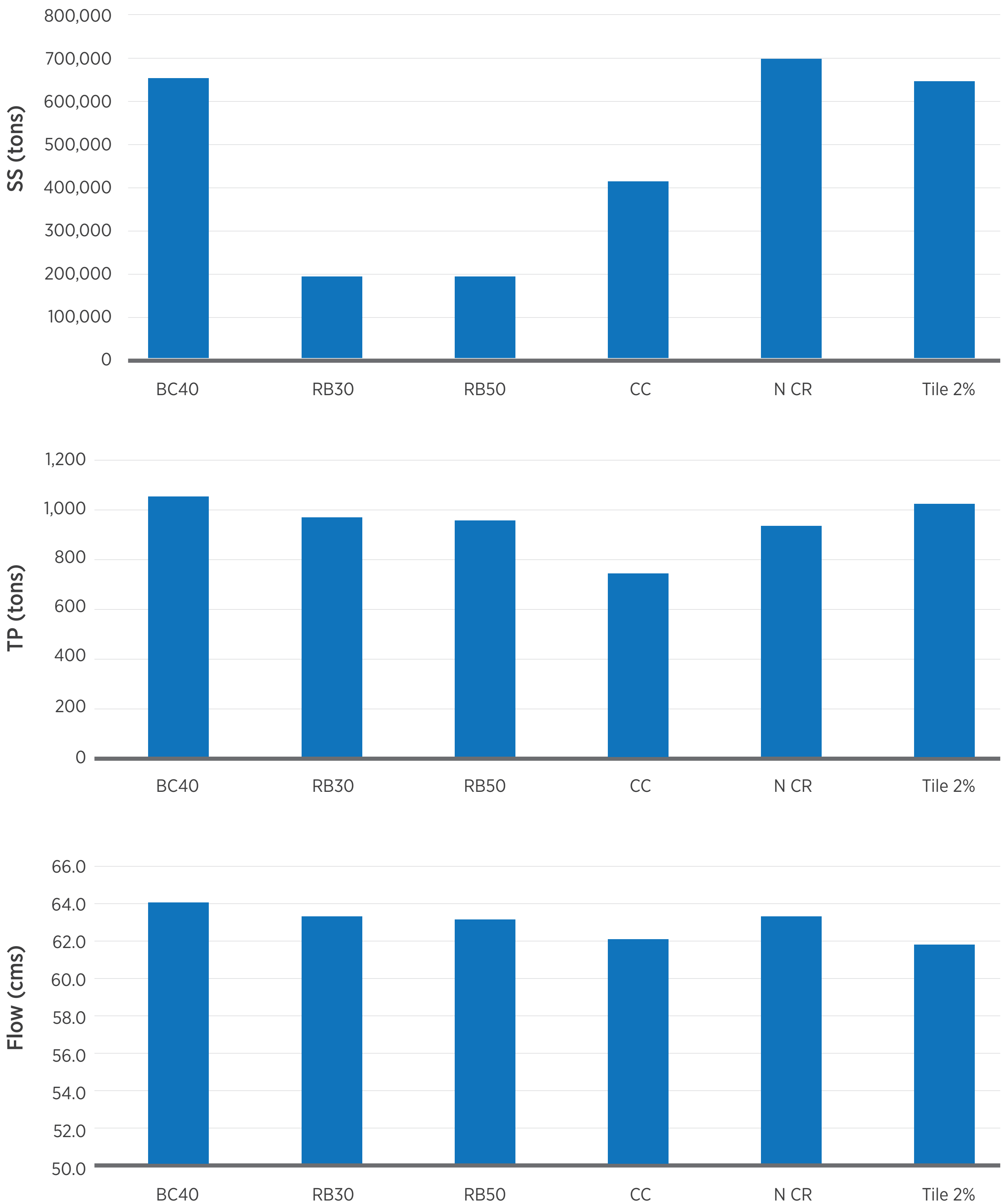
Our results show that plugging a fraction of the tile drains could result in substantial nitrogen reductions (28% to 29%) in the surface water in the IRB study area (fig. 5.21). In the Tile2% case, most areas simulated without tile drains occurred in the lower portion of the study area. The resulting reduction in nitrogen of 5,000 metric tons is significant for downstream communities. Unlike nitrate, our results suggest that tile drains are not a major pathway for the loss of organic nitrogen, organic phosphorus, or total phosphorus in this basin (fig. 5.21). This is because phosphorus and organic nitrogen are far less mobile in soils than nitrate. These results corroborate previous findings (Dinnes et al. 2002; Brouder et al. 2005).

Figure 5.21 | Nutrient losses from tile drains at the outlet of the IRB for the BC1 2040 production scenario with tile drains on all lands, on lands with <2% slope, and no lands



Acronyms: N – nitrogen; P – phosphorus.

Figure 5.22 | Locations of total phosphorus (TP), suspended sediments (SS), and flow at the outlet of the IRB under various conservation practices for the BC1 2040 scenario



Sediments and phosphorus were not responsive to tile drain control. Reasons for the reduction of phosphorus under slow-release nitrogen fertilizer are unclear. Compared with nutrients and sediments, the impact of conservation practices on water yield or water flow in the watershed was minimal (fig. 5.21). There was a slight decrease of flow (3.5%) because of tile-drainage control. This decrease could be caused by a diversion of the flow path—from direct transport via tile to seeping through soil naturally at a slower rate. Thus, it takes longer to reach the surface stream. When a cover crop is in place in a humid region, soil moisture would be expected to increase; thus, the surface runoff decreases.

5.4.2.2 Riparian Buffers

Riparian buffers have long been recognized as one of the most effective measures to trap sediments and reduce runoff. We simulated herbaceous riparian buffers along the main stem of the Iowa River bank adjacent to water. In HRUs with riparian buffers planted in switchgrass, simulated suspended sediments were reduced by 8.2% to 8.9% (fig. 5.21). The level of nitrogen removal by the buffer is likely affected by the buffer coverage in watersheds (Fischer and Fischenich 2000). The main stem of the Iowa River in the watershed boundary constitutes 125 km (77.6 miles) of stream, which is 13.7% of the total stream length in the IRB. In this study, the land area covered by riparian buffers (RB30 and RB50) totaled 19,202 acres and 30,591 acres and account for only 0.96% and 1.54% of the entire IRB area, respectively. The area planted in riparian buffer in the watershed is currently 502 acres, about 0.02% of the total IRB, of which most are lands enrolled in the USDA Conservation Reserve Program (Hubbert 2016, personal communication).[1] Excluding existing riparian buffers, the simulated buffers would still be 0.94% and 1.51% of the total IRB area. If the buffer were applied to the entire stream network in the IRB, which would increase coverage to 11.3% (RB50) of the total land, total nitrogen removal would increase substantially. We estimated that up to 22.7% total nitrogen (2,370 metric tons) and 10.8% nitrate (1,900 metric tons) can be avoided in the surface stream (table 5.4). Similarly, 80% of the sediment loadings can be removed (table 5.4), translating to a decrease in transport of sediment of 529,800 metric tons to the downstream Mississippi River. Removal efficiency can further increase if a mixture of trees and grasses is installed (Dosskey, Schultz, and Isenhart 1997).

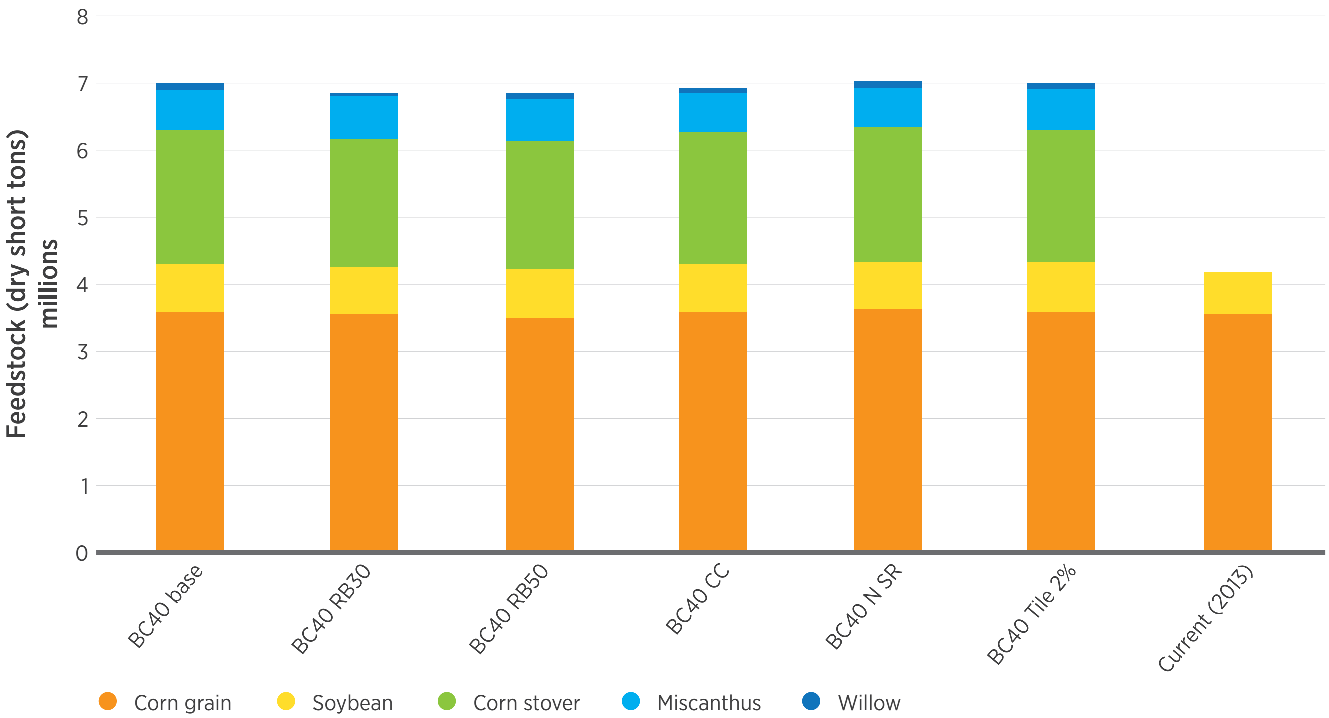
5.4.2.3 Biomass Production

The BC1 2040 scenario estimated that the feedstock production in the IRB from corn stover, willow, and miscanthus would total 2.68 million dt. Including corn grain and soybeans, total crop production (including all end uses) in the IRB would be 6.97 million dt (fig. 5.23). We found that implementing conservation practices would have minimal impacts on corn and soybean production under the future BC1 2040 scenario. Results indicate that annual production of corn grain would vary from -2.1% to 1.2% depending on the conservation practice, and soybean production would vary from -2% to 0% compared to the BC1 2040 base scenario. The BC1 2040 scenario produces 1% more corn and 10% more soybean compared with a 2013 reference.

In this study, we assumed that the riparian buffer and cover crop were not harvested for biofuel production. However, with care to protect the adjacent stream, both could potentially provide feedstock. By a rough estimate, if 50% of the switchgrass grown on riparian buffer were harvested, an additional 73,000 and 121,000 dt of biomass could be obtained from RB30 and RB50, respectively. In addition, if 40% of the cover crop were harvested, an additional 351,000 dt of biomass could be obtained from rye, a 12.8% in-

[1] Hubbert, J. 2016. USDA-NRCS record of riparian buffer installation in the Iowa River watersheds. Personal communication between Hubbert, J. and Ha, M. May 26, 2016.

Figure 5.23 | Annual feedstock production in BC1 2040 base case and in BC1 2040 with various conservation practices in the IRB



crease from the BC1 2040 base scenario. By harvesting rye and switchgrass from a 50-m riparian buffer, the cellulosic biomass production could potentially increase by 16%.

5.4.2.4 Regional Distribution of Cost and Benefits

At the sub-basin level, loadings of nutrients and sediments exhibit strong heterogeneity across the landscape (fig. 5.24). As expected, riparian buffer scenario for the entire IRB stream network resulted in nitrogen reductions across the watershed. In the cover crop scenario, reduction of nitrogen loadings appears aggregated because the basin is predominantly planted with corn/soybean rotation system (66.9%; figure 5.6) and residue is harvested from most cornfields. Similarly, we observed a reduction of nitrogen by using slow-release fertilizer in corn HRUs. The largest nitrogen reduction occurred in the middle of the basin where annual crops were grown in highest acreages.

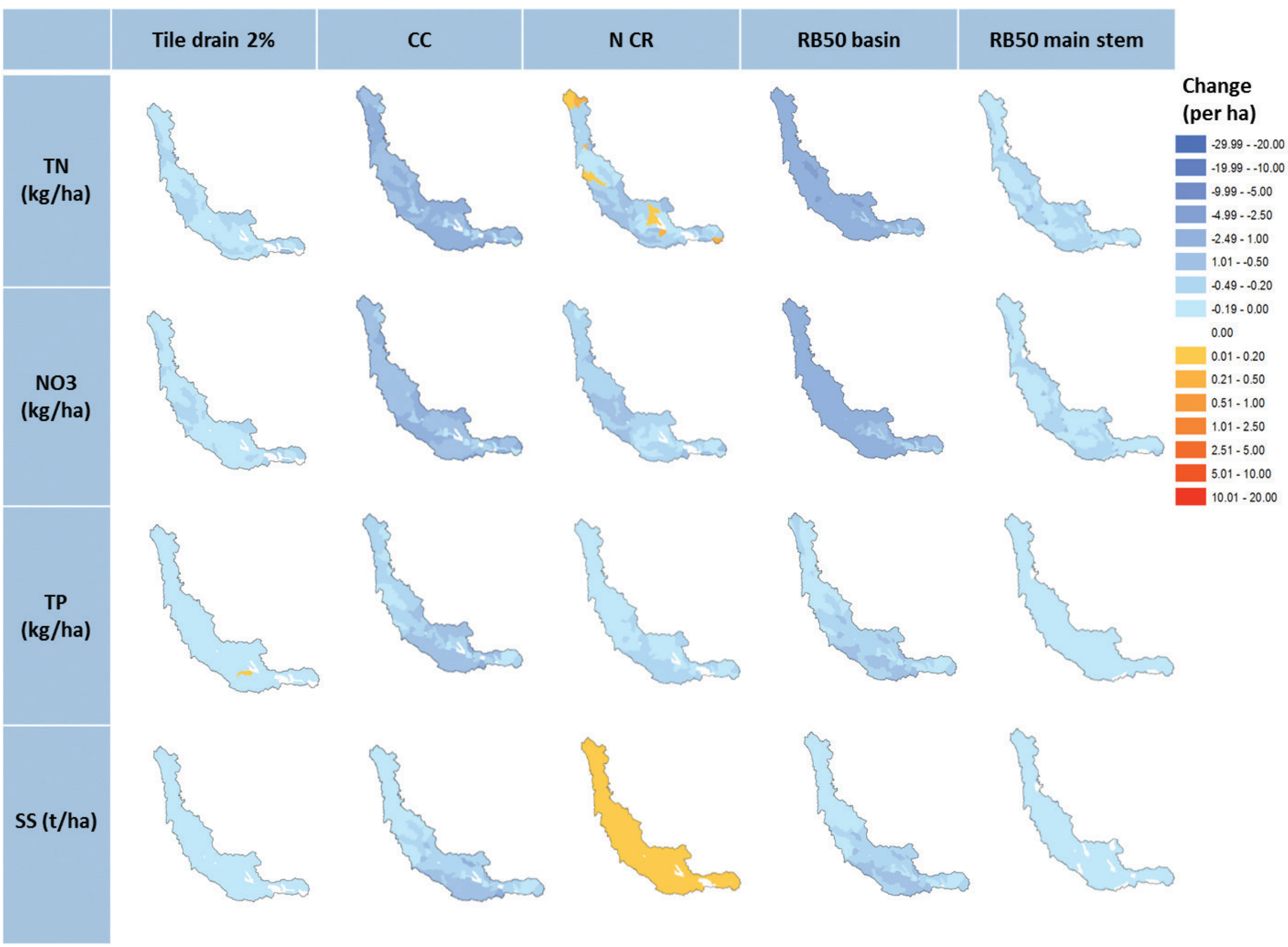
These results suggest that basin-wide effective nitrogen, phosphorous, and sediments removal could be achieved by installing a buffer in the riparian zone in the IRB, combined with planting a cover crop and using slow-release nitrogen for acreage planted in corn. Geographically, reductions in phosphorus and sediments occurred consistently in the lower sub-basins of the IRB, which has a larger flow and a denser stream network than upstream.

5.4.2.5 Uncertainties

Several factors contribute to uncertainties in this analysis. The simulation is based on historical 20 year climate data. Future potential climate change and its regional impacts for 2040 were not available at the time of this study. Climate issues and potential effects on biomass production are discussed in chapter 13. Riparian buffers can effectively trap sediments and nutrients; however, the scale of buffer implementation in the watershed would depend on land use and other economic considerations, as well. At present, most riparian buffers occur along streams on Conservation Reserve Program land. Increases in riparian buffers could affect the amount of land available for production. On the other hand, the use of riparian buffers could create a land-use change from annual to perennial cropping systems. Thus, a systems approach in land management, conservation, and feedstock production, with careful planning under a multiagency joint effort, will be a critical step toward water quality improvement.

Finally, this chapter addresses region-specific issues in two regions, the AWR and IRB, by evaluating conservation practices that are suitable for region-specific feedstocks at the production scale estimated by *BT16* volume 1. The differences in the choice of conservation practices selected are largely due to distinct regional environments and feedstock requirements. Due to regional heterogeneity, results may not be applicable to other regions. Nevertheless, this study provides valuable information for regions with similar characteristics.

Figure 5.24 | Changes of nitrogen, phosphorus, and suspended sediment under evaluated conservation practices relative to BC1 2040 scenario across the IRB



Acronyms: CC – cover crop scenario added; NCR – controlled release of nitrogen fertilizer added; RB30 – 30-m riparian buffer added; RB50 – 50-m Riparian Buffer Added.

5.5 Summary

In this chapter, we asked the question, "How can we manage future biomass production to protect water quality with minimal cost to feedstock supply?" We identified two tributary river basins of the Mississippi River Basin with contrasting future biomass feedstock profiles under the BC1 2040 scenario, each set against a different agricultural backdrop. Our analysis of these two regions identified the swing potential of different management practices.

For the modeled scenario, we found complementarities between simulated potential biomass yield, TSS and TP in the AWR basin, and tradeoffs between biomass yield and nitrate for perennial grasses and SRWCs. Higher fertilizer levels produced higher yields and lower TSS and TP, but higher nitrate. We note that if we had simulated even higher levels of fertilizer, we would have reached a point beyond which no improvement was observed in yield (and thus, TSS and TP). Thus, the challenge is to avoid nitrate runoff by using conservation practices such as filter strips, as we demonstrated for SRWCs.

In addition, our analysis revealed water quality benefits of coppiced willow, which minimized tradeoffs between nutrient and sediment reduction and biomass yield in the scenario. Filter strips also provided water quality benefits for both SRWC crops.

Among annual crops and residues in the AWR, implementing tile drainage only on the flattest lands produced the best outcomes in terms of productivity, as well as water quality. No-till reduced sediment loadings, but in some cases, it came with a small cost to productivity. Fertilizer practices did not produce much variation in any of the indicators in this analysis. When subtracting the effect of the annual crop without residue removal (corn and sorghum grain), we observed sizable percentage decreases in nutrient loadings and increases in sediment loadings. This is likely because we simulated variable residue removal (and associated nutrients), but applied the same amount of fertilizer. In other words, harvested nutrients were not specifically replenished.

For the AWR, a visualization tool allows users to explore simulated data. By selecting thresholds for each of the water quantity and quality indicators, users can evaluate (1) the 'sustainable' supply (thus defined) and (2) the set of conservation management practices that, according to SWAT simulations, lead to user-defined sustainable production. The visualization shows the relative benefits of different practices for each crop. The visualization can be found here: www.bioenergykdf.net.

In the IRB, we demonstrated the benefits of four conservation practices (riparian buffer, cover crop, slow-release nitrogen fertilizer, and tile-drain control) in the annual crop corn/soy dominant flat terrain. These practices could effectively reduce nitrogen up to 29%, phosphorus 27%, and suspended sediments 80%. Riparian buffer implementation on the entire IRB stream network could lead to the highest reduction of suspended sediments and phosphorous loadings in the watershed while partial control of tile drainage could bring the most benefits to nitrogen reduction in the practices evaluated. Reductions of sediments and phosphorus in IRB under the conservation practices were consistently concentrated in the middle and lower portions of the river basin while that of nitrogen could be extended to the entire IRB.

This study suggests that basin-wide effective nutrient removal and sediment reduction in the biomass development could be achieved by implementing a combination of the practices - installing a buffer in the riparian zone, controlling tile drainage and using slow-release nitrogen fertilizer in the crop growing area, and planting a cover crop in the area stover is harvested. If the effects of the four practices were additive, by adopting tile drain control (Tile 2%) and cover crop, together nitrogen could be reduced by nearly 50% and sediments reduced by more than a third compare to BC1 2040 scenario. We also highlight the potential benefits, both for production and water quality, of developing protocols for harvesting riparian buffers.

The Gulf of Mexico, which receives nutrient inputs from upstream agriculture in the Mississippi-Atchafalaya River Basin, has a large hypoxic zone that is deadly to aquatic life during summer. The river basins simulated here are both tributaries of the Mississippi River (fig. 5.1). By choosing perennial feedstocks (Jager et al. 2015) and implementing conservation practices (Hu and Wu 2015), we envision a win-win situation in which biomass production helps to reduce downstream nutrient loadings to the Gulf of Mexico. Done right, biomass production can decrease the environmental impacts of conventional crops.

5.6 References

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