Recent land use change in the Western Corn Belt threatens grasslands and wetlands

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In the US Corn Belt, a recent doubling in commodity prices has created incentives for landowners to convert grassland to corn and soybean cropping. Here, we use land cover data from the National Agricultural Statistics Service Cropland Data Layer to assess grassland conversion from 2006 to 2011 in the Western Corn Belt (WCB): five states including North Dakota, South Dakota, Nebraska, Minnesota, and Iowa. Our analysis identifies areas with elevated rates of grass-to-corn/soy conversion (1.0–5.4% annually). Across the WCB, we found a net decline in grass-dominated land cover totaling nearly 530,000 ha. With respect to agronomic attributes of lands undergoing grassland conversion, corn/soy production is expanding onto marginal lands characterized by high erosion risk and vulnerability to drought. Grassland conversion is also concentrated in close proximity to wetlands, posing a threat to waterfowl breeding in the Prairie Pothole Region. Longer-term land cover trends from North Dakota and Iowa indicate that recent grassland conversion represents a persistent shift in land use rather than short-term variability in crop rotation patterns. Our results show that the WCB is rapidly moving down a pathway of increased corn and soybean cultivation. As a result, the window of opportunity for realizing the benefits of a biofuel industry based on perennial bioenergy crops, rather than corn ethanol and soy biodiesel, may be closing in the WCB.

agriculture | Great Plains | land capability | land cover change

High corn and soybean prices, prompted largely by demand for biofuel feedstocks, are driving one of the most important land cover/land use change (LCLUC) events in recent US history; the accelerated conversion of grassland to cropland in the US Corn Belt (1–5). Likely impacts of such conversion include a reduction in bird diversity across the region (6) and accruement of a significant carbon debt (7). For example, reductions in soil carbon sequestration caused by grassland conversion may require more than three decades of biofuel substitution for fossil fuels to repay (8). The continued loss of native grasslands is also an important issue with respect to ecosystem conservation. Temperate grassland is the most-altered biome globally, and temperate grasslands are the least protected ecosystems in the countries where they occur (9). In the Corn Belt, nearly all tallgrass prairie has been converted to agricultural land uses, whereas conversion of mixed-grass prairie exceeds 70% (10). As a consequence, populations of grassland nesting birds are declining faster than any other group of birds in North America (11, 12).

Despite the importance of LCLUC in the Corn Belt, there is a lack of information on where, at what rates, and on what types of land current grassland conversion is occurring. Detailed studies of the economic drivers and biophysical correlates of grassland conversion have been conducted only over limited subsets of the Corn Belt (1, 2). Meanwhile, regional-scale studies of grassland conversion have been based on agricultural production statistics aggregated at the county level (3, 4), precluding large-area geospatial analysis of grassland conversion at farm to subcounty scales. Finally, most studies of grassland conversion (1–3) precede the doubling of corn and soybean prices between 2006 and 2011 (13), with the exception of one (4). From 2006 to 2008, the corn and soybean area harvested in the United States increased by more than 3.2 million ha (4). Farm-level surveys showed that nearly one third of this increase came from conversion of grass-dominated land covers to cultivated cropland (4). Since 2008, however, there has been no regional-scale accounting of grassland conversion in the Corn Belt.

The present study addresses knowledge gaps evident in previous research by assessing very recent grassland conversion (2006–2011) at relatively high spatial resolution (560 m) across the Western Corn Belt (WCB). The WCB encompasses five states—North Dakota, South Dakota, Nebraska, Minnesota, and Iowa—and contains most of the grass-dominated land cover remaining in the Corn Belt (Fig. 1*A* and Fig. S1). The WCB also intersects much of the Prairie Pothole Region (PPR; Fig. 1*B*), a wetland landscape of continental significance (14–16).

We analyzed contemporary grassland conversion in the WCB by using the National Agricultural Statistics Service (NASS) Cropland Data Layer (CDL). The NASS CDL is derived from satellite imagery and maps agricultural land cover at very high crop-type specificity (from apples to watermelons) at a 56-m spatial resolution (17–19). The NASS CDL is also a relatively new dataset, having been available for all five states in the WCB only since 2006. Thus, we focused on grassland conversion through the 2011 growing season, using 2006 as a baseline. In brief, we addressed the following questions: (*i*) Where are the rates of grassland conversion to corn/soy agriculture highest in the WCB? (*ii*) Are the observed changes over this period consistent with longer-term trends of land cover change? (*iii*) What are the agronomic and environmental characteristics of land currently being converted from grassland to corn/soy? (*iv*) To what degree are wetlands, a habitat of regional and international significance, being impacted by these changes?

Results and Discussion

Grass-dominated land cover in the WCB ranges from native prairie to anthropogenically modified grassland types including grass pasture and hay lands, in addition to retired cropland converted to perennial grasses through the Conservation Reserve Program (CRP). Given their spectral similarity, these different grass cover types are difficult to resolve in satellite imagery. For example, accuracy rates for the grass hay and fallow/idle cropland classes in the NASS CDL are typically less than 50% (17). By contrast, reported classification accuracies for corn and soybeans exceed 90% (18, 19). We combined all the grass-dominated classes in the NASS CDL—native grassland, grass pasture, grass hay, fallow/idle cropland, and pasture/hay—to create a broadly defined grass-dominated class. In doing so, we make an important assumption that this generalized class subsumes classification errors which might otherwise occur between different types of grass-dominated land cover. For purposes of brevity, we refer to this generic class simply as "grassland."

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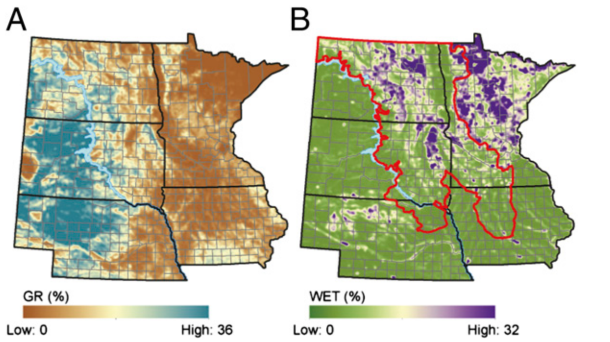

Fig. 1. Grasslands and wetlands in the WCB. Each map consists of smoothed percent cover at 560-m spatial resolution. (*A*) Percent grassland cover from the 2006 NASS CDL. (*B*) Percent wetland cover from the 2006 National Land Cover Dataset (53). The red outline indicates boundaries of the PPR within the WCB (52).

Grassland conversion between 2006 and 2011 was mostly concentrated in North Dakota and South Dakota, east of the Missouri River (Fig. 2*A*). Here, corn and soybean cropping has expanded westward into the transition zone between humid climates representative of the Corn Belt in general and the arid steppe of the High Plains (20). Similar westward expansion of the Corn Belt was found in Nebraska (Fig. 2*A*). The western periphery of the Corn Belt is characterized by a climate whereby mean annual evapotranspiration exceeds mean annual precipitation (21), suggesting that farmers here are willing to accept higher levels of drought risk in seeking higher cash returns from corn and soybeans. Federal crop insurance and disaster relief programs mitigate this risk, creating incentives for converting grassland to cropland, potentially at cross purposes with other national policies intended to conserve grasslands (3, 22, 23). In Minnesota and Iowa, grassland conversion forms a ring of LCLUC surrounding the core corn/soybean region in southern Minnesota and northern Iowa (Fig. 2*A*). Here crop production has expanded not into a less suitable climate per se, but rather onto less suitable land.

Cropping systems in the northern Great Plains often include grass hay or pasture rotated with corn and soybeans. This can result in substantial LCLUC from annual crops to grass-dominated land covers (3). Change from corn/soy to our generalized grassland class may also reflect fallow/idle lands that have temporarily been removed from crop production. We found that corn/soy to grassland change occurred predominantly along the western margin of the Corn Belt (Fig. 2*B*), and at much lower rates than grassland conversion (Fig. 2*C*). In sum, we found a net decline in grass-dominated land cover in the WCB totaling nearly 530,000 ha (>1.3 million acres; Table 1). This change was concentrated in two states, South Dakota and Iowa, with the majority of grassland conversion occurring in the WCB's three western states relative to the core corn/soy growing areas in Iowa and Minnesota (Table 1).

Normalizing absolute rates of grassland conversion (Fig. 2*A*) by grassland cover in 2006 (Fig. 1*A*), we generated a map of relative grassland conversion rates (Fig. 2*D*). This map reveals an arc of intermediate grass cover along the western edge of the Corn Belt (Fig. 1*A*) where grassland is being converted to corn or soybeans at comparatively fast rates; 5% to 30% from 2006 to 2011 (annualized rates, ∼1.0–5.4%). This range of annualized rates is very similar to grassland conversion rates predicted by an econometric model that takes into account recent increases in corn prices (2).

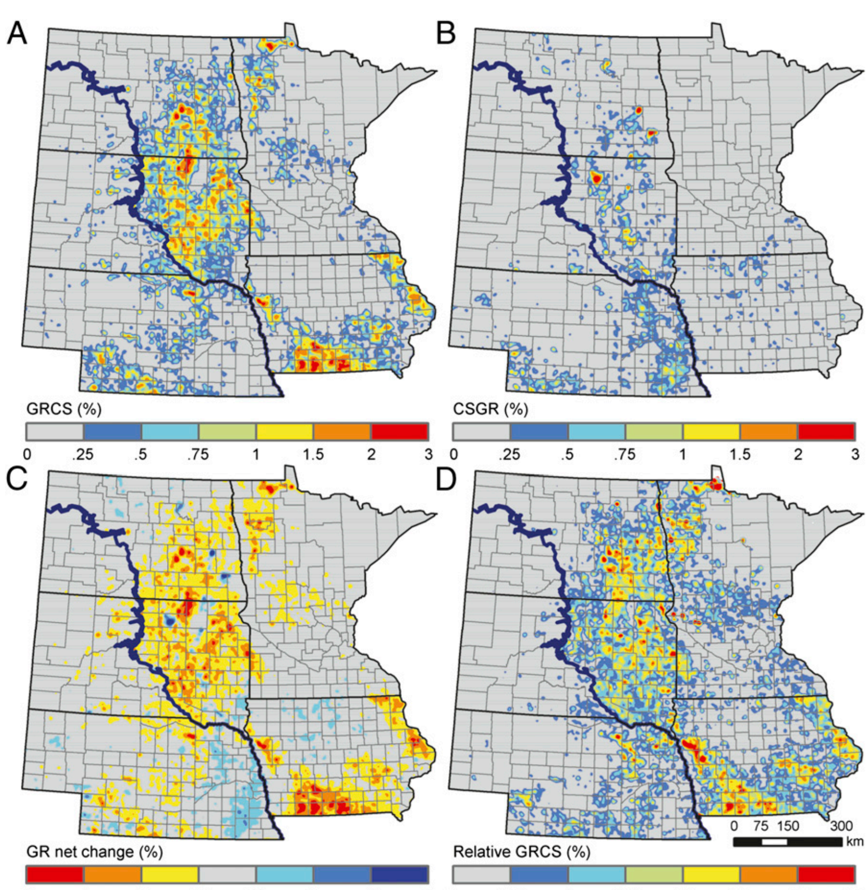

Fig. 2. LCLUC in the WCB. (*A*) Absolute change rate from grassland in 2006 to corn or soybeans in 2011 (GRCS). Smoothed absolute change rates at 560-m spatial resolution are calculated as the percentage of the landscape undergoing change (*Methods*). (*B*) Absolute change rate from corn or soybeans in 2006 to grassland in 2011 (CSGR). (*C*) Net result of GRCS and CSGR types of land cover change. Net change in grassland cover is calculated as CSGR minus GRCS, i.e., by subtracting the GRCS surface in *A* from the CSGR surface in *B*. Note this is not the same result one would obtain by comparing grassland cover in 2006 (i.e., Fig. 1*A*) with grassland cover in 2011, as we are ignoring transitions between grassland and other land classes exclusive of corn or soybeans. (*D*) Relative change rate from grassland in 2006 to corn or soybeans in 2011. Relative GRCS is calculated by normalizing absolute GRCS in *A* by grassland cover in 2006 (Fig. 1*A*).

Table 1. Area of LCLUC from 2006 to 2011

	Area, ha * 10^3 (acres * 10^3)		
State	Grassland to corn/soy	Corn/soy to grassland	Grassland net loss
North Dakota	129 (320)	40 (100)	89 (220)
South Dakota	256 (632)	73 (181)	182 (451)
Minnesota	92 (228)	13 (31)	80 (196)
Iowa	195 (481)	42 (104)	152 (376)
Nebraska	125 (309)	100 (247)	25 (62)
Sum	797 (1,969)	268 (663)	528 (1,306)

In those parts of Iowa outside the core corn/soy region, relative conversion rates were also comparably high (Fig. 2*D*).

One potential pitfall of inferring substantial grassland conversion over a relatively short interval like 2006 to 2011 is the possibility that such change is more a reflection of short-term variability in crop rotation patterns, rather than an underlying trend or enduring shift in land cover/land use. Also, by inferring change from two temporal snapshots, our results are potentially sensitive to measurement errors at one or both dates. However, longer-term NASS CDL agricultural data are available for only two states in the WCB, North Dakota and Iowa. We used these annual NASS CDL classifications from 2001 to 2011 to analyze trends in percent corn/soy cover and percent grass cover (Fig. 3). We found that elevated grass-to-corn/soy conversion rates in eastern North Dakota over the shorter term, 2006 to 2011 (Fig. 2*D*), were consistent with significant trends of increasing corn/soy cover ($P < 0.05$; Fig. 3*A*) and decreasing grassland cover ($P < 0.05$; Fig. 3*B*) over the longer period of 2001 to 2011. In Iowa, longer-term grassland trends were almost uniformly negative (Fig. 3*D*). Significantly positive corn/soy trends ($P < 0.05$) were concentrated in the southwestern and southeastern portions of the state (Fig. 3*C*). Thus, the pattern of higher relative grassland conversion rates outside the core corn/soy region in north-central Iowa (Fig. 2*D*) was broadly consistent with those areas where longer-term corn/soy trends are positive and grassland trends are negative. In sum, results from trend analyses in North Dakota and Iowa suggest that our approach to inferring grassland conversion across the entire WCB using NASS CDL data from 2006 and 2011—an approach made necessary by limited data availability—is representative of longer-term LCLUC region-wide.

Next, we consider the agronomic and environmental attributes of lands on which grassland conversion has occurred. In aggregate, conversion has been concentrated on more marginal lands characterized by high erosion potential, shallow soils, poor drainage, and less suitable climates for corn/soy production (Fig. 4*A*). At the state level, however, different patterns emerge. In Minnesota, we found a high proportion of grassland conversion occurring on land characterized by excess wetness, pointing to a likely increase in anthropogenic drainage (Fig. 4*B*). In Minnesota and the Dakotas, grassland conversion was concentrated on relatively high quality class II lands (Fig. 4 *B–D*). This suggests that land owners in those states are seeking higher rates of return from high-quality pasture and hay lands by converting those lands to corn and soybean cultivation rather than continuing their use in local livestock production. Such a shift from livestock to corn/soy cropping is consistent with a tipping point at which increasing rates of return caused by, e.g., rising commodity prices, subsidized crop insurance, improved corn and soybean cultivars, and adoption of no-till technologies make grassland conversion more profitable than continued livestock production (3, 4, 23). By contrast, grassland conversion in Iowa was concentrated on less suitable land (Fig. 4*E*), likely reflecting a relative lack of higher quality land available for additional corn/soy production. Prevalence of the climate modifier in the Dakotas and Nebraska was consistent with the westward expansion of the Corn Belt, as discussed earlier, and northward expansion of the Corn Belt into areas with shorter growing seasons. Finally, we found grassland conversion in Nebraska more evenly distributed across lands highly unsuited to crop production (Fig. 4*F*), suggesting an increase in irrigation practices largely concentrated in southwest Nebraska (cf. ref. 24).

The WCB intersects much of the PPR (Fig. 1*B*), a region that encompasses the most productive waterfowl breeding habitat in North America (14, 15), in addition to important breeding grounds for neotropical migratory shorebirds (25). For duck species (*Anas* and *Aythya* spp.), nesting success in the PPR is critically related to the amount of grassland cover adjoining

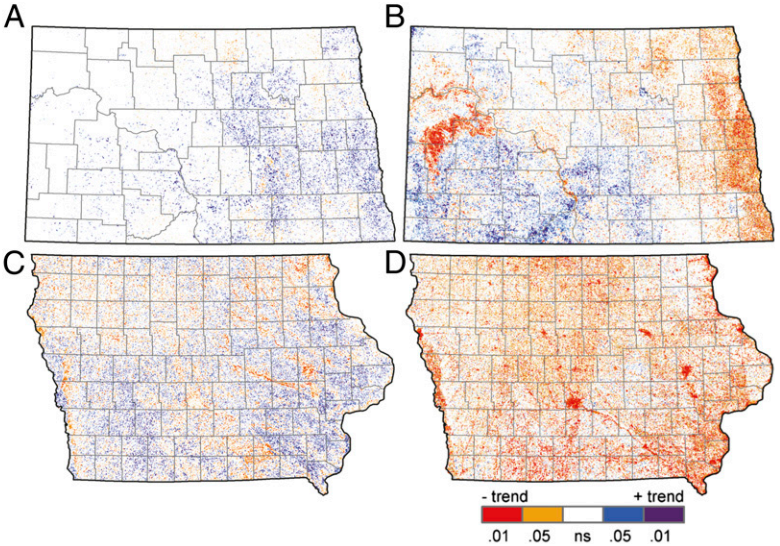

Fig. 3. Trend analysis of grassland and corn/soy percent cover over the period of 2001 to 2011. Nonparametric Mann–Kendall trend tests were conducted on percent corn/soy cover or percent grassland cover time series at 560-m spatial resolution. The color scheme indicates the sign (negative or positive trend) and significance level of geospatially referenced Mann–Kendall trend tests. (*A*) North Dakota corn/soy trends. (*B*) North Dakota grassland trends. (*C*) Iowa corn/soy trends. (*D*) Iowa grassland trends.

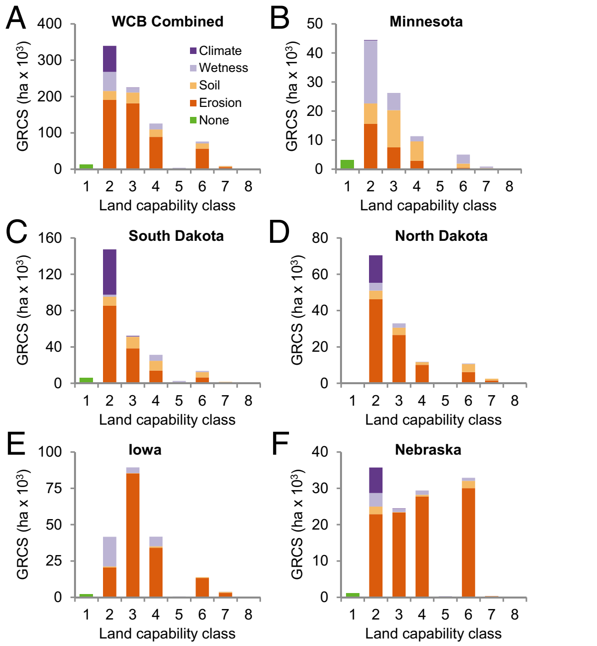

Fig. 4. Area of grassland conversion to corn or soybeans by land capability class. The Natural Resources Conservation Service ranks land by its suitability for agricultural production, with suitability declining as the index increases (49). Classes 1 to 4 are arable lands, classes 5 to 8 are suitable mainly as pasture or rangeland, and classes 3 and 4 have severe to very severe limitations, respectively. Class modifiers represent hazards affecting land use within a particular capability class. The climate modifier indicates low temperatures or a lack of moisture as major hazards affecting use. Excess wetness indicates soils with poor drainage, a high water table, or vulnerability to flooding. The soil modifier refers to soil limitations within the rooting zone; including shallow soils, rocky soils, or a low water-holding capacity. The erosion modifier indicates soils vulnerable to erosion or degraded by past erosion. (*A*) GRCS by land capability class for the entire WCB. (*B–F*) Results on a state-by-state basis.

wetlands, as such cover reduces nest predation (15). However, our results show that grassland conversion is occurring in very close proximity to PPR wetlands. In South Dakota, for example, nearly 100,000 ha of grassland conversion occurred within a 100-m buffer surrounding wetlands (Fig. 5*A*), with more than 80% of grassland conversion occurring within 500 m of neighboring wetlands (Fig. 5*B*). A nearly identical pattern was found in North Dakota (Fig. 5*B*), albeit over a lesser area (Fig. 5*A*). Comparatively fewer wetlands are found within the Minnesota portion of the PPR (Fig. 1*B*), with a more limited concentration of grassland conversion surrounding those wetlands (Fig. 5). Given that nearly all prairie pothole wetlands in Iowa have been lost to drainage (26), land use change in proximity to wetlands is negligible there. Finally, although grassland conversion within close proximity to wetlands in Nebraska was limited (Fig. 5), we note that Nebraska wetlands play a critical role as stopover habitat for migratory waterfowl and shorebirds (27).

Last, we examined the relationship between grassland conversion and lands protected under the CRP. The CRP pays farmers to establish and maintain grassland cover on retired cropland in exchange for a fixed rental payment over a fixed period. Given recent increases in corn and soybean prices, and projections that high commodity prices will be sustained, econometric models predict that landowners will be less likely to renew expiring CRP contracts given an expectation of higher rates of return from resuming crop production (28, 29). This has led some to project a substantial decline in CRP enrollment in the Northern Great Plains (5). Although county-level CRP data shows a decrease in CRP enrollment in the Dakotas and northwestern Minnesota from 2006 to 2011 (Fig. 6*A*), this decrease was not nearly as large as would have taken place if a more widespread failure to renew CRP contracts had occurred (5). In North Dakota, we found that county-level decreases in CRP enrollment generally exceeded grassland-to-corn/soy change (Fig. 6*B*). Here, grassland conversion might be largely attributed to a resumption of cropping on CRP lands. However, in far eastern North Dakota, eastern South Dakota, and Nebraska, grassland conversion generally exceeded changes in CRP (Fig. 6*B*). This result suggests an expansion of corn and soybean cropping onto grassland beyond those lands formerly protected by the CRP.

Other implications of results in Figs. 4–6 are several-fold. The concentration of grassland conversion on lands vulnerable to erosion implies negative impacts on soil quality and a subsequent cascade of negative impacts on, e.g., crop yields, primary productivity, and carbon sequestration (30). Tillage of adjacent uplands increases sediment inputs to PPR wetlands by several orders of magnitude (31), limiting the productivity of duck food sources, including aquatic plants and invertebrates, and reducing flood water storage (32). With respect to surface water hydrology, grassland conversion has been linked to historical increases in peak streamflows (and their variance) in the WCB, with a subsequent increase in flood risk (33). As noted earlier, the concentration of grassland conversion in Minnesota on lands characterized by excess wetness implies an increase in anthropogenic drainage, In Minnesota, extensive modification of presettlement drainage patterns has been shown to substantially modify stream geomorphology and increase sediment transport (34). Finally, the expansion of corn and soybean cultivation into less suitable climates and onto soils with lower water-holding capacities implies an elevated vulnerability to drought. Such vulnerability is exemplified by impacts of the unusually severe 2012 US drought. Here, negative vegetation anomalies were concentrated along the western periphery of the WCB whereas the core corn/soy region in southern Minnesota and northern Iowa exhibited positive vegetation anomalies (Fig. S2).

One shortcoming of the present study was our inability to use the NASS CDL to distinguish between different types of grassland conversion, i.e., to separate native prairie conversion from change involving CRP, hay lands, or grass pasture. Given the high conservation risk to temperate grasslands in the United States (9), we suggest that the NASS focus on improving their ability to identify native grasslands in the NASS CDL. There is a clear need to develop more effective approaches for grassland classification, and to apply these techniques for annual grassland monitoring in the WCB and other rapidly changing agricultural regions.

Broadly speaking, our results illustrate important heterogeneities in the geography of grassland conversion. With respect to biofuel development, the implications of such heterogeneity have generally been overlooked. For example, analyses of the effects of biofuel expansion typically simulate LCLUC by converting CRP lands to crop production (35, 36). Although such an approach may be reasonable in states like North Dakota, where CRP losses generally exceed grass-to-corn/soy change (Fig. 6*B*),

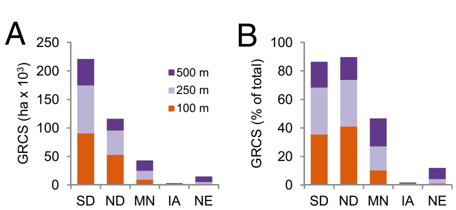

Fig. 5. Grassland conversion as a function of buffer distance around palustrine wetlands in the PPR. The source of wetland locations for this analysis was the National Wetlands Inventory (51). (*A*) Total area of grassland conversion by state within 100, 250, and 500 m of palustrine wetlands in the PPR. (*B*) Grassland conversion within wetland buffers as a percentage of the total amount of grassland conversion occurring in each state's portion of the PPR.

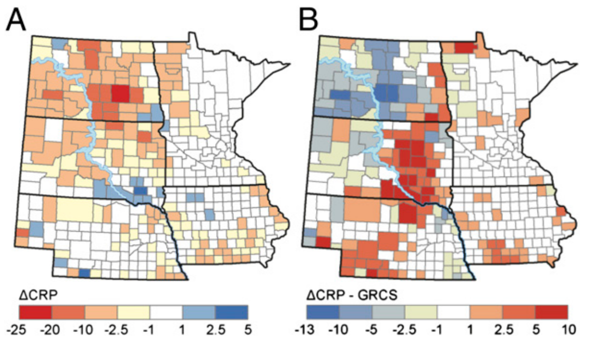

Fig. 6. Enrollment in the CRP relative to grassland conversion. (*A*) Change in land area enrolled in the CRP from 2006 to 2011 at the county level (in ha * 10^3). Negative values indicate a net loss in CRP area, positive values a net increase. Analysis based on county-level CRP data from the US Department of Agriculture (54). (*B*) Difference between CRP change and GRCS conversion. Negative values indicate counties in which CRP losses are greater than GRCS conversion. Positive values indicate counties in which GRCS conversion exceeds CRP losses.

this strategy would likely underestimate change in eastern South Dakota, where grassland conversion exceeds CRP losses. We also find that studies that simulate LCLUC as limited to marginal lands, e.g., land capability classes III or higher (5), may miss substantial grassland conversion occurring on higher quality class II lands (Fig. 4).

Conclusions

Our results show that rates of grassland conversion to corn/soy (1.0–5.4% annually) across a significant portion of the US Western Corn Belt are comparable to deforestation rates in Brazil, Malaysia, and Indonesia (37, 38), countries in which tropical forests were the principal sources of new agricultural land, globally, during the 1980s and 1990s (39). Historically, comparable grassland conversion rates have not been seen in the Corn Belt since the 1920s and 1930s (40), the era of rapid mechanization of US agriculture. Across the WCB, more than 99% of presettlement tallgrass prairie has been converted to other land covers, mostly agricultural, with losses in Iowa approaching 99.9% of an original 12-million ha of tallgrass prairie (10). Potential expansion of corn and soybean cultivation into remaining fragments of tallgrass prairie in the WCB presents a critical ecosystem conservation issue (9).

Under the most likely climate change scenario for the Northern Great Plains, a 3- to 4-°C increase in mean annual temperature offset by a 10% increase in mean annual precipitation, much of the wetland habitat in the PPR is projected to be lost (14, 16). High-quality waterfowl habitat most likely to persist under climate change is projected to be concentrated in South Dakota east of the Missouri River (14, 16). However, this is precisely where grassland conversion in close proximity to PPR wetlands is most prevalent (Fig. 5). LCLUC in eastern South Dakota poses a dual threat to what may be one of the most important climate-change refugia for North American waterfowl.

With respect to biofuel development, Tilman et al. (35) point to risks of the US biofuel industry developing down counterproductive pathways if public policy and economic incentives are not properly aligned with delivered benefits. A number of studies have now shown that a biofuel strategy based on corn ethanol and soy biodiesel may indeed be suboptimal in terms of net energy and carbon balances (5, 7, 36) and negative impacts on other ecosystem services (5, 41, 42). Our results show that the WCB is rapidly moving down the corn ethanol and soy biodiesel pathway, with an estimated net loss of ∼528,000 ha (1.3 million acres) of grassland from 2006 to 2011. Our methodology, which generated relatively high-resolution estimates of LCLUC rates (Fig. 2) over the most rapid (and important) period of biofuel expansion, might be uniquely suited as an input for estimating the direct greenhouse gas signature of a US biofuel industry based primarily on corn ethanol (cf. refs. 8, 36, 43–45).

Cellulosic biofuels produced from perennial feedstocks have a number of desirable attributes with respect to net energy and greenhouse gas balances (43–45) and wildlife conservation (5, 6). Many of these positive attributes could be realized in the WCB by planting perennial bioenergy crops (e.g., switchgrass, *Panicum virgatum*) or diverse prairie (44) on lands currently in corn and soybean cultivation. However, the carbon debt arising from grassland conversion is largely accrued during the conversion process and 2 to 3 y of tillage postconversion (7, 46). Even if recently converted grasslands were subsequently converted to perennial bioenergy crops, substantial carbon debts would still persist. With respect to conservation of biodiversity and wetlands, the maintenance of mixed-grass prairie as pasture, or possible harvest of mixed-grass prairie as a cellulosic biofuel feedstock, is clearly a preferable alternative to grassland conversion. However, the development of a cellulosic biofuel industry in the United States has been slow (47). The present study indicates that the window of opportunity for realizing benefits of perennial bioenergy crops may be closing in the WCB.

Methods

We assessed grassland conversion in the WCB over the period 2006 to 2011 by using the 2006 NASS CDL as a baseline and comparing it with the 2011 NASS CDL on a per-pixel basis. Grass-dominated land covers in the 2006 NASS CDL were combined in a generalized grassland class whereas corn and soybean pixels in the 2011 NASS CDL were merged in a general corn/soy class. We then identified pixels that changed from grassland in 2006 to corn/soy in 2011. In doing so, we found numerous very small patches of grassland conversion (Fig. S3*A*). We assumed that the vast majority of these small patches were erroneously identified as LCLUC as a result of classification errors. Presumed errors were filtered out by running a five-pixel by five-pixel majority filter across the raw change layer (see details in Fig. S3). The resulting majority-filtered change layer contained objects that clearly resembled corn or soybean fields in size and shape (Fig. S3*B*). To assess LCLUC in the opposite direction, we identified pixels that changed from corn/soy in 2006 to grassland in 2011. We then applied the same five-by-five majority filter to this raw change layer. Majority-filtered change layers were subsequently used in tabulating total areas of grassland to corn/soy change and corn/soy to grassland change summarized in Table 1.

Because of the small sizes and scattered distribution of change areas, it was difficult to visualize regional patterns of LCLUC at the original 56-m spatial resolution. As a result, we used spatial smoothing techniques to create a regional change surface that highlighted local hotspots of change. Related approaches are used in fields such as spatial epidemiology to generate stable estimate of disease rates (48) but have not been broadly applied in the field of land change science. In our smoothing approach, change pixels at 56-m spatial resolution were first aggregated to the percentage of change at 560-m resolution. This was done by taking 10-by-10 blocks of 56-m pixels (i.e., 100 pixel blocks) and summing the binary change within each block (Fig. S4*A*). Next we used a 2D kernel smoother to compute a smoothed estimate of percent change for each of the 560-m resolution pixels (Fig. S4*B*). A quartic kernel function was used to calculate moving averages across the study area at a bandwidth of 10 km. The same quartic kernel function was used to smooth percent change from corn/soy in 2006 to grassland in 2011. Finally, we generated a smoothed map of grassland cover in 2006 by aggregating grassland presence at 56-m resolution to percent grassland cover at 560-m resolution, and then smoothing this aggregated cover layer by using the same 10-km quartic kernel. This smoothed grassland cover layer was subsequently used as the denominator in generating a map of relative rates of grassland conversion.

In Iowa and North Dakota, we used annual NASS CDL land cover classifications over the period 2001 to 2011 to analyze longer-term trends in corn/soy and grassland land cover. These are the only states in the WCB in which such longer-term land use data are available. In each year, corn and soybean pixels were combined in a corn/soy class at 56-m resolution and then aggregated to percent corn/soy cover at 560-m resolution. Similarly, pixels falling in our generalized grassland class were aggregated to create annual maps of percent grassland cover at 560-m resolution. At each 560-m pixel, we then tested the 2001 to 2011 time series for presence of a monotonic trend by using the nonparametric Mann–Kendall trend test.

We evaluated the suitability for crop production on lands where grassland conversion is occurring using the Soil Survey Geographic Database [SSURGO (49)]. The majority-filtered grassland to corn/soy change layer (e.g., Fig. S3*B*) was overlaid on the SSURGO Non-Irrigated Capability Class-Dominant Condition layer (50) to extract the distribution of land capability classes within areas undergoing grassland conversion. The proximity of LCLUC to wetlands was evaluated with respect to palustrine wetlands identified by the National Wetlands Inventory [NWI (51)]. This analysis was confined to those parts of the WCB contained within the boundaries of the PPR (52). Buffer regions surrounding palustrine polygons mapped by the NWI were drawn at 100, 250, and 500 m distances. We then overlaid the majority-filtered grass to corn/soy change layer to determine the total area of grassland conversion occurring within those buffers.

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