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Does the Conversion of Grasslands to Row Crop Production in Semi-aridareas Threaten Global Food Supplies

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Does the conversion of grasslands to row crop production in semi-arid areas threaten global food supplies?[☆]

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ABSTRACT

In the world's semi-arid regions, high crop demands have produced short term economic incentives to convert food production on native grasslands to dryland row crop food production, while genetic enhancements and equipment have reduced the risk of crop failure. The objectives of this paper were to discuss (1) the importance of considering the long-term sustainability of changing land use in semi-arid regions; (2) the impact of extreme climatic events on ecosystem functioning; and (3) factors contributing to higher crop yields in semi-arid regions. Semi-arid regions contain fragile areas where extreme climate events may be a tipping point that converts an apparent sustainable system to a non-sustainable ecosystem. However, semi-arid regions also contain zones where "better" management practices have reduced the agricultural impacts on the environment, increased soil carbon levels, and stimulated economic development. Research suggests that food production can be increased by enhancing the productivity of existing cropped land. However, this statement does not infer that crop production on all existing cropped lands in semi-arid regions is sustainable. Worldwide, targeted research should be conducted to clearly identify local barriers to conservation practice adoption and identify the long-term ramifications of extreme climatic events and land-use changes on semi-arid ecosystem functioning.

1. Introduction

Over the last three hundred years, immigration from Europe and Asia to Africa, Australia, North America and South America resulted in half of the arable grasslands being converted to cropland (Goldewijk, 2001). Earliest grassland conversions occurred near forest margins (Coupland, 1979) and are typified by the near elimination of the North America tallgrass prairie (Samson and Knopf, 1994) and the Argentinean Pampas (Hannah et al., 1994). Until recently, arid and semi-arid grasslands, further from forest margins remained in natural vegetation (Hannah et al., 1994; Samson and Knopf, 1994). However, technology advances have provided the ability to convert these grasslands to row crop production (Braschler, 1983; Marsh, 2003; Aadland, 2004; NASS, 2013).

Semi-arid regions often have high climate variability, vegetation that is dominated by grasses and shrubs, and precipitation/potential evapotranspiration ratios that are greater than 0.2 and less than 0.5. The semi-arid regions of the United States Great Plains, Sub-Saharan Africa, Australia, and large portions of eastern and southern Africa, India, and Asia provide important habitat for numerous grazing animals, birds, insects, and livestock. Climate variability, which is projected to increase, complicates agricultural activities in these regions. For example, in the Turkana district in Kenya droughts can occur as often as every 5 years (Ellis, 1992), while in the Australia Murray–Darling River Basin drought occurs on average once every 10 years (Schwabe and Conner, 2012).

Globally the amount of semi-arid grasslands converted to croplands is unknown. However, at select locations the conversion rate has been reported. For example, in North Dakota, South Dakota, Nebraska, Iowa, and Minnesota alone Wright and Wimberly (2013) estimated that from 2006 to 2011 over 530,000 ha of grassland were converted to row crop production, while in South America, Vega et al. (2009) reported that in the Río de la Plata grasslands, 1.2 million ha of grasslands from 1986–1990 to 2002–2005 were converted to implanted forests or croplands. This conversion is driven by many factors including high grain prices (http://futures.

Abbreviations: NHC, Non-Harvested Carbon; SOC, Soil Organic Carbon

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tradingcharts.com/chart/CN/M), increasing global food demand (Tilman et al., 2011), the development of more drought resistant maize (*Zea mays*) cultivars (Chang et al., 2014), policy changes designed to produce economic development, and equipment improvements.

To provide a more sustainable local food supply individuals, communities, corporations, governments, and private foundations are supporting efforts that stimulate economic development in many of the world's semi-arid areas. However, the need for economic development and improved food production must be balanced with agricultural long-term sustainability and the services provided by grasslands. Tilman et al. (2011) states that, "Attainment of high yields on existing croplands of under-yielding nations is of great importance if global crop demand is to be met with minimal environmental impacts." Based on Tilman et al. (2011) we identified several key questions. First, can management and genetic improvements increase yields in the world's semi-arid regions? Second, can crops be sustainability produced in the world's semi-arid regions? The objectives of this paper were to discuss: (1) the importance of considering the long-term sustainability of changing land use in semi-arid regions; (2) the impact of extreme climatic events on ecosystem functioning; and (3) factors contributing to higher crop yields in semi-arid regions.

2. The importance of considering long-term sustainability

Erosion or salinization has degraded agricultural land productivity in historic and modern times. For example, in modern times, settlers of the United States Great Plains were granted land titles through the U.S Homestead Act of 1862. These settlers plowed the prairie, seeded wheat (*Triticum aestivum*), and controlled weeds during fallow years with a one-way plow, which pulverized the soil and increased the risk of erosion (Hansen and Libecap, 2004). The impact of these practices when combined with a multi-year drought resulted in the Dust Bowl that occurred during the 1930s.

Crop production in semi-arid regions has also been challenged by irrigation and dryland salinization. One of the first recorded problems of irrigation induced salinization occurred in the Fertile Crescent, between the Tigris and Euphrates rivers 3000–4000 years ago. Salinization occurs when more salts are added in the irrigation water than what is removed in the drainage water (http://archive.unu.edu/unupress/unupbooks/80858e/80858E04.htm). The impact of salinization was land abandonment, decreased food production, and a gradual decline of the Sumerian civilizations.

Dryland agriculture salinity problems result when water movement into groundwater is greater than outflow. Water imbalance causes the water table to rise, which transports subsurface salts to the surface soil. Salinity problems can result from a variety of management changes including: (1) the replacement of deep root shrubs by annual crops and/or, (2) switching from a moldboard plow (high evaporation) to a no-tillage system (low evaporation). For example, in Australia the removal of shrubs from backslopes resulted in a rising water table and a gradual increase in the salt concentration in footslope soils. Salinity is predicted to increase the amount of salt effected lands in Australia from 2.5 million - hectares in 1999 to 17 million hectares in 2050 (Merz et al., 2006).

Land use changes and sustainability

Local and global pressures are providing short term incentives to convert grasslands to dryland row crop production in semi-arid regions.

New technologies such as improved genetics, better planters, and improved rotations can reduce the risk of crop failure in semi-arid ecoregions.

Land use changes and sustainability

Caution must be used when promoting land use change because grasslands provide services that are difficult to quantify and extreme climate events may provide the trigger that converts an apparently sustainable system to a non-sustainable system.

Ecoregion stability can rapidly be degraded.

In many areas the adoption of conservation practices have been limited by barriers that are not clearly understood.

Food production on the world's fragile soils does not always reduce food security. For example, the Incan Empire on the Peruvian coast in South America improved sustainability (1) by domesticating many plants including maize, squash (*Cucurbita)*, and beans (*Phaseolus vulgaris*) which were then planted in complex rotations across landscapes; (2) by installing terraces that reduced erosion at highly erodible sites; and (3) by using waru waru (raised beds and water canals) to lengthen the growing season http://www.oas.org/dsd/publications/Unit/oea59e/ch27.htm). These technologies allowed the Incas to reduce erosion, reduce pest pressures, and reduce the risk of crop failure in some of the world's most challenging environments (Mamani-Pati et al., 2011).

A second example of improved food security occurred during the European middle ages (1500 to 700 years ago) when many farmers switched from a three year rotation, consisting of a cereal (oats, *Avena sativa*; rye, *Secale cereale*; wheat; and barley, *Hordeum volare*), a legume (peas, *Pisum sativum*; and beans), and fallow (Knox, 2004) to a 4 year rotation that included wheat, barley, turnips (*Brassica rapa*) and ryegrass (*Lolium multiflorum*) or clover (*Trifolium*). This change: (1) improved nutrient budgets, (2) increased the amount of land devoted to food production by 33%, (3) increased wheat and pulse yields 68 and 44% from 1750 to 1860, (4) increased stocking densities for milk cows, sheep, and swine 46, 25, and 43%, respectively; (5) powered the Industrial Revolution, (6) provided the food needed to grow the English population from 5.7 million in 1750 to 16.6 million people in 1850, and (7) provided the theoretical basis for the organic agricultural industry today (Broadberry et al., 2010).

3. Increasing yields on semi-arid croplands and reducing erosion

The development of the moldboard plow, tractors, disk-harrow, cultivators, and the one-way plow during the 18th, 19th, and 20th centuries provided the technology needed to convert grasslands to row crop production. In the United States Great Plains, these technologies pulverized soil, improved weed control, and produced economic development between 1880 and 1930. However, in 1930s a series of droughts resulted in crop failure and extensive erosion that eventually was called the Dust Bowl. The impact of tillage technologies on soil erosion can be staggering. For example, in Ethiopia soil loss rates as high as 290 Mg (ha year) were reported in grasslands that were converted to dryland crop production (Fowler and Rockstram, 2001). Tillage had similar impacts in Turkey where grassland conversion to crop production resulted in a 10.5% increase in bulk density, a 46.2% increase in soil erodibility, a 48.8% decrease in soil organic matter, and a 30.5% decrease in plant available water (Evrendilek et al., 2004).

Tillage produced similar impacts on erosion in the Northern Great Plains. However, research also showed that erosion can be reduced by adopting no-tillage. For example, Lindstrom et al. (1994) reported that in the Northern Great Plains the conversion of grass sod to a moldboard plow crop production system increased runoff

Table 1
The influence of year on land use and erosion in South Dakota, Nebraska, and North Dakota (modified from NRCS, 2007). Developed land has been permanently removed from the rural land base.

Year	Land use					Erosion		
	Developed ha × 1000	Rural ha × 1000	Cropland ha × 1000	Range ha × 1000	Pasture ha × 1000	Wind Mg/(ha y)	Sheet+rill Mg/(ha y)	Wind+sheet Mg/(ha y)
1982	370	18,050	8668	7850	785	8.9	7.2	16.1
1987	374	18,037	8712	7659	717	8.9	6.6	15.4
1992	384	18,004	8148	7590	702	6.9	5.4	12.4
1997	403	17,977	8256	7536	657	6.3	4.7	11.0
2002	410	17,961	8193	7585	660	7.2	4.8	12.0
2007	417	17,954	8130	7597	682	7.2	4.8	12.0

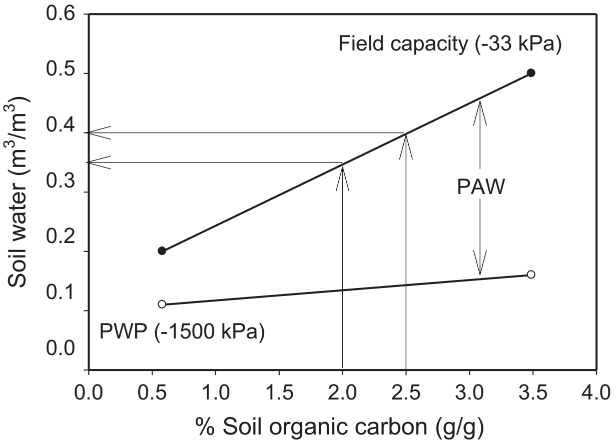

Fig. 1. Relationship between soil orgnaic carbon (SOC) and plant available water (modified from http://soils.usda.gov/sqi/assessment/files/available_water_capacity_sq_physical_indicator_sheet.pdf). In the chart, PWP is permanent wilting point and PAW is plant available water. Percent organic matter was converted to SOC by dividing soil organic matter by 1.72. Based on Clay et al. (2012). SOC was estimated to be approximately 2% in 1974 (100 × 38,000/188,000,000). A 24% increase would increase SOC to 2.48%.

Table 2
The impact of SD NASS region on no-tillage adoption and estimated increase in plant available water (Clay et al., 2012). The no-tillage estimates are based on 34,704 production surveys.

SD NASS	No-tillage			Water increase in the surface 15 cm			
region	2004–2007	2008–2010 % adoption	2004–2010	No-till cm	Con. till cm	SOC cm	Total cm
NC	97	69	85	4.42	0.39	0.61	5.42
C	68	57	63	3.28	0.96	0.61	4.85
NE	20	11	16	0.83	2.18	0.61	3.63
EC	11	5	8	0.42	2.39	0.61	3.42
SE	29	33	31	1.61	1.79	0.61	4.02
NW	40	ns	nc	2.08	1.56	0.61	4.25
SC	88	ns	nc	4.58	0.31	0.61	5.50
CW	82	ns	nc	4.26	0.47	0.61	5.34
Ave.	54	35	41				4.55

ns the sample did not contain adequate samples and nc is not calculated.

from 0 to 66% of a simulated rainfall. However, when the native sod was converted to a no-tillage dryland crop production system runoff was only marginally (0 to 3% of simulated rainfall) increased. Across a region, the impacts of conservation tillage on erosion can be substantial. For example, from 1982 to 2007 there was a 34, 23, and 20% decrease in wind, sheet, and rill erosion in South Dakota, Nebraska, and North Dakota, respectively (Table 1, NRCS, 2007). Additional benefits from conservation tillage adoption are increased C storage, increased plant available water and reduced water evaporation from the soil surface (Smika, 1983; Hatfield et al., 2000; Pryor, 2006; Su et al., 2007; Triplett and Dick, 2008; Salado-Navarro and Sinclair, 2009; Klocke et al., 2009; Baumhardt et al., 2010; Clay et al., 2012; Mitchell et al., 2012).

No-tillage is not uniformly adopted in world′s semi-arid regions. Adoption rates are high in the United States Great Plains and the Argentina and Brazilian grasslands, whereas adoption rates are low in Africa, Asia, and Europe (Frisvold et al., 2007; Givens et al., 2009; Clay et al., 2012; Hansen et al., 2012).

No-tillage induced increases in soil organic C (SOC) can produce many positive impacts on long-term sustainability. To demonstrate these effects, the impact of tillage on SOC and plant available water was calculated (Fig. 1; Cardwell, 1982). Over a 25 year period (1985 to 2010) a tillage change from moldboard plow to conservation tillage corresponded to a 24% increase in soil organic matter (Clay et al., 2012). Associated with the SOC increase was an increase in plant available water, which represents the maximum amount of water that plants can extracted from a soil, and it is the difference between the amount of water held at the permanent wilting point (-1500 kPa) and field capacity (-33 kPa). Based on Fig. 1, the 24% increase in SOC, from 1985 to 2010 should increase the surface soil plant available water 0.61 cm $\{15\ \text{cm} \times [(0.39-0.142)-(0.34-0.134)]\}$.

Reduced tillage systems also have lower water evaporation than conventional tillage systems. Based on Pryor (2006) a South Dakota water savings resulting from a tillage change was estimated with the equation, $\delta(\text{soil water, cm}) = 1.3\ (\text{cm/tillage pass}) \times (\delta \text{ in \# of tillage passes})$ (Table 2). Based on this equation, it was estimated that annual evaporation decreased 5.2–2.6 cm in the no-tillage and reduced tillage systems, respectively.

3.1. *Extreme climatic events impact on productivity*

Agricultural production has been challenged by extreme climatic events (droughts, flooding, frosts, and hurricanes), growing populations, the use on non-sustainable practices, habitat destruction, invasive species, and soil erosion since the agricultural revolution 10,000 years ago. The inability to mitigate these factors contributed to the failure of Greenland Norse, and the Maya and Anasazi civilizations (Diamond, 2005). Modern societies are not immune from this problem. For example, drought in Syria between 2006 and 2011 resulted in wide spread crop failures, which in turn resulted in the migration of farmers and ranchers from rural to urban areas, and eventually political unrest.

To assess the risk of extreme climatic events (drought) causing a modern crop failure the South Dakota crop yields of 1974 and 2012 were compared. From 1974 to 2012 the dominant tillage system in South Dakota changed from moldboard plow to conservation tillage and the maize hybrids changed from non-transgenic to transgenic with improved ability to withstand abiotic and biotic stresses (Clay et al., 2012). Under similar climatic conditions, South Dakota maize, soybeans, and wheat yields were 4.26, 0.671, and 1.84 Mg grain ha^{-1} higher in 2012 than 1974 (Tables 3 and 4). Based on the 2012 crop selling prices the net impact of higher maize, soybean, and wheat yields were $1183, 347, and 556 per hectare. Management impacts were calculated by multiplying water savings, discussed above, by the precipitation use efficiency (PUE) values [yield/(rainfall − changes in stored soil water)] for maize (Kim et al., 2008), soybeans (Monsanto Company, 2010), and wheat (Kharel et al., 2011). These calculations suggest that increases in plant available water derived from improved soil management could account for 22, 63, and 36% of the maize, soybean, and wheat yield increases from 1974 to 2012. These findings indicated that improved soil management had a 1.1 billion dollar impact on South Dakota's net agricultural returns in 2012. These calculations were based on semi-arid dryland agriculture having a positive relationship between crop yield and rainfall and that water savings can be converted to yield increases (Clay et al., 2003; Munodowafa, 2012; Guo et al., 2012). These yield increases were attributed to the implementation of locally-based adaptive management practices that leveraged genetic improvements with crop and soil management practices. We believe that similar results could be observed in semi-arid regions worldwide. These findings are conceptually in agreement with Norwood (1999).

The above discussion suggests that in semi-arid regions the long-term sustainability of dryland agriculture can be improved by adopting reduced tillage technologies. Unfortunately, no-tillage has not been uniformly adopted in semi-arid regions worldwide. Conservation tillage adoption is much lower Asia, Africa, and Europe than South America, North America, and Australia (Derpsch et al., 2010). The barriers to increasing the adoption of conservation tillage in areas with low adoption rates are numerous and in some locations they are based on societal beliefs. For example, many African communities view crop residues as community assets, and that the soil conservation structures, built by colonists as instruments of oppression (Fowler and Rockstram, 2001). Overcoming local barriers will likely require a paradigm change, and may result in the use of hedgerows or terraces to reduce runoff (Stroosnigder, 2009), providing low cost fertilizers and high quality seeds to increase yields, or promoting low technology solutions to problems (Sanchez, 2002, 2013). Other barriers to conservation tillage techniques are the lack of local knowledge, the lack of available equipment to test reduced tillage techniques, the lack of effective alternative techniques to control pests, and small farm sizes.

Table 3
A comparison between rainfall and corn, wheat and soybean yields in 1974 and 2012 (NASS, 1973, 1974, 2011, 2012; http://www.ncdc.noaa.gov/temp-and-precip/time-series/index.php?parameter=hdd&month=11&year=2012&filter=7&state=39&div=0). A Palmer Drought Severity of −2 is characterized as a moderate drought and a −4 value is extreme drought. The South Dakota heating degree days was calculated using a base 18.3 °C.

Year	SD Palmer drought Severity	SD heating degree day (°C)	Eastern SD rainfall (cm)	All wheat (kg/ha)	Soybean (kg/ha)	Corn (kg/ha)
1974	−2.18	1091	28.2	1234	1341	2065
2012	−3.35	1048	28.2	3071	2012	6321
2012–1974	–	–	0	1837	671	4256

3.2. Increasing extreme climatic events in semi-arid regions

Climate change is projected to complicate food production in the world's semi-arid regions, which already have high climate variability (Fig. 2; Molles et al., 1992; IPCC, 2008). Regardless of conservation tillage practice adoption, extreme climate events will likely provide the tipping point that converts an apparently sustainable system to a non-sustainable system. However, due to the lack of research funding this risk cannot be calculated (Chang et al., 2014).

4. Improved ability to manage abiotic and biotic stresses

The factors responsible for land use change are different in various parts of the world (Maitima et al., 2009). In Africa, the primary factor might be to convert local economies from subsistence agriculture to small businesses, while in South Dakota the goal might be to create jobs and produce economic development. Higher yield potentials in semi-arid regions can result in two outcomes. The first outcome is higher yields on current cropland which reduces the pressure to convert grasslands to crop production. The second outcome is higher profits which increases the economic incentives to covert grasslands to crop production.

Crop yield gains are being achieved through improved ability to manage abiotic and biotic stresses. For maize, yield increases have been derived from better genetics as well as improved soil health, matching genetics and plant populations to locations, reduced tillage intensity, and increased precipitation use efficiencies (PUE) (Duncan, 1954; Eck, 1984; Norwood, 1999; Fig. 3). The easiest way to increase PUE is to reduce evaporation through the adoption of no-tillage. However, the ability to convert water savings into greater yield is dependent on many factors including temperature, soil drainage, and location (DeFelice et al., 2006).

Higher PUE could also be related to improved stress tolerance (Gaskell and Pearce, 1983; O'Neill et al., 2004; Kim et al., 2008; Lorenz et al., 2010). Gaskell and Pearce (1983) reported that maize

Table 4
The impact of increased plant available water on net economic return for corn, soybean, and wheat grown in South Dakota in 2012 (NASS, 2012). The selling prices for maize, soybean, and wheat was $277/mg, $518/mg, and $302/mg, respectively. The precipitation use efficiency for maize, soybean, and wheat was 217 kg of grain (cm × ha)$^{-1}$, 95.1 (cm × ha)$^{-1}$, and 302 (cm × ha)$^{-1}$, respectively.

NASS	Water	Harvested			Total yield			$ return
Region	increase (cm)	maize (ha)	soybean (ha)	wheat (ha)	maize (ha)	soybean (mg)	wheat (mg)	due to management ($)
NC	5.42	487,647	450,011	137,593	573,541	231,955	114,846	314,079,090
C	4.85	348,435	240,384	145,930	366,710	110,873	108,995	192,165,957
NE	3.63	368,265	373,121	53,580	290,086	128,806	29,953	156,307,287
EC	3.42	403,836	397,402	5220	299,703	129,252	2750	150,989,862
SE	4.02	372,311	397,402	29,927	324,782	151,928	18,527	174,465,985
NW	4.25	81,625	2023	114,041	75,279	818	74,640	43,869,379
SC	5.50	73,936	34,317	99,229	88,243	17,950	84,047	59,185,895
WC	5.34	61,148	0	56,575	70,857	0	46,525	33,724,833
Total		2,197,204	1,894,660	642,095	2,089,201	771,581	480,282	1,124,788,289

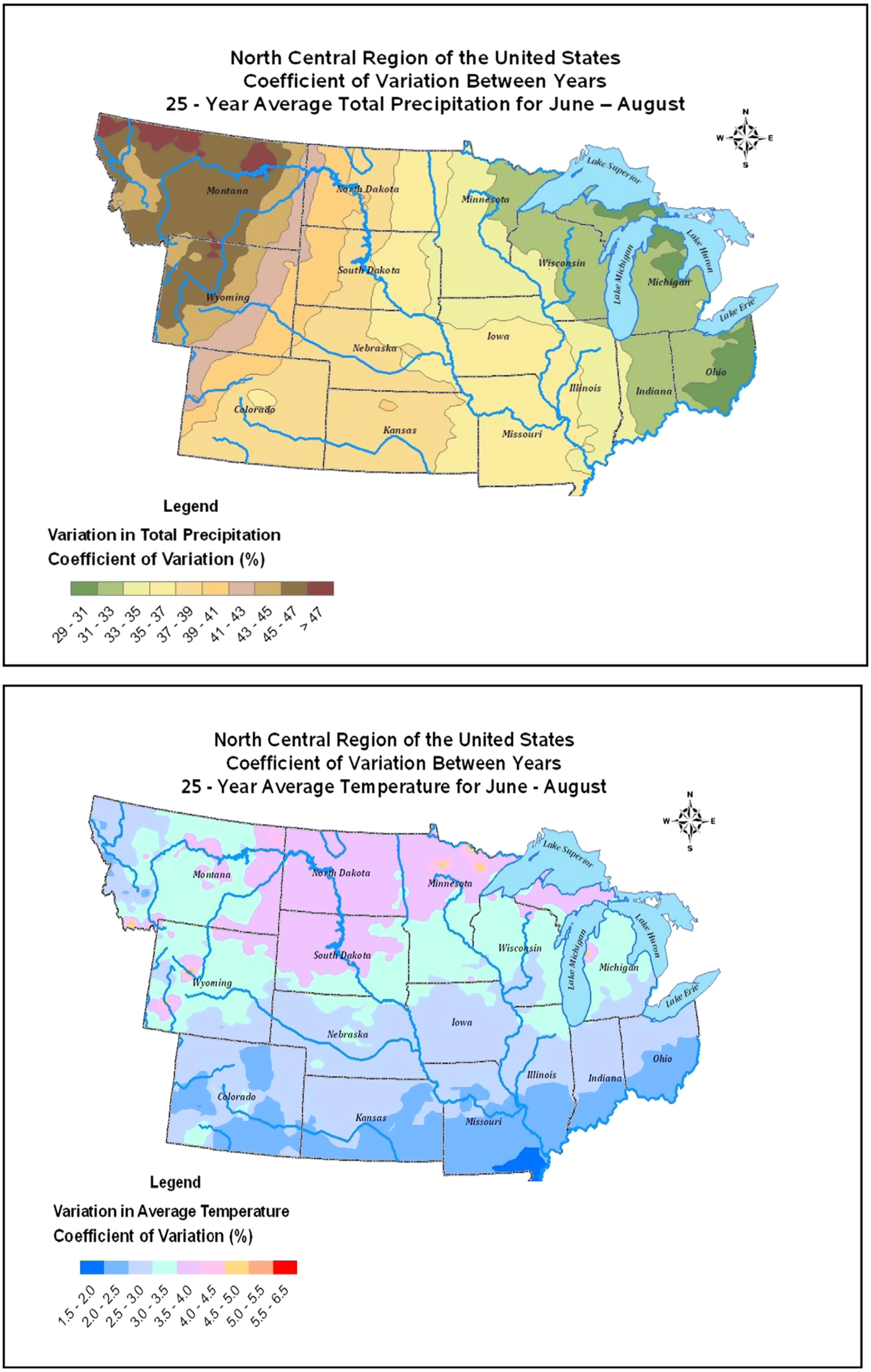

Fig. 2. The 25 year precipitation (a) and temperature (b) coefficient of variation for the north central region of the United States. These maps are based on data collected from 1640 weather stations between 1982 and 2006. The data source was the U.S.National Weather Service.

hybrids with relatively high CO_2 exchange capacity tend to have higher stomatal frequency and lower resistance (sec/cm). Hammer et al. (2009) suggested that PUE is influenced by root architecture while Lee and Tollenaar (2007) suggested that higher yields could be linked to more erect leaves, higher plant population, and the selection of leaves that stay green longer. Others have reported that modern maize hybrids have (1) higher photosystem II quantum efficiency (O'Neill et al., 2006), and (2) improved photosynthesis and reduced transpiration under water stressed conditions (Nissanka et al., 1997). Nissanka et al. (1997) also reported that (1) recovery from water stress was slower in the hybrid released in 1959 (Pride 5) than 1988 (Pioneer 3902); (2) CO_2 losses through respiration were less for the hybrid released in 1988, and (3) water use efficiency (CO_2 fixed/transpiration) was less for Pride

5 than Pioneer 3902 when exposed to water stress. Tollenaar and Wu (1999) attributed corn yield increases to increased leaf longevity, a more active root system and a higher assimilate supply to demand ratio during grain filling. There are a several studies that conducted side-by-side comparisons of maize plants released in different decades (Pioneer, 2009; Monsanto Company, 2011). These studies show that improvements in PUE are at least partially attributed to genetic improvements.

In many semi-arid regions, opportunities to increase yields through improved management exist. For example, in Africa subsidized fertilizers provided to small farmers increased yields 10% to 30% from 2005 to 2010 (Sanchez, 2013); while in the North America Great Plains precision nutrient, water, populations, pests, cover crops, and cultivar selection could reduce the gap between the crops genetic potential and achieved yield. In both systems, significant opportunities exist to increase yields (Fig. 4; Duvick and Cassman., 1999; Dobermann and Shapiro, 2004; Stewart et al., 2005; Kitchen et al., 2010; Bundy et al., 2011; Butzen, 2011; Midwest Cover Crop Council, 2012; Tremblay et al., 2012; Sanchez, 2013). Closing the gap between the crop genetic potential and achieved yield can increase food production without converting grasslands into crop production.

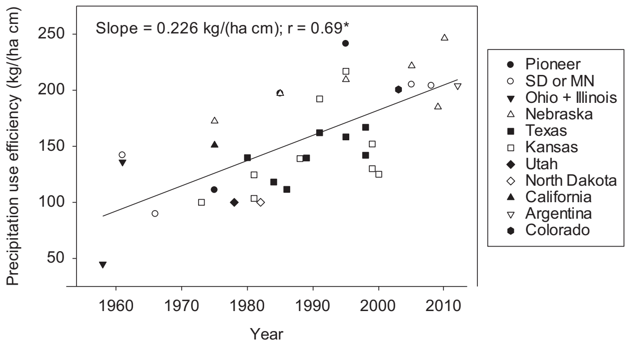

Fig. 3. Relationship between year of published research and maize precipitation use efficiency in studies conducted across the US Great Plains. PUE is equal to, grain yield/during the season rainfall – the change in stored water. Based on Dreibelbis and Harold (1958); Gard, et al. (1961) only no-irrigated treatments; Holt and Van Daren (1961); Timmons et al. (1966); Hillel and Guron (1973); Stewart et al. (1975); Hanks et al. (1978); Musick and Dusek (1980); Stegman (1982); Eck (1984); Unger (1986); Hattendorf et al. (1988); Howell et al. (1989, 1995, 1998); Steiner et al. (1991); Scheekloth et al. (1991); Lamm et al. (1995); Tolk et al. (1998); Trooien et al. (1999); Norwood (1999, years 92–95); Norwood (2000); Al-Kaisi and Yin (2003); Sharratt and McWilliams (2005); Kim et al. (2008); Payero et al. (2009); Monsanto Company (2010); Pioneer (2009) and Barbieri et al. (2012). Where possible dryland, fertilized, and seeded at an appropriate rate were selected for comparisons. Experiments were only included if they contained adequate measurements.

In the past, the adoption of precision systems was limited by barriers related to simplicity, economic returns, and time demands during critical periods. Fortunately, new precision farming implements, such as light bars, self-guided tractors, yield monitors, global positioning systems (GPS), remote sensing, computers and smart phones, and planters and fertilizer applicators with variable rate capacity are helping producers integrate new innovative technologies into their operation.

Improved techniques to diagnose yield limiting factors may also increase yields. The traditional approach to diagnose problems is based on visual interpretation or the chemical analysis of soil and plant samples. These technologies can result in large diagnosis errors, because the techniques don't account for interactions between abiotic and biotic stresses. For example, Hansen et al. (2013) reported that in response to water stress, maize down-expressed genes involved in wound recovery and nutrient uptake, which resulted in maize plants in water stressed areas having *P* concentrations that were less (1.9 g kg^{-1}) than the *P* critical level (2.2 g kg). The tissue sample suggests that that even though P fertilizer was applied, yields were limited by P availability.

New molecular biology techniques also provide an opportunity to improve light, water, and nutrient use efficiency. For example, Clay et al. (2009) used transcriptome analysis to assess how plant population affected light, water, and N utilization. They showed that modern maize hybrids, in response to increasing population pressure, reduced the expression of many genes associated with photosynthesis. The net result was shorter plants with a reduced per plant yield but a greater yield per hectare. Surprisingly, gene expression changes indicated that

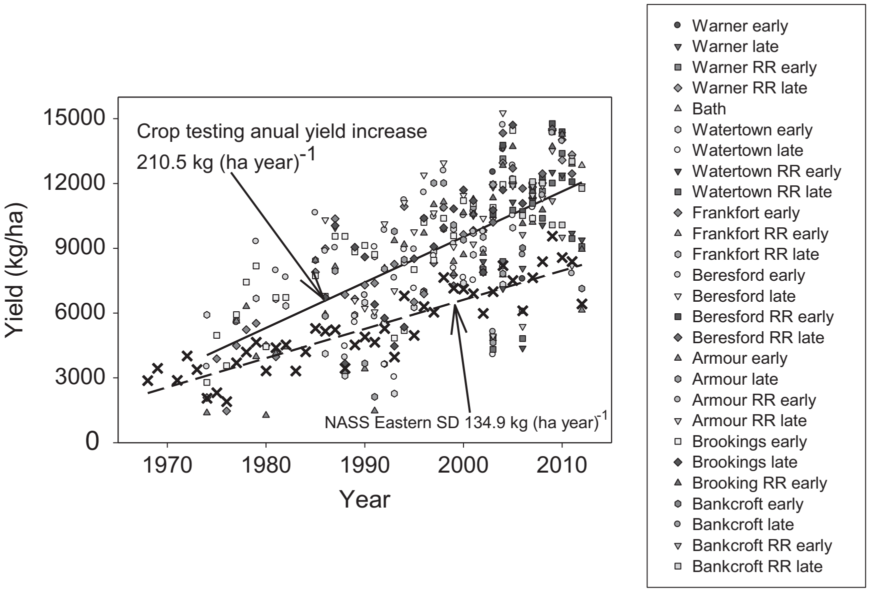

Fig. 4. Corn yields on the eastern side of South Dakota (NASS, 2000a, 2000b; NASS, 1995, 1996, 1997, 1998a, 1998b, 1999, 2000a, 2000b, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012) and the average annual yield increase from 1970 through 2012 in the South Dakota crop testing program, at various locations (Bonnemann, 1969, 1970, 1973, 1975, 1976, 1977, 1978, 1979, 1981, 1982, 1983, 1984, 1985, 1986; Hall and Bonnemann, 1989, 1990, 1992; Hall, 1993, 1994, 1995, 1996, 1997, 2000; Hall and Kirby, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2006; Hall et al., 1987, 1988, 2005, 2007, 2008, 2009, 2010, 2011, 2012a, 2012b, 2012c, 2012d). Differences between the two curves represent the widening yield gap. In 1974 and 2012, the crop testing yielded 31% and 46% more than the eastern side of the state average, respectively.

these modern maize varieties did not have the classic shade response (Horvath et al., 2007; Moriles et al., 2012), and suggest that success of the skip row maize seeding configurations (high population within a row) under water stress is the result of photosynthesis genes that were down expressed.

5. Summary

Over the last 30 year agricultural prices have increased and the U.S. total gross value/total costs ratio for maize, soybeans, and wheat were 1.24, 1.34, and 1.07, respectively in 2012 (http://www.ers.usda.gov/data-products/commodity-costs-and-returns.aspx). These economic opportunities when combined genetic enhancements and management improvements are providing the opportunity to convert grasslands to row crop production. However, grassland conversion to row crop production in semi-arid regions contains risk because there are many fragile areas where extreme climatic events can provide the tipping point that converts an apparently sustainable system to a non-sustainable system.

Research also shows that (1) better genetics and management practices have reduced the risk of crop failure, and (2) that food production in semi-arid region can be increased by enhancing the productivity of existing cropped land. However, this statement does not infer that crop production on all existing cropped lands in semi-arid regions is sustainable. Worldwide, targeted research should be conducted to clearly identify local barriers to conservation practice adoption and identify the long-term ramifications of land-use changes in semi-arid regions.

Increasing the sustainability in semi-arid regions may require several paradigm shifts that involve a change in focus from the use of no-tillage to the use of hedgerows or terraces to reduce runoff (Stroosnigder, 2009), providing low cost fertilizers and high quality seeds to increase yields (Sanchez, 2002, 2013), developing molecular assessment techniques that account for the up and down expression of genes associated with photosynthesis, wounding recovery, nutrient uptake, and disease resistance in response to water stress. It is important to consider that each problem is unique and requires the development of innovative solutions that matches management to the cultural and biophysical constraints.

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