Global Food Security 3 (2014) 22–30

Contents lists available at ScienceDirect

Global Food Security

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

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

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ARTICLE INFO

Article history:
Received 14 August 2013
Accepted 11 December 2013

Keywords:
Precision farming
Soil health
Cropping systems
Extreme climatic events

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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http://dx.doi.org/10.1016/j.gfs.2013.12.002

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.
- 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