The future of agriculture over the Ogallala Aquifer: Solutions to grow crops more efficiently with limited water

Bruno Basso¹, Anthony D. Kendall¹, and David W. Hyndman¹

¹Department of Geological Sciences, Michigan State University, East Lansing, Michigan, USA

Abstract We explore the unsustainable path that the Ogallala region faces, and provide some suggestions for policies that would extend the usable lifespan of the water in the aquifer, which supports the vast majority of the economy across this region. We emphasize the critical role of science as a foundation for policies that can help mitigate the disaster that is occurring across the region and provide insights because we believe that there are solutions to some aspects of this water crisis.

Summary In some areas of the HPA, farmers can no longer pump enough water for crops. Water-use efficiency and farmer’s profitability can be significantly enhanced by adopting site-specific agro-nomic management identified by coupling precision agricultural technologies with crop models. Policies grounded in science are critical to ensure long-term sustainability.

The Ogallala Aquifer is one of the largest water bodies in the United States. Large portions of the Ogallala-High Plains Aquifer (HPA), underlying approximately 450,000 km² of farm and range land stretching from Texas to South Dakota, are experiencing fundamentally unsustainable groundwater withdrawals due to large-scale irrigation. In some areas of Kansas and Texas, farmers can no longer pump sufficient water to meet crop demand due to aquifer depletion. If current withdrawal rates continue, such depletion will expand across extensive portions of the central and southern HPA during the next few decades.

The HPA provides water to grow more than $35 billion in crops each year. The region is dominated by agriculture (41%) and rangeland (56%), by virtue of productive soils and what was once thought to be an essentially inexhaustible water supply. However, since the 1950s, when high-volume pumping began, the HPA’s saturated volume has declined by approximately 500 km³ — roughly the volume of Lake Erie. Despite widespread rapid decline of the water table, which has depleted portions of the aquifer, irrigated acreage continues to expand (National Agricultural Statistics Service, Ag Census 2007 Quick Stats Tool, 2007, http://quickstats.nass.usda.gov). The expansion in water demand is being exacerbated by policies in the current Farm Bill that reward and even mandate growth in biofuels. These policy-backed incentives have contributed to higher corn prices [Pingali et al., 2008], spurring many farmers across the HPA to grow irrigated corn every year in a monoculture.

Agriculture could be sustainable across much of the HPA if crops are chosen for water requirements rather than for economic returns. However, farmers make crop selections based on a complex array of factors, driven primarily by economics. In this article, we address how broader adoption of research technologies such as crop modeling and precision agriculture can help identify best management practices to move this region toward sustainability given the current cropping systems, and advocate for policies that reward farmers for adopting soil and water conservation strategies.

Average groundwater recharge rates are highly variable across the region, with historical predevelopment estimates of less than 1 mm/yr in parts of Texas to more than 150 mm/yr in the Sandhills of Nebraska. This is driven by a strong climate gradient across the HPA with nearly three times the precipitation in the east relative to the west, and average temperatures that are 13°C warmer in the south, which results in much higher potential evapotranspiration rates. The total pumping for irrigation from the HPA exceeds estimates of average recharge by a factor of 2–7; thus, most of the region is clearly on an unsustainable path.

An exceptional drought began in the southern HPA in 2011, and since 2012 has spread across the region bringing issues of water management to the forefront. Although this recent drought has had significant...
impacts, it does not yet compare to the devastating and much longer droughts of the Dust Bowl or the 1950s. In the depths of the Dust Bowl, major shifts in land management began to be implemented by farmers, guided and incentivized by the newly formed Soil Conservation Service of the USDA (U.S. Department of Agriculture, Washington, D. C.). In the 1950s the region started to be less sensitive to droughts due to widespread use of irrigation from the underlying aquifer. A silver lining to the damage caused by the current drought would be to raise water management to the same level as soil management, and rather than simply having county offices focused on soil conservation, the USDA could expand their role to include water management assistance.

Climate change is expected to bring warmer temperatures and exacerbate existing precipitation and evapotranspiration gradients, increasing aridity in the southwest and humidity in the northeast [Intergovernmental Panel on Climate Change, 2007; Karl et al., 2009]. Despite the fertilization effects of increasing CO₂ concentration in the atmosphere, the projected temperature increase will ultimately cause yield declines owing to faster crop development, allowing less time for biomass accumulation. New drought-resistant cultivars are being developed to increase yields, but they will likely not give higher yield during optimal or wet years. In addition, drought-resistant cultivars do not reduce the demand for water by corn, but simply increase the likelihood of a small percentage increase in yield during dry years. Thus, it is a clear misperception that these cultivars will solve water limitation issues. Recent papers have suggested a drastic rethinking of agricultural strategies [Fedoroff et al., 2010], underscoring the importance of new cultivars through molecular breeding. Although this may be a valid path, genetics alone will not be sufficient, because the yield is a result of interaction among genetics × environment × management.

One of the main impediments to water conservation is the current policy associated with federal crop insurance. Such insurance currently requires a crop to be managed as either fully irrigated or as dryland. Full irrigation insurance mandates a certain amount of water application over the growing season, disallowing deficit irrigation approaches that could save significant amounts of water. The governor of Kansas recently asked the USDA to add a limited irrigation crop insurance option, and signed a law establishing Local Enhanced Management Areas (LEMAS) under which locally generated water plans with mandatory water-use reductions can be put forward to the State Engineer for approval.

One of the primary goals of water management for agriculture is to increase the amount of crop produced per drop of water. Clear evidence exists of improved transpiration efficiency (yield per unit of transpired water) over time for irrigated crops [Basso and Ritchie, 2012]. Opportunities for further enhancement largely involve decreasing soil water evaporation relative to plant transpiration using improved irrigation systems and new agronomic practices (e.g., variable rate irrigation). Planting crops with higher plant density increases yield and decreases soil water evaporation in favor of plant transpiration [Ritchie and Basso, 2008]. The efficiency of irrigation technologies has dramatically improved in recent years, moving from early spray systems that could lose as much as 30% of the water before it hits the ground, to recent drop-pipe systems that spray water below the canopy and lose almost none. Yet even efficient irrigation systems must be operated carefully, as excess water drains through the root zone thereby leaching nutrients from the soil, demanding additional fertilizer use, and impacting water quality in the recharged aquifer below.

Evidence of crop yield variations within fields and among seasons has been extensively reported [Basso et al., 2012]. New analysis clearly shows that growers have consistently high returns from some parts of the field but are not realizing full returns and are thus wasting money. New precision agriculture strategies combine Global Positioning System (GPS) technologies with site-specific management to apply the optimal amount of water and nutrients in space and time [Gebbers and Adamchuk, 2010]. Such methods are intuitively appealing, because they can translate into optimal management at the field scale. With advancement in technologies, precision agriculture is a reality and globally many farmers are adopting or considering it. Agronomic inputs including seeding rate, cultivars, pesticides, herbicides, fertilizers, and water can be applied in different quantities over space and time. The increase in yield from site-specific application brings multiple benefits, ranging from increased farmer profitability to improved environmental integrity by enhancing the natural and agricultural resource-use efficiency. The adoption of precision agriculture may still be considered expensive for some farmers, but its adoption would increase with policies that help pay for technical support or equipment upgrades.
Yield mapping using harvesters equipped with sophisticated sensors is one of the most important achievements of agronomic sciences and agricultural engineering over the past several decades [Pierce and Nowak, 1999]. These yield maps integrate all the factors that affect crop production and provide farmers with critical perspectives on the range of yield and the potential profitability of their land. However, the yield maps themselves do not provide management solutions. Analysis that integrates modeling, expert knowledge, and detailed field data is necessary for prescription of appropriate spatially variable rates. Providing knowledge to farmers who wish to adopt variable rate seeding has become an important marketing strategy for large seed companies. Policy makers can and should do more by leveraging Land Grant state university agricultural extension programs. These widely trusted institutions can disseminate information about interpretation of yield maps, and offer guidance for those who wish to incorporate crop model results and adopt precision agriculture technologies.

The current unsustainable water management strategies of the HPA and other similar regions call for a paradigm shift. In these regions, water-use efficiency and farmer’s profitability can be significantly enhanced by adopting site-specific management identified by coupling precision agricultural technologies with crop models [Basso and Ritchie, 2012]. Such models can also quantify the value of different management strategies including implementing water-saving technologies such as conservation tillage, optimizing rotations, planting dates, and potential new cultivars over space and time. These approaches would keep crop yields from plummeting in water-limited environments such as the HPA, but policies solidly grounded in science are critical to ensure long-term sustainability and environmental integrity for future generations.

References
Ritchie, J. T., and B. Basso (2008), Water use efficiency is not constant when crop water supply is adequate or fixed: The role of agronomic management, Eur. J. Agron., 28, 273–281.