Wind, Water, and Growing Season: Cropping System Selection Pressures in the Southern Great Plains

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Abstract
Successful cropping systems are a consequence of adapting cultural practices, crops, and cropping sequences to thrive both environmentally and economically under the unique selection pressures imposed by the soil resources and climatic conditions of a region. The southern Great Plains region comprises a physiographic region beginning south of the Arkansas River (southern Kansas and Colorado), east of the Rocky Mountain foothills (eastern New Mexico), west of the Miocene-Pliocene deposits in central Oklahoma (~97° W), and north of the Texas coastal prairies. The cropping systems used on the southern Great Plains have been adapted in a region where the annual wind speed averages 5.5 m s⁻¹, precipitation varies from >900 mm to <400 mm, water deficit (evaporation minus precipitation) increases from 750 mm to more than 1500 mm, and the frost free period increases from <180 days to approximately 300 days. That is, wind, water, and growing season length are the principal selection pressures acting on adaptable cropping systems. The adapted cropping sequences and rotations optimize crop use of precipitation with residue-retaining tillage practices that minimize soil losses to wind erosion and water losses as runoff or evaporation. Irrigation was introduced on the southern Great Plains to meet the water needs of more diverse crops, but the resulting cropping systems were less durable because of declining water tables. Growing season length may be the least flexible factor governing adapted cropping systems and often excludes production of late maturing crops from many parts of the region. Alternatively, where the southern Great Plains has an extended growing season and adequate precipitation multiple crops are possible. Future cropping systems are being adapted to integrate livestock and more intensive crop sequences, while retaining cultural practices that control soil erosion and increase water storage. The common paradigm for adapted cropping systems on the southern Great Plains must apply durable management solutions to the wind, water, and growing season selection pressures governing crop productivity.

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As with the rest of the Great Plains, mean annual precipitation amounts vary little from north to south; however, precipitation decreases along an east to west transect from approximately 900 mm near central Oklahoma to <400 mm in eastern New Mexico (Fig. 1). Although precipitation amount in the region is often marginal for crop production, more than one-half of
the precipitation occurs during the summer growing season as observed at Goodwell, OK and Amarillo, TX in the Oklahoma and Texas Panhandles. Where the southern Great Plains merges into the Texas coastal prairies near San Angelo, TX, a second September and October rain season results in a pronounced bi-modal or spring and fall precipitation pattern (Fig. 1).

![Figure 2](image)

Figure 2. Southern Great Plains precipitation increases from west to east, varies little north to south, and occurs primarily during the summer growing season in the north compared with a bimodal, May and September, pattern in the south where climate is more dramatically influenced by the Gulf of Mexico (after Baumhardt and Salinas-Garcia).

In contrast to precipitation, evaporation increases from 1800 mm in the east near central Oklahoma to more than 2600 mm in west Texas (Fig. 2). Evaporation follows this gradient because the dry downslope winds from the Rocky Mountains and southwesterly winds from the Coahuila desert that typically do not mix with the moist airstreams flowing northward from the Gulf of Mexico. The resulting water deficit, i.e., the difference in evaporation and precipitation, exceeds 1500 mm (Fig. 2) in the west and decreases below 750 mm in the eastern part of the southern Great Plains.

![Figure 3](image)

Figure 3. Mean cumulative annual pan evaporation and water-deficit (evaporation minus precipitation) plotted as contours for the southern Great Plains. Evaporation and water deficit increase from east to west (after Baumhardt and Salinas-Garcia).
The crops, cropping sequences, and tillage practices used in the southern Great Plains region are combined as cultural practices that permit economic survival and conserve on-farm resources under local environmental selection pressures. The principal selection pressures of wind, water, and growing season length will be related in this paper to the thriving cropping systems adapted to this region.

Cropping Systems Selection Pressures

Wind

The southern Great Plains was part of the extensive range inhabited by the North American bison (Bos bison) that was labeled the "Great American Desert" in 1820 by the early explorer, Stephen Long (Price and Rathjen, 1986). Euro-American settlement of this region may have been delayed by the perceptions of "Desert" life; however, the 1870's introduction of windmill pumps that stabilized domestic water supplies, consequently, promoted settlements away from surface water sources (Welborn, 2002). Cultivated land on the southern Great Plains also expanded rapidly to about 16 million hectares of annual wheat (Triticum aestivum L.) after the introduction of agricultural mechanization, increased demand for wheat by Europe during World War I, and above average precipitation from 1918-1929 (Hurt, 1981). Cultivation and cropping systems had been introduced from more humid regions and employed maximum tillage with inversion type plows to incorporate crop residues and prepare an "ideal" seedbed. The limited knowledge of the regional climate that included periodic, ~20 year, drought (Johnson and Davis, 1972), or recognition that the soil was formed from aeolian deposits did not prepare the farmers for matching their ill-suited cropping systems to the drought and winds of the 1930's. The over-cultivation and loss of vegetative cover due to grazing on the southern Great Plains exposed loose soil to the effects of drying winds and, ultimately, catastrophic soil erosion (Fig. 3) resulting in the 1930's "Dust Bowl." Aggressive research efforts then developed tillage and cropping systems that were adapted to prevent soil erosion.

Some of the developing soil erosion control practices included windbreaks and emergency tillage with the Graham-Hoeme chisel plow, which roughened the soil and produced aggregates too large to erode. Tree row windbreaks reduced both velocity and carrying capacity of eroding wind; conversely, trees competed for water and were difficult to establish, which handicapped their use in adapted cropping systems. The desired reduction of the surface wind velocity was eventually achieved using crop residues retained on the soil after tilling with newly developed, non-inverting, sweep-plow implements adapted from the Graham-Hoeme (Allen and Fenster, 1986). Annual wheat cropping systems that relied on timely fall rain for crop establishment were successful in the eastern part of the southern Great Plains, but did not consistently produce grain or adequate residue for soil protection under semiarid conditions to the west. Consequently, annual wheat cropping systems were adapted by integrating fallow periods into the crop sequence to increase precipitation storage as soil water for the subsequent wheat crop (Fig. 4). Production intensity was reduced from an annual wheat crop, albeit highly variable and usually low yielding, to a more dependable single wheat crop grown in alternate years.
Water
Although less dramatic than the billowing clouds of dust lifted from the soil by excessive winds, water availability for crop production poses the greatest selection pressure for adaptable cropping systems on the southern Great Plains. Precipitation frequency and amount is erratic (Jones et al., 1985), but generally adequate for limited dryland grain and forage (residue) yields. The annual wheat cropping system that was adapted, in the west, by adding a 14-month fallow period to permit storage of precipitation as soil water for crops in alternate years was further modified to include a summer crop. The principal benefit of this cropping sequence is that it increased cropping intensity to two crops in three years while utilizing the storage of precipitation as soil water during fallow periods preceding the planting of winter wheat and summer crops such as grain sorghum [Sorghum bicolor (L.) Moench] or cotton (Gossypium hirsutum L.). The wheat-sorghum-fallow, WSF, crop sequence...
(Fig. 5) is well adapted to the southern Great Plains and achieves a remarkably stable crop production output (Jones and Popham, 1997) largely because precipitation stored during fallow is available to meet crop water demands. In an effort to, again, increase cropping intensity, the WSF cropping system is being adapted to exploit the spring-summer rain patterns of the southern Great Plains to meet water demands for more modest production levels of annual summer crops. The shift from a WSF sequence to annual sorghum or sorghum cropped in rotation with cotton is conducted as an opportunity cropping system contingent on soil water storage and the prevailing growing conditions. This flexible cropping system permits a return to fallow as needed.

Successfully adapted cropping systems for the southern Great Plains usually integrate i) crop sequences with fallow periods spanning high rainfall months, ii) planted crops capable of producing residue for ground cover, and iii) tillage practices that reduce runoff or retain residue at the soil surface. For example, Jones and Stewart (1990) describe the use of small earthen dams formed periodically in a ridge-furrow tillage system or small basins created in the loosened soil behind a chisel shank known as furrow dikes (Fig. 6). Tillage formed basins delay rainstorm or irrigation runoff, allow the water to infiltrate, and increase the plant available soil water with few exceptions (Baumhardt et al., 1993). Alternatively, a progressive reduction in tillage from dust mulching in the 1920's toward no-tillage practices of the 1970's increased the fraction of fallow precipitation stored in the soil from approximately 20% to 50% (Greb, 1979). Typically, residue retaining management practices increase infiltration by intercepting raindrop impact (Baumhardt and Lascano, 1996) and reduce evaporation by, among other things, intercepting the radiant energy driving evaporation (Lascano and Baumhardt, 1996). Cropping systems adapted to reduce water losses to runoff and evaporation using no-tillage residue management have increased soil water storage and resulted in the significant dryland yield increases (Unger, 1978; 1984; Unger and Baumhardt, 1999). Adoption of improved residue management, such as no-tillage, for adapted cropping systems in the southern Great Plains has been delayed, regardless of potential increased dryland yields, because crop water demands were met through irrigation.

Improved dryland management practices offset the effects of periodic water stress conditions in all but the infrequent sustained droughts, which have a catastrophic impact on production. Williams and Bloomquist (1996) documented wide spread adoption of irrigation practices in southwestern Kansas in order to adapt cropping systems for the drought conditions during the mid-1950's. Additionally, irrigation elevated and stabilized yield of all crops and encouraged production of crops with greater water demands, e.g., soybean [Glycine max (L.) Merr.] and corn (Zea mays L.). Steadily improving irrigation technologies expanded irrigable land, increased delivery efficiency to approximately 95% for low energy precision application (LEPA) systems (Bordovsky and Lyle, 1996), and permitted more intense and diverse cropping systems. For example, sandy soils such as those found in the rolling plains of Texas and western Oklahoma, that were previously unsuitable for irrigation, have become very productive by adapting irrigation
into cropping systems. As a consequence of continued reliance on irrigation to augment rainfall; much of the irrigated land on the southern Great Plains now overlies a declining water table (Musick et al., 1990). The developing characteristic relationship between irrigation and water table depletion illustrates the need to return to more durable technologies when adapting cropping systems for this region.

Growing Season
Growing season duration, at least for summer crops, is largely governed by the number of frost free days and soil temperature. The southern Great Plains growing season increases from <180 days in the north to >300 days to the south (Fig. 7). The common frost free days, drawn as contour lines, reflect the effect of altitude and the temperature moderating effects of the Gulf of Mexico with its associated northerly flowing moist air. Many of the adapted cropping systems in this region appear along similar contours. For example, typical cotton production thrives in regions where the growing season exceeds 180 to 200 frost free days, which may be observed as far north as southeast Kansas, but not in the northwestern Texas or Oklahoma panhandles. In contrast, most cultivars of grain sorghum require fewer than 130 days to mature and can be grown throughout the southern Great Plains. Where water selection pressures are negated by irrigation, other rapidly maturing crops such as corn and soybean are substituted for sorghum in cropping systems.

The most adaptable cropping systems in use on the southern Great Plains usually take advantage of early maturing crops to obtain a broad planting or re-planting window-of-opportunity. For example, after widespread rain and hail damaged cotton seedlings in the Texas South Plains in 1992, shorter season grain sorghum and soybean (but not cotton) were successfully grown as “catch” crops because of the broad planting window. Where the number of frost free days and the precipitation plus irrigation is adequate to permit crop regrowth, early maturing crop yields may be increased through ratooning (successive harvest of forage or grain from the same crop). This practice is generally adapted to forage cropping systems and, occasionally, for grain production with sorghum. Contingent on obtaining adequate precipitation plus irrigation to meet crop water needs, some adapted cropping systems employ two planted crops such as cotton after corn to take advantage of the longer growing season to increase overall yield (Smart and Bradford, 1999). Corn grown in this cropping system also provides valuable residue for no-tillage management that increases the water available for cotton production.
Reintroducing Selection Pressures
Adaptable cropping systems on the southern Great Plains or any other region must compete within an aggressively contested world commodity market. In response to the almost volatile production and market opportunities, adapted crop sequences and/or rotations must meet dynamic production requirements with seamless integration of alternative crops and technologies. In contrast, the soil resource and wind, water, and length of growing season selection pressures that have governed the cropping systems best adapted for use on the southern Great Plains will not change significantly. Apparent reintroduction of a selection pressure may occur if adapted cropping systems rely on unavailable technologies.

Adapted cropping systems that have implemented finite technologies to achieve management solutions to crop management selection pressures may, eventually, become obsolete or impractical. For example, on the southern Great Plains water may be reintroduced as a selection pressure on adapted cropping systems because irrigation to meet crop water needs faces declining water tables (Nativ and Smith, 1987) and volatile fuel costs (Musick et al., 1990). These factors will eventually force a return to dryland crop production and total reliance on precipitation and stored soil water. Successfully adapted cropping systems utilize durable technologies that increase infiltration and storage of precipitation in the soil.

Research has identified many durable soil and water conservation practices for adapted cropping systems that effectively protect the soil and stabilize crop yields in response to wind and water selection pressures. These durable technologies implement residue management and fallow periods that are counter to practices for intensifying production, e.g., limited grazing of residues for forage. Where the effects of wind on erodible southern Great Plains soils are acute, potential solutions to soil erosion integrate residue-producing crops like wheat that is chemically terminated as a green fallow crop within an annual cotton production system (Fig. 8). The terminated-wheat-cotton (TWC) practice is an adapted cropping system that provides needed residue for timely protection of the soil during the spring high wind periods and permits desired annual cotton production, but it is not well suited to dryland production (Baumhardt and Lascano, 1999) and may not present a durable management practice. The TWC cropping system may be adapted to a cotton and wheat rotation with intervening fallow periods.

Conclusions
The lessons learned in adapting cropping systems for use in the southern Great Plains, thus far, apply knowledge of climate, soil resource, and an understanding of how these interact with the...
introduction of crop management practices. Past mistakes of introducing cropping systems without considering wind and water effects on the soil resource must be avoided while continuing to explore alternative crops or innovative sequences that fall beyond accepted wisdom. Conventionally grown fully irrigated cotton can require >200 frost free days to achieve optimal yields and traditional wisdom discourages production in the Texas panhandle. Cotton cropping systems have been adapted to achieve modest yield levels with fewer growing days, however, and expand production potential of this crop. Likewise, the “very innovative” wheat-cotton-fallow rotations with no-tillage residue management practices are becoming more common for use under dryland and limited irrigation conditions (Fig. 9).

Future efforts to adapt cropping systems must exploit resource compatibility and strengths. For instance, grazing practices are well suited to the southern Great Plains because they take advantage of a historical asset exemplified by extensive bison herds that roamed throughout the region (Fig. 10). Building on that strength, future cropping systems may integrate limited livestock grazing to intensify production of otherwise stable and well adapted cropping systems including grazed wheat in the wheat-sorghum-fallow sequence.

Ultimately, successful cropping systems on the southern Great Plains, and elsewhere, must be broadly adapted to permit dynamic resource allocation and use in response to both volatile commodity market and unpredictable climate conditions. Agricultural producers are seeking and adopting those cropping system strategies that are capable of rapid and significant commodity shifts. Future innovations in adapted cropping systems must offer this trait.

Figure 9. Newly adapted cropping system includes a cotton-winter wheat rotation using no-till residue management.

Figure 10. Future cropping system adapted for use on the southern Great Plains will recognize historical strengths such as grazing livestock.
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