doi:10.2489/jswc.71.2.44A

IDEAS & INNOVATIONS

Circles of live buffer strips in a center pivot to improve multiple ecosystem services and sustainability of irrigated agriculture in the southern Great Plains

Sangamesh V. Angadi, Prasanna H. Gowda, Herb W. Cutforth, and O. John Idowu

Life on Earth, including that of humans, depends entirely on ecosystem services. In spite of that, in the last 50 to 60 years, human activities have degraded ecosystems more rapidly than in any comparable time in human history (MEA 2005). This is happening at a time when the global population is rapidly increasing to reach nine billion and other drivers, like climate change, overexploitation and pollution of natural resources, and economic growth, are also increasing (Carpenter 2009). Therefore, innovative ideas are needed to improve ecosystem services while increasing food production.

Irrigation from the Ogallala Aquifer has converted the southern Great Plains (SGP) from a dust bowl to a highly productive agricultural region. Water from the aquifer is used to irrigate over 2.6 × 10^6 ha (6.5 × 10^6 ac) in the SGP and has supported a flourishing rural economy that includes large beef and dairy industries. The water level of the aquifer is gradually decreasing because extraction exceeds recharge. In extreme cases, the water level has declined up to 84 m (277 ft) below predevelopment levels (McGuire 2007). Because of overexploitation of the Ogallala Aquifer, 35% of the irrigated acreage is expected to be rainfed in a few decades (Scanlon et al. 2012). Considering overexploitation trends (McGuire 2007), most of the conversion will be in the SGP. Many groundwater districts are limiting water withdrawals. Declining irrigation well outputs are also limiting the cultivation of high water-utilizing crops on the entire irrigation pivot. As a result, in spite of farmers' efforts to join multiple wells to reduce the problem, partial pivots are becoming more and more common in the region.

Strong winds in the region lead to increased water loss by evapotranspiration, severe topsoil erosion, abrasion of seedlings, soil accumulation in roadside ditches, human health decline, and massive economic losses to agriculture and the public. Increasing frequency of dust storms in the region in recent times is bringing back memories of the Dust Bowl of the 1930s. In the SGP, more than 50% of irrigation water is lost by evaporation early in the growing season due to strong winds (Agam et al. 2012). Therefore production practices that reduce water loss by evapotranspiration and/or increase water additions to the soil profile are strongly encouraged. Tillage is used to increase soil surface roughness and mitigate wind damage. However, tillage reduces the amount of crop residue covering the soil surface thereby increasing the evaporative loss of surface soil moisture (Brun et al. 1986) as well as increasing the energy cost to producers. Some farmers plant into herbicide-terminated wheat (*Triticum aestivum* L.) to reduce wind damage, but growing wheat also uses water. Standing stubble from the previous crop will decrease wind speeds near the soil surface and provide a more positive microclimate for the crop growth (Cutforth et al. 2006). As well, standing wheat stubble will increase ponding of heavy rainfall or snowmelt and allow more time for infiltration of water that would otherwise be lost by runoff or evaporation. However, without proper management, practices such as grazing reduce the amount of stubble left in the field; this increases evaporation water loss and decreases protection of the soil and seedlings in the spring. While much is known about the effect of abiotic stressors like water and temperature on crop growth, very little is known about wind stress.

Precipitation in the SGP is characterized as low, and distribution is unpredictable and of high intensity. The severity of these characteristics is expected to increase under the future climate. Therefore, conserving limited precipitation and increasing water use efficiency will greatly improve the sustainability of agriculture in the region. In spite of extremely dry soil profiles, most of the rainfall from high-intensity events runs off the field. Even for center pivot irrigation, surface runoff of irrigation water is common and has forced farmers to irrigate with smaller amounts of water more frequently. Low organic matter content, poor soil structure, and lack of ground cover have resulted in poor infiltration rates, which reduce the amount of water entering the soil profile and increase runoff. Farmers cultivate their field with deep ripper shanks to increase infiltration of water. However, this practice increases energy cost and loses water that is already in the profile. In addition, rainfall impact seals these openings in one or two rains. As a result, the region is prone for severe wind as well as water erosion (USDA NRCS 2010). Systems that increase ponding, similar to standing wheat stubble, or systems that improve soil organic matter content and soil structure can improve water conservation in the region.

A typical quarter section center pivot is a circle of 50 ha (125 ac) that is surrounded by nonirrigated corners and roads. The pivot wets a small piece of land with frequent irrigation applications (sometimes every three to four days) of small quantities of water to keep crops stress free. Compared to pivot irrigation, rainfall events in a semiarid region occur much less frequently, with much larger amounts over a much larger area. Because of these conditions, atmospheric cooling occurs over the entire area. As a result, evaporation losses are reduced, and a larger fraction of water may be used for crop productivity. For pivot irrigation, atmospheric cooling over the pivot area is negligible. Frequent irrigation also keeps the soil surface wet resulting in higher evaporation losses. The first stage of evaporation from wet soil is energy limited (Burt et al. 2005). This energy is obtained from abundant sunlight and from advected energy as wind blows

Sangamesh V. Angadi is an associate professor in the Department of Plant and Environmental Sciences and Agricultural Science Center at Clovis, New Mexico State University, Clovis, New Mexico. **Prasanna H. Gowda** is a research ecologist in the USDA Agricultural Research Service Grazinglands Research Laboratory, El Reno, Oklahoma. **Herb W. Cutforth** is an agricultural meteorologist in the Swift Current Research and Development Centre, Agriculture and Agri-Food Canada, Swift Current, Saskatchewan, Canada. **O. John Idowu** is an associate professor in the Department of Extension Plant Science, New Mexico State University, Las Cruces, New Mexico.

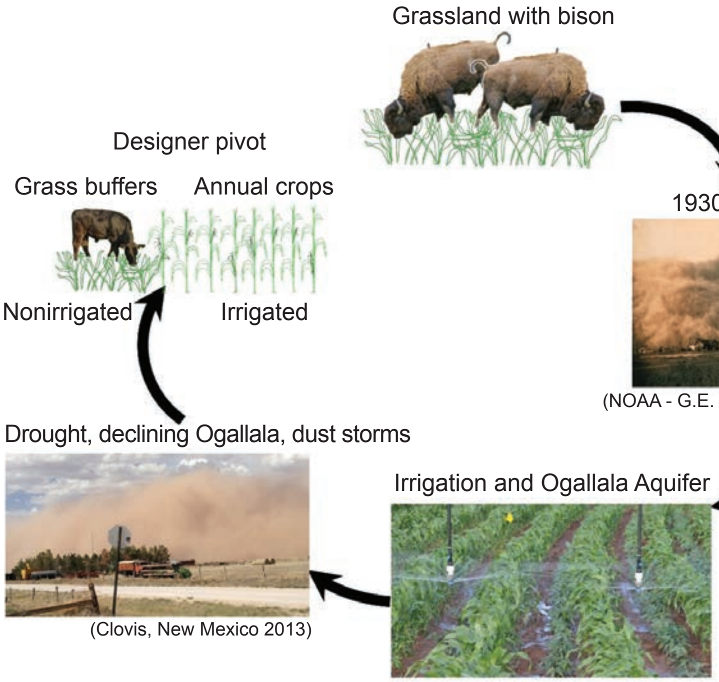
Copyright © 2016 Soil and Water Conservation Society. All rights reserved.
Journal of Soil and Water Conservation 71(2):44A-49A www.swcs.org

over the warmer, drier surroundings. As a result, a center pivot irrigated field can act as a hotspot for evaporation. Therefore, research specifically addressing wind moderation issues in a center pivot system is urgently needed.

The Great Plains was a tall- and shortgrass prairie before immigrants moved into the region to develop agriculture (figure 1). Large herds of bison grazed these grasslands. The system was sustainable, with grass conserving limited but high-intensity rains; protecting soil resources; and providing multiple ecosystem services, including wildlife refuge. The settlers who first ploughed the semiarid Great Plains experienced the damaging effect of wind in their annual cropping systems (Tatarko et al. 2013). Intensive cultivation and drought led to the Dust Bowl of 1930s (Zobeck et al. 2006). Conservation tillage and irrigation from the Ogallala Aquifer protected the soil and reduced wind damage for a time. However, reduced well outputs and recent droughts have resulted in regional dust storms (Bayeye et al. 2011). Therefore, reintroducing a tall prairie grass mix in strips alternated with strips of annual crops provides one significant, relatively cheap solution to a potentially massive problem. Partial pivots can be rearranged into innovative circular buffer strips of perennial grasses for improving many ecosystems services of irrigated agriculture (figure 2). Instead of a single row of shelter belts, this rearrangement allows for multiple circles of buffer strips spaced using aerodynamic principles. The novel circular design can contribute to improved productivity, profitability, natural resource conservation, and quality of life—all four pillars of sustainability (NRC 2010).

Figure 1

Timeline of agricultural changes in the southern Great Plains since the arrival of immigrants. Introduction of perennial grass buffer strips along with annual crops is similar to contour strip cropping, practiced in many rainfed cropping areas to reduce water erosion and pollution control. The system initiates a new era of thinking in cropping system research.



BENEFITS OF CIRCULAR BUFFER STRIPS

Concentric rings of perennial grass buffer strips offer multiple benefits. Each component of the system including perennial grasses, buffer strips, the circular design, and multiple buffers will contribute to the benefits (table 1).

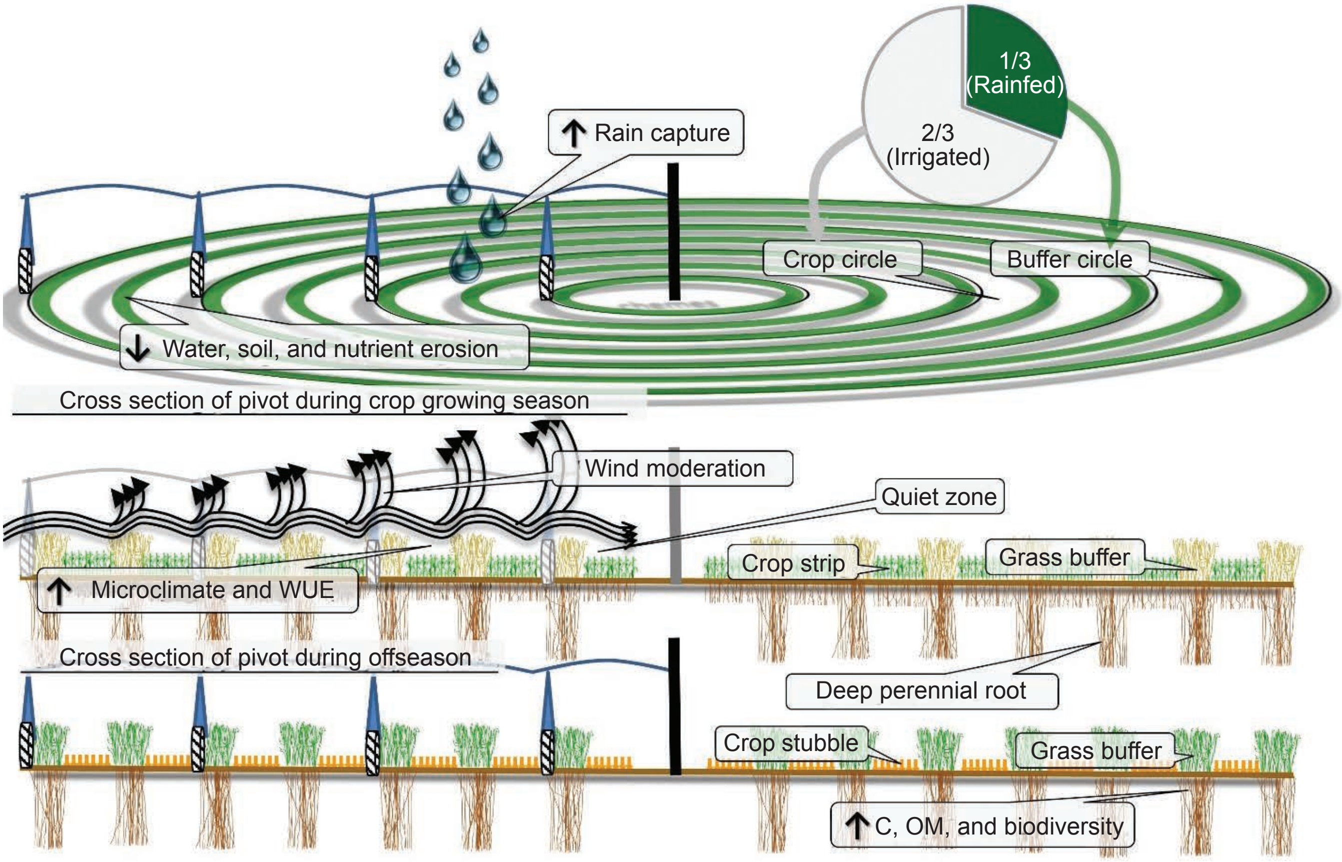
Direct benefits of perennial grasses (MEA 2005) will be mostly confined to the portion of the pivot planted with a grass mixture. For example, the one-third of the partial pivot shown in figure 2 sown to grass will get a perennial grass benefit while the annual crop area will not get those benefits with some exceptions (e.g., biodiversity benefit may be realized by crop area also). Compared to annual crop production, perennial grasses reduce erosion, sequester more carbon (C), use less energy, reduce inputs (water, fertilizer, and other agrochemical inputs), reduce pollution, provide greater access to resources (sunlight, carbon dioxide [CO$_2$], etc.) over longer periods of time, improve system resiliency, and improve system resource use efficiency (MEA 2005; NRC 2010). When an agriculture resource, whether a nutrient or an agrochemical, is retained on the farm, resource use efficiency is improved; if it leaves the farm, pollution results. Introducing perennial crops into annual cropping systems will increase belowground C sequestration, organic matter content, and soil quality (Glover et al. 2010). The deep roots of perennial grasses can increase infiltration rate and soil water holding capacity. Further, grasses can increase ponding time by slowing water runoff from high-intensity rain events thereby increasing infiltration rate and increasing soil water reserves at the deeper rooting depths. Perennial grasses can also act as a nitrogen (N) sink and reduce greenhouse gas emissions (Mitchell et al. 2015; Iqbal et al. 2015).

If the grass is planted in a straight line as buffer or wind barrier strips, it will add a number of benefits (table 1). Extent of benefit will vary based on height, porosity, and thickness of the grass strip. For example, a 1.5 m (5 ft) tall grass buffer strip can reduce wind speed or protect seedlings to distances more than 15 m (50 ft) from the buffer (Brandle et al. 2004). The buffer also needs to be perpendicular to the wind direction or the runoff slope to realize the maximum benefits. Benefits of buffer strips include improved microclimate, water conservation, and soil protection, which improve growing conditions (Bang et al. 2010; Cleugh et al. 1998) and increase crop yield (Senaviratne et al. 2012). Wind barrier research under irrigated conditions is limited. A New Zealand study reported 10%

Copyright © 2016 Soil and Water Conservation Society. All rights reserved.
Journal of Soil and Water Conservation 71(2):44A-49A www.swcs.org

Figure 2

Rearranging the unirrigated portion of a partial pivot into circular buffer strips (top). The example here is a partial pivot with one-third of the area not irrigated. During the crop growing season (middle) the grass buffer strips offer some benefits. Once the crop is harvested, the grass protects the soil in early spring (bottom).



to 20% reduction in water use with windbreaks under irrigated conditions (de Vries et al. 2010). There is a need to understand how windbreaks affect water use and water use efficiency under center pivot irrigation systems in the semiarid SGP.

Converting buffer strips into a circular design will add or improve benefits as well. The circle will filter anything leaving or entering the system and will be perpendicular to wind direction all the time. Thus it will realize most of the benefits regardless of wind direction or slope. Similarly, planting grass or tree buffer strips on contours or across the slope to minimize water erosion have shown promise (Senaviratne et al. 2012). When the direction of the resource or pollutant movement is known, building a barrier across it will reduce the loss of that resource or pollutant. Wind direction at any one place is not constant (e.g., the Clovis wind direction shown in figure 3). However, the area of benefit is still limited to 10 to 15 times the height of the buffer.

Laying out perennial grasses as multiple rings of buffer strips (figure 2) will further enhance the benefits listed in table 1. Assuming 9 m (30 ft) wide grass buffer strips (2 swath width) work well with both aerodynamic principles and farm implement widths, alternate grass buffer (9 m or 30 ft) and crop (18 m or 60 ft) strips result in approximately 14 circular grass buffer strips in a typical quarter section center pivot. Thus, each buffer strip has to moderate wind speed over a crop strip that is 60 ft wide; this is much easier than covering the entire pivot with a tall tree shelter belt on the outer edge. In addition, the grass mixture offers many other benefits listed in the "Multiple circles" column of table 1. Other combinations of circular grass buffer and crop strips can be explored to meet a farmer's needs once a basic understanding of one combination is determined—hence the conversion of the one-third to two-thirds partial pivot to a circular buffer strips arrangement.

FEASIBILITY OF CIRCULAR BUFFER STRIPS

Circular buffer strips of perennial grasses alternated with circular annual crop strips planted within a center pivot was only recently possible. To make this configuration possible, two changes to irrigated agriculture occurred: (1) the increased adoption of center pivot irrigation systems in the Ogallala Aquifer region, especially in the southern part; and (2) planting crops in a circular direction in a center pivot. Increased use of real time kinematic global positioning systems (RTK-GPS) in agriculture has made circular planting very easy. Since it was not possible to plant alternate strips of perennial grass buffer strips and annual crop strips in a flood irrigated field a few decades back,

Copyright © 2016 Soil and Water Conservation Society. All rights reserved.
Journal of Soil and Water Conservation 71(2):44A-49A www.swcs.org

Table 1

Contribution or improvement from each aspect of circles of perennial grass buffer strips in a center pivot irrigation system to sustainability of irrigated crop production in the southern Great Plains.

Contribution/improvements from			
Perennial grass	**Buffer/wind barrier strip**	**Circular design**	**Multiple circles**
↑ Net primary productivity	↓ Wind speed	Protection from wind from any direction	More pivot area will benefit from ↓ wind protection
↑ Resource capture and duration of capture	↓ Evaporation and runoff	↑ Rain and snow capture (increased ponding)	Multiple barriers may separate turbulent wind from quiet zone
↑ Carbon sequestration	↓ Pollution	↓ Evaporation and runoff	With multiple barriers, shorter height (≈ 1.5 m) grass is enough to realize all benefits
↑ Soil quality	↓ Soil and water erosion	Barrier ring traps water, snow, nutrients, chemicals, soil, etc. moving in any direction	Multiple barrier rings ↑efficiency trapping water, snow, nutrients, chemicals, soil moving in any direction
Deeper rooting and uses most of the soil profile	↑ Rain and snow capture	↑ Crop microclimate and growth	↓ Evaporation and ↑ water use efficiency
↑ Infiltration and water holding capacity	↑ Crop microclimate	↑ Seedling protection	↑ Crop microclimate and lower vapor pressure deficit
↓ Input requirement	↑ Seedling protection	↑ Water/resource use efficiency	↑ Seedling protection over larger area
↓ Soil and water erosion	↑ Air quality	↑ Air quality	↓ Saltation and soil erosion, and ↑ air quality
↓ Greenhouse gas emission		↓ Soil and water erosion	↓ Pollution and greenhouse gas emission
↑ Biodiversity and wildlife		↓ Pollution	↓ Energy, carbon, nitrogen, and water footprints
			↑ Biodiversity and wildlife

Note: ↑ indicates increase or improvement, while ↓ indicates decrease.

no research information exists on it. The first mention of the benefits of a circular design to reduce wind damage from winds in any direction was by Ticknor (1988). The accuracy of the RTK-GPS guidance system coupled with auto-steer has made circular strip planting feasible. Further, RTK-GPS guided auto-steer coupled with a geo-coordinated spatial map of the field enables a tractor or other motorized equipment to access any part of the field day or night. Once a geo-coordinated spatial map of the field is developed, it can be stored in the GPS computer and used for multiple years and for multiple purposes including planting, application of nutrients and pesticides, and harvesting. There are also cost effective ways of turning nozzles on and off so as to irrigate the crop strips and grass strips with different or varying amounts of water. Unlike tree shelter belts, grass buffer strips can be harvested and allowed to regrow depending on the farmer's needs.

In addition, circular perennial grass strips ideally fit with the seasonal weather pattern of SGP (figure 3). Early in the spring, high-speed windy days are more common in the region and majority of pivot-irrigated circles are bare, with hardly any stubble covering the ground at that time. Wind erosion and seedling damage by sand blasting are serious concerns. Occasionally, there are early spring blizzards, and pivots are not in a shape to trap the snow for moisture. Thus, multiple rings of perennial grasses protect soil and seedlings from wind damage and capture snow/rainfall to increase water reserves for the crop to use later in the growing season. In addition, perennial grass will start using solar radiation as soon as temperature warms up for plant growth. Wind moderation also contributes to the improvement of the microclimate for the stimulation of rapid seedling growth early in the spring.

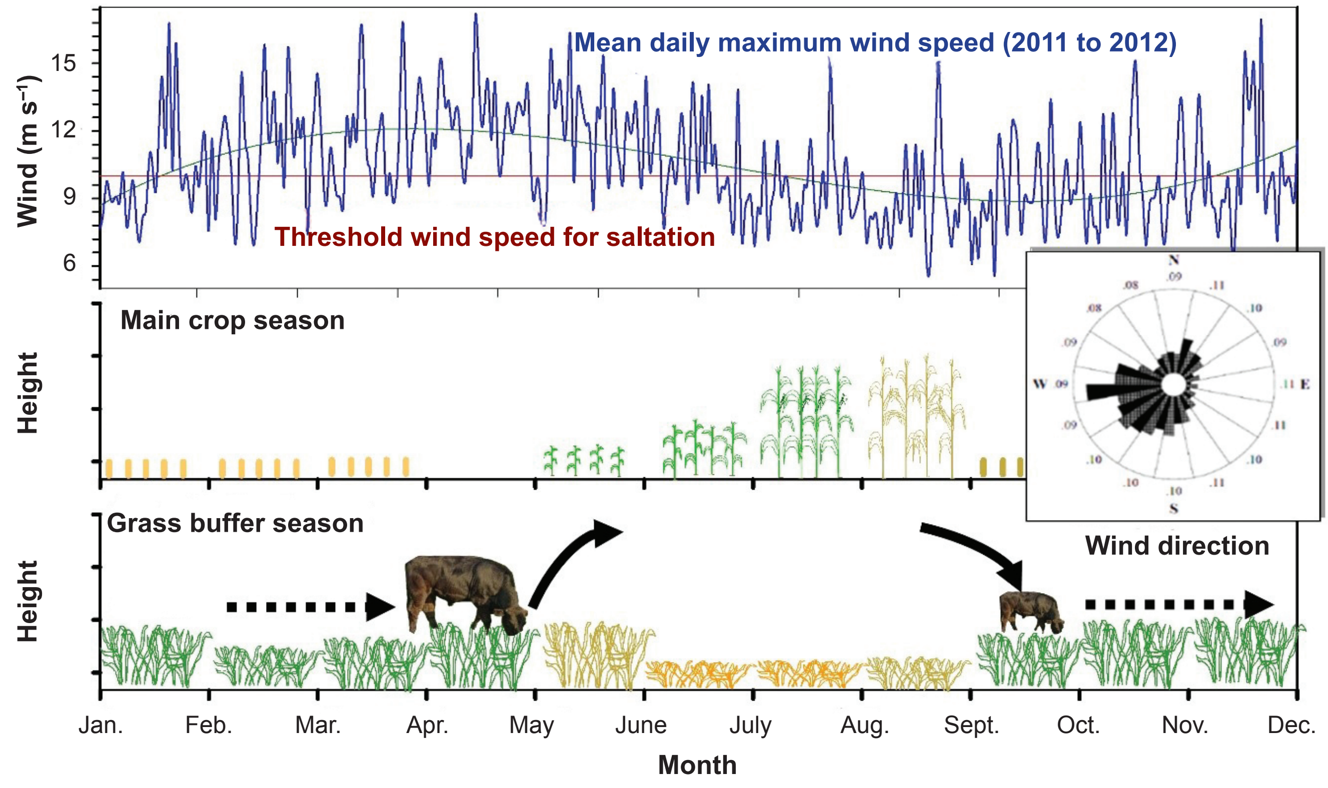
CHALLENGES FOR ADOPTION

Planting in circles in a center pivot system is a common practice in the region. However, planting annual and perennial crops in alternating circular strips necessitates additional management skills. Crop management would include choosing the perennial grass types that offer all benefits, but are not excessively competitive with the main crop. To design circular buffer strips, the plan should take into account aerodynamic principles to maximize the benefits, and it should also consider widths of major equipment (planting and harvest) of the farmer to decide width of grass or crop strips as the multiple passes of this equipment. There will be some additional adjustments and costs involved in using circular buffer systems. Sprayers and center pivots should have the capability of turning various nozzles on or off. These controls can be low-cost manual shutoff valves or more expensive solenoids controlled by electronic switches. Shutting off part of the center pivot nozzles will help in reducing the pressure problems associated with lower well outputs. If aerial spray is used, it has to spray the entire circle. Even in partial pivots, it is very difficult to avoid small area by the spray plane. However, if grass buffers act as barriers for pest entry and spread, spraying only outer strips with a tractor driven on the pivot road can save lots chemicals and fuel, and will be environmentally friendly. Wheel tracks in the grass strips will help alleviate the pivots getting stuck in mud.

Copyright © 2016 Soil and Water Conservation Society. All rights reserved.
Journal of Soil and Water Conservation 71(2):44A-49A www.swcs.org

Figure 3

Typical daily maximum wind speed (m s⁻¹) in the southern Great Plains is presented using 2011 and 2012 data from Agricultural Science Center at Clovis, New Mexico. The horizontal line (in red) represents the threshold speed required for wind erosion (Stout 2012). Annual wind direction (black) at Clovis in 2012 is presented in the inset. In general, buffer strips will have greater role to play early in the spring (before and immediately after planting). The bottom two pictures show corn and grass growth stages in different months. The grass buffer will not receive any water when corn is growing and will be cut for hay after corn is well established. Grass can be grazed for a few months in the winter and allowed to regrow before corn is planted



LONG-TERM BENEFITS TO AGRICULTURE

Circular grass buffer strips ideally fit the future farming strategy proposed by the National Academies of Sciences committee for long-term sustainability of agriculture (NRC 2010) because benefits cover all four aspects: productivity, environmental quality, profitability, and quality of life. The system improves the water cycle of a center pivot by capturing most of the rainfall and snowfall, reducing evaporation and runoff losses, utilizing water during the off season, and increasing water use efficiency. It will improve the resiliency of the system under a more variable future climate. It improves resource capture and thus improves resource use efficiency and net primary productivity while reducing nonpoint source pollution. Adding a mixture of perennial grasses will increase food and shelter available for both aboveground and belowground life. Beneficial insects, microbes, or animals harbored by grass strips extend benefits to crop strips. Compared to most annual crops, deeper rooted perennial grasses utilize the soil profile to greater depths, capture more C, reduce greenhouse gas emissions, and improve soil quality. Being less amenable to no-till farming, irrigated pivots contribute significantly to dust storms and air-quality reduction. Circular buffer strips significantly reduce those problems. Thus, circular buffer strips will develop into a new system that offers more ecosystem services and is more sustainable under future climate than the current practices. Many of the benefits will increase with the length of time the system is in place or implemented.

REFERENCES

Agam, N., S.R. Evett, J.A. Tolk, W.P. Kustas, P.D. Colaizzi, J.G. Alfieri, L.G. McKee, K.S. Copeland, T.A. Howell, and J.L. Chavez. 2012. Evaporative loss from irrigated interrows in a highly advective semi-arid agricultural area. Advances in Water Resources 50:20-30.

Bang C., J.L. Sabo, and S.H. Faeth. 2010. Reduced wind speed improves plant growth in a desert city. PLOS ONE 5(6):e11061, doi:10.1371/journal.pone.0011061.

Baveye P.C., D. Rangel, A.R. Jacobson, M. Laba, C. Darnault, W. Otten, R. Radulovich, and F.A.O. Camargo. 2011. From Dust Bowl to Dust Bowl: Soils still a frontier of science. CSA News, Dec 2011. https://www.soils.org/files/publications/csa-news/soils-still-a-frontier-of-science.pdf.

Brandle J.R., L. Hodges, and X.H. Zhou. 2004. Windbreaks in North American agricultural systems. Agroforestry Systems 61:65-78.

Brun L.J., J.W. Enz, J.K. Larsen, and C. Fanning. 1986. Springtime evaporation from bare and stubble-covered soil. Journal of Soil and Water Conservation 41(2):120-122.

Copyright © 2016 Soil and Water Conservation Society. All rights reserved.
Journal of Soil and Water Conservation 71(2):44A-49A www.swcs.org

Burt C.M., A.J. Mutziger, R.G. Allen, and T.A. Howell. 2005. Evaporation research: Review and interpretation. Journal of Irrigation and Drainage Engineering 131:37-58.

Carpenter, S.R., H.A. Mooney, J. Agard, D. Capistrano, R.S. DeFries, S. Diaz, T. Dietz, A.K. Duraiappah, A. Oteng-Yeboah, H.T. Pereira, C. Perrings, W.V. Reid, J. Sarukhan, R.J. Scholes, and A. Whyte. 2009. Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. Proceedings of the National Academy of Sciences 106:1305–1312

Cleugh, H.A. 1998. Effects of windbreaks on airflow, microclimates and crop yields. Agroforestry Systems 41:55-84.

Cutforth H.W., S.V. Angadi S.V., and B.G. McConkey. 2006. Stubble management and microclimate, yield and water use efficiency of canola grown in the semiarid prairie. Canadian Journal of Plant Science 86:99-107.

de Vries T.T., T.A. Cochrane, and A. Galtier. 2010. Saving irrigation water by accounting for windbreaks. New Zealand: University of Canterbury. http://hdl.handle.net/10092/5429.

Glover, J.D., J.P. Reganold, L.W. Bell, J. Borevitz, E.C. Brummer, E.S. Buckler, andY. Xu. 2010. Increased food and ecosystem security via perennial grains. Science (Washington) 328(5986):1638-1639.

Iqbal J., T.B. Parkin, M.J. Helmers, X. Zhou, and M.J. Castellano. 2015. Denitrification and nitrous oxide emissions in annual croplands, perennial grass buffers, and restored perennial grasslands. Soil Science Society of America Journal 79:239–250.

McGuire, V.L. 2007. Water-Level Changes in the High Plains Aquifer, Predevelopment to 2005 and 2003 to 2005. US Geological Survey Scientific Investigations Report 2006–5324. http://pubs.usgs.gov/sir/2006/5324/.

MEA (Millennium Ecosystem Assessment). 2005. Ecosystems and Human Well-Being: Scenarios. Washington, DC: Island Press.

Mitchell, D.C., X. Zhou, T.B. Parkin, M.J. Helmers, and M.J. Castellano. 2015. Comparing nitrate sink strength in perennial filter stripsat toeslopes of cropland watersheds. Journal of Environmental Quality 44:191-199.

NRC (National Research Council). 2010. Toward Sustainable Agricultural Systems in the 21st Century. National. Research Council Report. Washington, DC: The National Academies Press. http://www.nap.edu/

Scanlon, B.R., C.C. Faunt, L. Longuevergne, R.C. Reedy, W.M. Alley, V.L. McGuirre, and P.B. McMahon. 2012. Groundwater depletion and sustainability of irrigation in the US high plains and central valley. Proceedings of the National Academy of Sciences 109:9320-9325.

Senaviratne G.M.M.M.A., R.P. Udawatta, K.A. Nelson, K. Shennon, and S. Jose. 2012. Temporal and spatial influence of perennial upland buffers on corn and soybean yields. Agronomy Journal 104:1356-1362.

Stout. J.E. 2012. A field study of wind erosion following a grass fire on the Llano Estacado of North America. Journal of Arid Environments 82:165-174.

Tatarko J., M.A. Sporcic, and E.L. Skidmore. 2013. A history of wind erosion prediction models in the United States Department of Agriculture prior to the Wind Erosion Prediction System. Aeolian Research 10:3-8.

Ticknor K.A. 1988. Design and use of field windbreaks in wind erosion control systems. Agriculture, Ecosystems, and Environment 22/23:123-132.

USDA NRCS (Natural Resources Conservation Service). 2010. National Resources Inventory 2007. http://www.nrcs.usda.gov /Internet/FSE_MEDIA/stelprdb1041882.png.

Zobeck T.M., and R.S. Van Pelt. 2006. Wind-induced dust generation and transport mechanics on a bare agricultural field. Journal of Hazardous Materials 132:26-38.

Copyright © 2016 Soil and Water Conservation Society. All rights reserved.
Journal of Soil and Water Conservation 71(2):44A-49A www.swcs.org