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agroecosystem restoration through strategic integration of perennials

By Lisa A. Schulte, Matt Liebman, Heidi Asbjornsen, and Thomas R. Crow

A dominant trend in arable farming systems worldwide is the replacement of large areas of perennial vegetation with a small number of annual crops (Green et al., 2005). Some of this change occurs as native vegetation is replaced by annual crops, but change in the latter half of the 20th Century has also occurred through the simplification of diverse systems that formerly included perennial forages and annual crops (Bullock, 1992). Extreme examples of these processes can be seen over the last century in the U.S. Midwest, where prairies, savannas, forests, and wetlands have been almost completely replaced by corn and soybean (Figure 1).

Landscape simplification and the expansion of annual crops have been accompanied, and to a large extent driven, by the broad scale use of synthetic pesticides and fertilizers, new cultivars and machinery,

and soil drainage and irrigation. The resulting increases in yields and farm labor productivity are well documented (e.g., Cochrane, 1993). Less well documented but increasingly evident are the unintended consequences of simplified, intensive farming systems, including contamination of drinking water sources and coastal areas by soil sediment, pesticides, nitrates, and phosphates; threats to human health and non-target plant and animal species resulting from agrichemical exposure; increased frequency and severity of flooding; reductions in wildlife habitat and outdoor recreational opportunities; shifts in pest communities toward resistant genotypes; persistent low crop prices and ensuing farm dependence on subsidy payments; and long-term declines in rural populations and community vitality (USGS, 1999, 2006; Pretty, 2002; Levins, 2003; Tegtmeier and Duffy, 2004).

In response to these and other problems, numerous efforts to improve agricultural sustainability began to emerge throughout the world in the mid to late 1980s (NRC, 1989). One major and widely held conclusion developed over the last several decades is that agroecosystems need to be designed and managed to serve multiple functions: they should satisfy society's needs for food, fiber, and perhaps energy at an affordable price while protecting environmental quality and human health, conserving non-renewable resources, fostering economic development, and providing desirable places to live in rural areas (Pretty, 2002; Boody et

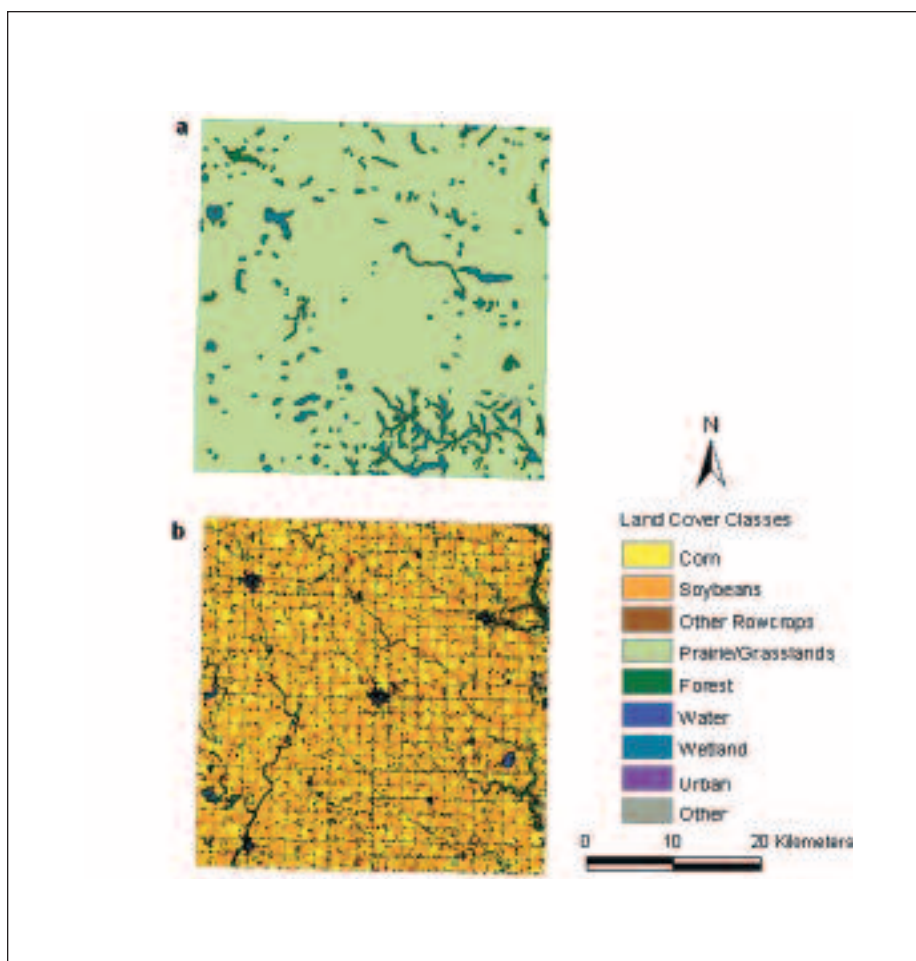


Figure 1
Land cover of Pocahontas County, Iowa. a) around 1850 and b) in 2002

al., 2005). However, although many specific production practices and policies have been suggested as components of sustainable agricultural systems, guiding principles still remain largely obscure or not fully articulated. We suggest that the strategic integration of perennial plants in agricultural landscapes is a fundamental strategy for restoring agroecosystem health and function.

Here we describe the portfolio of perennial systems available for use in agroecosystems, and review existing literature that addresses whether perennial systems at specific places in and around agroecosystems can provide benefits disproportionately greater than the land area they occupy. We then outline a research agenda that will more fully investigate the strategic location-disproportionate benefits hypothesis, as well as policy opportunities that may facilitate greater use of perennial vegetation.

The perennial portfolio

Smith (1929), Wallace (1944), Jackson (1980), and others have emphasized the importance of particular types of perennial plants as components of healthy agricultural systems. We believe, however, that there is a need to draw upon the full and diverse range of options that the perennial growth habit offers, including perennials as harvestable crops and providers of ecosystem services.

Perennials as harvestable crops. Perennial systems that presently have the potential to function as harvestable crops include forages for hay and pasture, agroforestry for wood, nuts, and other products, and herbaceous and short-rotation woody species for bioenergy. As a consequence of shallow rooting depth and a short growing season, annual crop systems in humid areas can leak large quantities of water and nutrients, leading to water pol-

lution; comparatively, perennial forages improve water quality, better regulate water flow, and increase carbon sequestration (Randall et al., 1997; Drinkwater et al., 1998; Randall and Goss 2001; Lal et al., 2003). Agroforests can produce substantial economic benefits in the form of high-market value products (e.g., pecan, hazelnut, chestnut, pawpaw, mulberry). These species can additionally provide buffering and filtering functions similar to those obtained from other perennial systems used specifically for soil and water conservation (Schmitt et al., 1999; Udawatta et al., 2002). Perennial crops may play an especially important role in meeting the world's increasing need for fuels and electricity. The efficiency of energy production by perennial switchgrass could exceed that of corn by as much as 15-fold (McLaughlin and Walsh, 1998). Additional opportunities may exist in the future for perennial grains. Though all of the world's current staple grains are annual species, concerns over soil erosion and energy costs of tillage have propelled interest in developing perennial grain crops, and studies indicate that considerable gains in yield may be achieved through investments in genetics research and breeding (Scheinost et al. 2001).

Perennials as ecosystem service providers.

Perennial systems useful for the provision of ecological services include riparian buffers, grass filters, and restored wetlands for soil conservation and hydrologic regulation, shrubs and trees for wind breaks and shelterbelts, forbs and grasses for pollinator and natural enemy reserves, and a variety of native vegetation types for wildlife habitat and human recreation. Of these, the functions of perennial riparian buffers are particularly well known: buffers adjacent to annual crops can substantially reduce soil sediment and nutrient inputs into surface waters, increase carbon storage, diversify wildlife populations, stabilize stream banks, and cool surface waters (Maisonneuve and

Rioux, 2001; Allan, 2004; Schultz et al., 2004). Vegetative filter strips composed of perennial grasses planted along the contours of hillslopes have the ability to reduce runoff, sediment loss, and nutrient loss from annual crops. Reported efficiencies for sediment and nutrient capture are substantial, but vary according to slope, soil type, rainfall patterns, and the characteristics of individual filter strips (e.g., width, species composition) (Daniels and Gilliam, 1996; Schmitt et al., 1999; Udawatta et al., 2002). Increased deployment of wetlands can help retain large quantities of N and P, which currently are transported directly to streams through surface channels and tile drains (Drury et al., 1996; Xue et al., 1998), rendering riparian buffers and vegetative filter strips ineffective. Shelterbelts can significantly improve production of annual crops, pastures, and livestock (Bird, 1998; Grala and Colletti, 2003), and help to compensate for effects of global warming through microclimate amelioration (Easterling et al., 1997). Although biodiversity and aesthetic goals are often paramount in tallgrass prairie restoration efforts, other important services include carbon sequestration (Baer et al., 2002), nutrient regulation (Baer et al., 2002; Brye et al., 2003), and water purification (Schilling, 2002). Further, diverse agricultural systems that include sown or conserved perennial plants can provide substantial social and economic benefits through increased recreational and aesthetic opportunities (Pimentel et al., 1997; Cordell et al., 2004).

A research agenda

Although perennials have been integrated into conventional U.S. agricultural systems in a limited way since the inception of the Soil Conservation and Domestic Allotment Act of 1936 and the Conservation Reserve Program in 1985, many unanswered questions inhibit their

broad scale adoption. Key questions include:

- How do different perennial systems perform according to multifunctional criteria (e.g., food and energy production, water purification and regulation, nutrient cycling, pest regulation, bio-diversity preservation, recreational and aesthetic opportunities)?
- How does performance according to multifunctional criteria vary depending on the location of the perennials within the landscape (e.g., steep vs. gentle slopes, headwater vs. riparian environments, inter-crop strips vs. field edge)?
- How much of the landscape needs to be planted in perennials to realize significant gains in functionality?

Simulation models with the capacity to extrapolate data collected over small spatial extents to patterns and processes at broader scales, combined with targeted empirical studies, will certainly play an important role within the perennials-in-agroecosystems research agenda. Despite the difficulties involved, replication across watersheds and landscapes is essential for accurately parameterizing and calibrating models of ecosystem functions (Krysanova et al. 1998; Luzio et al. 2002; Miller et al. 2002). Such field data are also needed to address the high degree of heterogeneity in the environment; for example, slight variations in slope angle and extent will affect hydrological outputs (Schmitt et al., 1999; Udawatta et al., 2002), past soil management practices will affect nutrient dynamics (Foster et al., 2003), and landscape context will affect the presence and abundance of many taxa (Landis et al., 2000; Freemark and Kirk, 2001).

A critical piece in executing the perennials-in-agroecosystems research agenda is developing the funding and social mechanisms needed to work with private landowners in experimental tests. Given the lack of sufficiently large tracts of public land suitable for landscape-scale





experiments, incentives must be provided to garner the support and services of private individuals to enable agroecological research at the appropriate scales. Also, because individuals rather than institutions would adopt the practices developed from such a program, the research must be participatory, involving farmers throughout the process. For example, local farms can participate in discussions on the potential experimental design and treatments that would address specific needs, and may also engage actively in the research through contracts to conduct the treatments, especially when land preparation, planting, harvesting, and other agricultural practices are required. Further, the amount of farmer labor associated with different land use practices can be tallied and compared.

Policy considerations for strategic perennialization

Another key question relates to the types of incentives that will be effective in encouraging strategic integration of perennial systems within working landscapes over the long-term (Keeney and Kemp 2004). Green payment programs may provide opportunities but raise several important issues. First, if perennial vegetation systems create the greatest conservation benefits when placed strategically at selected sites on a restricted number of farms, then the most cost-effective means of achieving those benefits for society at large may preclude dispersal of funds to large numbers of farmers. Alternatively, green payments might be viewed as a means of providing revenue to farmers and concomitantly gaining conservation benefits on a broader scale, even though this approach may not necessarily optimize the placement of perennials over watersheds and landscapes. Cost and benefit estimates for both approaches are lacking. Second, the most desirable forms of perennial vegetation for meeting conservation objectives may not be ideal for meeting farm income objectives, e.g., reconstructed wetlands may be highly effective in reducing nitrogen pollution of streams and rivers, but fail to generate a saleable crop. Strategies for cost-effective implementation of green payments will need to consider ways to compensate farmers for

both environmental and financial impacts. Finally, attention needs to be directed toward potential tensions deriving from land-tenure patterns, perennial-based conservation practices, and the identities of the recipients of green payments. A high percentage of Midwestern farm land is rented—in Iowa this figure is close to 60% at present (Duffy, 2004). Incentives that equitably compensate both landlords and tenants need to be developed.

Concluding remarks

We have highlighted the multiple goods and services perennial systems can provide within and around agroecosystems. No single perennial planting can bestow all of these benefits, but integrated suites of perennials—such as patches of food-bearing perennial crops, in-field vegetative filter strips, forested riparian buffers, and reconstructed wetlands at the ends of tile drains—over agricultural watersheds and landscapes are likely to provide benefits far greater than their spatial extent would suggest. Indeed, we propose the strategic placement of perennial plants within agricultural landscapes provides the foundation for multifunctional agricultural systems. As policy makers, farmers, and rural residents begin to assess agricultural systems more holistically, scientists in the agricultural and ecological fields can quicken the pace of positive change by assembling a broad portfolio of high functioning perennial systems, developing the technical and policy means to establish them, and determining their optimal spatial arrangement so that, when deployed, systems are locally adapted and successful from the start.

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