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Dec 1st, 12:00 AM

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Matt Liebman
Iowa State University, mliebman@iastate.edu

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Liebman, Matt, "Diversified weed management tactics in diversified cropping systems: Foundations for durable crop production and protection" (2011). *Proceedings of the Integrated Crop Management Conference*. 12.
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Diversified weed management tactics in diversified cropping systems: Foundations for durable crop production and protection

Matt Liebman, professor and H.A. Wallace Chair for Sustainable Agriculture, Agronomy, Iowa State University

One of the key questions facing Iowa's agricultural community is how to produce sufficient amounts of food and farm income while improving and protecting environmental quality. Because synthetic fertilizers and pesticides constitute important expenses in Iowa farming systems (Duffy 2011; National Agricultural Statistics Service 2011) and because their use can be linked to environmental damage (U.S. Geological Survey 1999; Dinnes et al. 2002; Gilliom et al. 2006), learning how to reduce reliance on these materials without compromising farm productivity and profitability is a key priority for Iowa and other parts of the U.S. Corn Belt. Fossil energy costs associated with farming have increased over the last decade and reducing reliance on non-renewable energy sources is also an important priority for improving profitability (Economic Research Service 2008). With regard to biological challenges to productivity and profitability, weed resistance to commonly used herbicides, including glyphosate, is a growing problem in Iowa and other Corn Belt states (Heap 2011; Tranel et al. 2011). Addressing weed resistance effectively will require approaches that integrate multiple control tactics (Beckie 2006).

To address these issues and other related challenges, a 22-acre field experiment was initiated in 2001 at the Iowa State University Marsden Farm in Boone Co., IA. The experiment is designed to test the hypothesis that diversifying a corn-soybean rotation with small grain and forage crops can maintain or improve yields, weed suppression, and profitability, while allowing large reductions in chemical inputs. In addition to a conventionally managed 2-year corn-soybean rotation, the experiment includes a 3-year corn-soybean-small grain + red clover rotation, and a 4-year corn-soybean-small grain + alfalfa-alfalfa rotation.

After uniformly cropping the site with oat in 2001 and tuning the three rotation systems in 2002, intensive data collection began in 2003. Spring triticale was used as the small grain in 2003-2005, whereas oat was used in 2006-2010. During 2003-2010, manure was applied before corn production in the 3-year and 4-year rotations at a mean dry matter rate of 4 tons acre^{-1}, providing a mean of 106 lb N acre-1 once every three years in the 3-year rotation system, and once every four years in the 4-year rotation. Corn in the 2-year rotation received 100 lb N acre^{-1} as urea at planting, whereas corn in the 3-year and 4-year rotations did not. The late spring nitrate test (Blackmer et al. 1997) was used to determine rates for post-emergence side-dress N applications (as urea ammonium nitrate) for corn in all rotation systems. Weed management in the 2-year rotation was based largely on herbicides applied at conventional rates. In the 3-year and 4-year systems, herbicides were applied in 15-inch-wide bands over corn and soybean rows rather than broadcast, greater reliance was placed on cultivation, and no herbicides were applied in small grain and forage legume crops. Choices of herbicides used in each system were based on the identities, densities, and sizes of weed species observed in the plots. Sampling procedures and other details of farming practices used in the different cropping systems during 2003-2010 are described in Liebman et al. (2008), Cruse et al. (2010), and Gómez et al. (in review).

Over the years 2003-2010, synthetic N fertilizer use was 76% and 84% lower in the 3-year and 4-year rotation systems, respectively, than in the 2-year rotation; similarly herbicide use was reduced 85% and 89% in the 3-year and 4-year rotation systems, respectively, relative to the 2-year rotation (Table 1). Over the period 2007-2010, reductions in N fertilizer and herbicide use were greater: compared with the 2-year rotation system, fertilizer N use was 89% and 93% lower in the 3-year and 4-year systems, respectively, and herbicides inputs were 96% and 97% lower in the 3-year and 4-year systems. The conventional 2-year system used the largest amount of fossil fuel energy, the 4-year system used the least, and the 3-year system was intermediate (Table 1). Gas for drying corn grain, fertilizer, and fuel for farm machinery were responsible for the majority of fossil energy consumption (Cruse et al. 2010).

Table 1. Inputs, crop yields, weed dry mater production, net returns, and selected soil characteristics for the three cropping systems in the Marsden Farm rotation experiment, Boone Co., IA. Within rows, means followed by different letters are significantly different ($P < 0.05$); means not followed by letters are statistically equivalent. Data are from Liebman et al. (2008), Cruse et al. (2010), Gómez et al. (in review), and Wander and Lazicki (unpublished).

	Cropping system		
	2-year rotation: Corn-soybean	**3-year rotation: Corn-soybean-small grain†/ red clover**	**4-year rotation: Corn-soybean-small grain†/ alfalfa-alfalfa**
Whole rotation			
Fertilizer N inputs, lb N acre^{-1} year^{1} (2003-2010)	68 a	16 b	11 c
Herbicide inputs, lb a.i. acre^{-1} year^{1} (2003-2010)	1.71 a	0.25 b	0.19 c
Fossil energy inputs, barrels of oil equivalent acre^{-1} year^{1} (2003-2008)	1.06 a	0.63 b	0.47 c
Labor requirements, hr acre^{-1} year^{1} (2003-2010)	0.73 c	1.13 b	1.42 a
Net returns to land and management‡, $ acre^{-1} year^{1} (2003-2010)	279	286	284
Crop yields			
Corn, bu acre^{-1} (2003-2010)	194 b	200 a	203 a
Soybean, bu acre^{-1} (2003-2010)	51 b	55 a	57 a
Small grain†, tons acre^{-1} (2003-2010)	—	1.7	1.7
Alfalfa, tons acre^{-1} (2003-2010)	—	—	4.0
Weed dry matter production			
In corn, lb acre^{-1} (2003-2010)	1.8	4.1	3.3
In soybean, lb acre^{-1} (2003-2010)	1.3	3.4	3.2
Soil characteristics			
Particulate organic matter-C, mg C cm^{-3} soil, 0-20 cm depth (2009)	2.0 b	2.3 a	2.2 a
Potentially mineralizable N, mg N cm^{-3} soil, 0-20 cm depth (2009)	33.9 b	39.4 a	39.3 a

† Triticale was grown as the small grain crop in 2003-2005; oat was used in 2006-2010.
‡ Crop subsidy payments were not included as sources of revenue.

Despite large reductions in N fertilizer, herbicide, and fossil fuel inputs, corn and soybean yields were higher in the more diverse systems than in the conventional corn-soybean system (Table 1). Weed dry matter production in corn and soybean was low (< 5 lb acre-1) in all systems (Table 1). Weed seed densities in the soil declined in all of the rotation systems during 2003-2010, indicating that reductions in herbicide inputs were not contributing to a buildup of long-term weed problems. In 2010, when soybean sudden death syndrome was prevalent in central Iowa, the incidence and severity of the disease were lower in the 3-year and 4-year rotations than in the 2-year rotation.

Soil particulate organic matter carbon concentrations were significantly greater in the 3-year and 4-year rotation systems than in the conventional 2-year system (Table 1), suggesting that soil organic carbon is increasing in the more diverse rotation systems. Soil potentially mineralizable nitrogen levels were also higher in the 3-year and 4-year rotations than in the 2-year rotation (Table 1), indicating that the more diverse rotation systems had greater capacity to supply crops with N.

Net returns to land and management for 2003-2010 were essentially equivalent for the three rotation systems, with the diversified 3-year and 4-year systems providing a few dollars more than the conventional 2-year system (Table 1). Labor requirements increased with increases in rotation length, but labor costs were only a small fraction of total production costs. Energy gain in crop products per unit of fossil fuel energy invested and net economic returns per unit of fossil energy input were greatest in the 4-year system, least in the 2-year system, and intermediate in the 3-year system.

Taken together, results of this study indicate that diversified crop rotation systems can produce high yields of corn and soybean, suppress weeds effectively, and improve soil quality, while substantially reducing requirements for synthetic N fertilizer, herbicides, and fossil energy. The mixture of chemical, mechanical, and cultural weed control tactics used in the 3-year and 4-year rotation systems is likely to retard the evolution of herbicide resistance in weeds and provide more options for effective control over the long term.

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