SOIL AND CROP MANAGEMENT

Economics of Cropping Systems Featuring Different Rotations, Tillage, and Management

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ABSTRACT

Economics is the dominant factor influencing the adoption of cropping systems. The objective of this 6-yr study was to determine profitability of cropping systems featuring four crop rotations (continuous corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.]–corn, soybean–corn–corn, and soybean–wheat (*Triticum aestivum* L.)/red clover (*Trifolium pratense* L.)–corn), three tillage systems (moldboard, chisel, and ridge) and two management input (high and low chemical) systems. The soybean–corn rotation under low chemical management resulted in the greatest net returns in chisel ($100 ha^{-1}) and moldboard plow tillage ($148 ha^{-1}) because the reduction in production costs (~$110 ha^{-1}), associated with less fertilizer and pesticide costs in corn and less herbicide costs in soybeans, offset the reduction in gross returns ($72 ha^{-1} in chisel and $38 ha^{-1} in moldboard plow), associated with lower corn and soybean yields in chisel and lower corn yields in moldboard plow. Continuous corn under high chemical and soybean–corn–corn and soybean–corn rotations under low chemical management had similar net returns in ridge tillage ($33, $26, and $17 ha^{-1}, respectively). Growers who substitute soybean–corn and soybean–corn–corn (in ridge) rotations for continuous corn can maximize profits and reduce starter fertilizer use by 33 to 50%, N fertilizer by 60 to 70%, herbicides by about 60%, and insecticides by 65 to 100%. Growers who use moldboard plow tillage may realize maximum profits by adopting the soybean–wheat/red clover–corn rotation under low chemical management if they market the wheat straw, a common practice in New York.

The 1996 Federal Agriculture Improvement and Reform Act decouples support payments from production. Consequently, farmers must select cropping systems based on expected market returns and risks associated with those returns (Young and Westcott, 1996). Cropping systems depend greatly on the mix and sequence of crops or crop rotations that farmers select (Francis and Clegg, 1990). Crop rotations, however, interact with tillage systems (Raimbault and Vyn, 1991) and management inputs (Riedell et al., 1998). An economic analysis of cropping systems that include different tillage, crop rotation, and management inputs can help farmers identify the most profitable cropping systems based on market prices.

Chase and Duffy (1991) reported that in an Iowa study, a moldboard plow tillage system had greater net returns ($338 ha^{-1}) than chisel ($324 ha^{-1}) and ridge tillage systems ($324 ha^{-1}) in continuous corn. In the soybean–corn rotation, chisel ($366 ha^{-1}) and moldboard plow tillage systems ($361 ha^{-1}) had greater net returns than ridge tillage ($321 ha^{-1}). Liu and Duffy (1996), however, reported that Iowa growers in 1992 and 1993 had greater average net returns in ridge ($106 ha^{-1}) compared with moldboard plow ($80 ha^{-1}) and chisel tillage ($68 ha^{-1}) in a soybean–corn rotation. Doster et al. (1983) also reported that ridge tillage had net returns equal to or greater than moldboard plow tillage and chisel tillage in continuous corn and soybean–corn rotations on major production soils in Indiana. Martin et al. (1991) reported that in another Indiana study, moldboard plow had slightly greater net returns than chisel tillage when averaged across continuous corn, soybean–corn, and soybean–wheat–corn rotations. Martin et al. (1991) also reported that farmers would optimize net farm income by selecting a soybean–corn rotation on about 55% of the land, continuous corn on about 30%, continuous soybean on about 10%, and soybean–wheat–corn on about 5% under both moldboard plow and chisel tillage. Zacharias and Grube (1984) reported that in an Illinois study, a soybean–corn–corn rotation had greater net returns ($286 ha^{-1}) compared with a corn–soybean–wheat rotation ($224 ha^{-1}) and continuous corn ($188 ha^{-1}) in the presence of herbicides. In the same study, the substitution of three cultivations for herbicides in corn and soybeans reduced net returns by about 55% when averaged across the three rotations.

An economic analysis should be the dominant factor for evaluating different cropping systems (Wesley et al., 1995). The objective of this study was to determine the economic consequences of 24 cropping systems that featured four crop rotations (continuous corn, soybean–corn, soybean–corn–corn, and soybean–wheat/red clover–corn), three tillage systems (moldboard plow, chisel, and ridge), and two management input levels (high and low chemical). Most previous crop rotation and tillage studies did not evaluate management input levels, so economic analyses of these studies did not identify which cropping systems can maintain or even increase profits with less chemical inputs. We varied management inputs from high to low chemical management to test the hypothesis that the more diverse cropping systems would result in similar or greater net returns under low vs. high chemical management.

MATERIALS AND METHODS

A 6-yr tillage × rotation × management study was conducted from 1992 to 1997 on a silt loam soil (fine loamy, mixed, mesic Aeric Haplaquept) at the Robert B. Musgrave

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Research Farm near Aurora, NY (42°45′ N, 76°35′ W). The 2-ha experimental site had been under chisel tillage since 1988 and had been planted to soybeans in 1991. Soil test values at the tile-drained experimental site in the fall of 1991 indicated a pH of 7.8 and medium values of P and K.

Experimental design was a randomized complete block design in a split-split plot treatment arrangement with four replications. Main plots, 55 m wide by 30 m long, consisted of three tillage systems (chisel, moldboard plow, and ridge). Subplots, 6.1 m wide by 30 m long, consisted of four crop rotations. Crop rotations included continuous corn, soybean–corn, soybean–corn–corn, and soybean–wheat/red clover–corn. All phases of each rotation were included, so a total of nine crops (five corn phases, three soybean phases, and one wheat phase) were planted annually. Sub-subplots, 6.1 m wide by 15 m long, consisted of high and low chemical management.

Crop management practices under high and low chemical management are described in more detail in a companion paper (Katsvairo and Cox, 2000) and are listed in Table 1. All management inputs including seed, fertilizer, and herbicides were applied at recommended rates in high chemical management plots for continuous corn, soybean, and wheat (Cornell Recommends for Integrated Field Crop Management, 1998). Low chemical management plots in corn received only half the recommended sidedress N rate (67 kg N ha^{-1}) for continuous corn because previous studies indicated that preceding soybean and red clover crops could provide between 50 and 90 kg N ha^{-1} to the subsequent corn crop (Bundy et al., 1993; Bruulsema and Christie, 1987). In wheat, we also applied half the recommended topdress N rate (33 kg N ha^{-1}) to the low chemical management plots to test the hypothesis that wheat would require less N when following soybeans in the rotation. Low chemical management plots in corn received banded herbicides at planting instead of preemergence and postemergence broadcast herbicides because Mt. Pleasant et al. (1994) reported that both weed control methods resulted in similar weed control and corn yields in New York. Also, low chemical management plots in soybeans received only half the recommended preemergence and postemergence broadcast herbicide rates because Martin et al. (1991) reported greater net returns in soybean when using reduced compared with full herbicide rates.

Although the study commenced in 1992, crop rotations were not in place until 1993, so we conducted the economic analysis on data from 1993 to 1997. Production costs for each rotation were calculated using average costs over the 5-yr period. Corn, soybean, and wheat production costs were estimated separately, summed, and divided by two or three to determine production costs for soybean–corn, soybean–corn–corn and soybean–wheat/red clover–corn rotations for each tillage system. Seed, fertilizer, and pesticide costs were determined by multiplying the average variable inputs over the 5 yr within each tillage system by the average 5-yr prices for seed, fertilizer, and pesticides, which were obtained from local agribusinesses. Machinery operation costs, as well as drying and hauling charges, were determined for each rotation within each tillage system, using average Pennsylvania custom rates for the 5-yr period (Pennsylvania Agricultural Statistics Service, 1998; Table 2). Custom rates include ownership, operator labor, fuel, and repair and maintenance costs normally associated with machine operation. Interest on operating capital was calculated using the average commercial interest rate

Table 1. Planting rate, starter fertilizer, weed control inputs, and sidedress or topdress N rates for corn, soybean, and wheat at Aurora, NY, during the 1993 to 1997 growing seasons.

	Management	
Crop input	**High chemical**	**Low chemical**
	Corn	
Plant population		
Planting rate	**72 000 seeds ha^{-1}**	**72 000 seeds ha^{-1}**
Fertilizer		
Starter	**278 kg ha^{-1} (10-20-20)**	**278 kg ha^{-1} (10-20-20)**
Sidedress N	**133 kg N ha^{-1} (33-0-0)**	**67 kg N ha^{-1} (33-0-0)**
Weed control		
Herbicides		
Preemergence	**2.2 kg ha^{-1} a.i. metolachlor + 2.5 kg ha^{-1} a.i. cyanazine (broadcast)**	**0.73 kg ha^{-1} a.i. metolachlor + 0.83 kg ha^{-1} a.i. cyanazine (band)**
Postemergence	**0.56 kg ha^{-1} a.i. dicamba (broadcast)**	–
Broadcast knockdown	**0.56 kg ha^{-1} a.i. glyphosate + 1.12 kg ha^{-1} a.i. dicamba†**	**0.56 kg ha^{-1} a.i. glyphosate + 1.12 kg ha^{-1} a.i. dicamba**
Cultivation	–	**1–2 times**
Corn root worm control		
At planting	**1.12 kg ha^{-1} a.i. terbufos**	–
	Soybean	
Plant population		
Planting rate	**222 000 seeds ha^{-1}**	**222 000 seeds ha^{-1}**
Weed control		
Preemergence (Broadcast)	**2.2 kg ha^{-1} a.i. metolachlor + 2.2 kg ha^{-1} a.i. linuron†**	**1.1 kg ha^{-1} a.i. metolachlor + 1.1 kg ha^{-1} a.i. linuron**
Postemergence (Broadcast)	**2.2 kg ha^{-1} a.i. basagran**	**1.1 kg ha^{-1} a.i. basagran**
	Wheat	
Plant population		
Planting rate (wheat)‡	**133 and 183 kg ha^{-1}**	**133 and 183 kg ha^{-1}**
Planting rate (clover)	**11 kg ha^{-1}**	**11 kg ha^{-1}**
Fertilizer		
Starter	**222 kg ha^{-1} (6-24-24)**	**222 kg ha^{-1} (6-24-24)**
Sidedress N	**67 kg N ha^{-1} (33-0-0)**	**33 kg N ha^{-1} (33-0-0)**

† Glyphosate and dicamba were applied to clover in the soybean–wheat/clover–corn rotation under ridge and chisel tillage in high and low chemical management in the fall of 1993, 1994, 1995, and 1996. Glyphosate alone was applied to the clover in the spring of 1993 in ridge tillage under high chemical management and to the other three rotations in ridge tillage in the spring of 1995 and 1997.

‡ Wheat was planted at 133 kg ha^{-1} in chisel and moldboard plow tillage and 183 kg ha^{-1} in ridge tillage.

(8.5%) over the 5 yr as reported by Farm Credit (Hastings, 1996). Also, typical farmer insurance costs of \$12 ha^{-1} for corn, \$8 ha^{-1} for soybean, and \$6 ha^{-1} for wheat and land rental fees of \$148 ha^{-1} in New York were used for the crop insurance and land rental charges in this study. No charges for management or overhead were included in the calculations.

The marketing year weighted average prices in New York from 1993 to 1997 were \$0.120 kg^{-1} for corn, \$0.217 kg^{-1} for soybean, and \$0.134 kg^{-1} for wheat (New York State Department of Agriculture and Markets, 1998). Gross returns for each crop were determined as the product of the average price and the average 5-yr yield for each crop within each rotation, tillage, and management system. Net returns for each crop within each rotation, tillage, and management system were calculated as the difference between gross returns and production costs per hectare. In the soybean–corn rotation, it was assumed that half of the area was in soybean production and half in corn production. Consequently, returns were calculated by taking the product of the average soybean yield and price, doing a similar calculation for corn, adding them, and dividing by two to determine the return per hectare for the soybean–corn rotation. Likewise, similar calculations were made for the soybean–corn–corn and soybean–wheat/red clover–corn rotations, except that crop return was summed and divided by three.

Crop yields and net returns were analyzed with the analysis of variance procedures using SAS statistical software (SAS Inst., 1991). We used a combined analysis across years because we were most interested in the 5-yr average rather than the annual variability, which is greatly influenced by fluctuations in weather patterns and crop prices. Mean separation among treatment means was obtained by Fisher's protected LSD, as described by Little and Hills (1978). Effects were considered significant in all statistical calculations if $P \leq 0.05$.

Table 2. Average custom rate costs from 1993 to 1997 for machinery operations and drying and hauling charges.†

Operation	Cost
	\$ ha^{-1}
Tillage	
Moldboard plow	29.06
Chisel plow	27.58
Disk with cultipacker	25.80
Harrow	18.73
Cultivate	20.66
Ridge construction	24.71
Corn planting	
Moldboard	28.47
Chisel	30.89
Ridge	34.15
Soybean planting	
Moldboard	26.89
Chisel	29.95
Ridge	35.59
White/clover planting	
Drilled wheat with fertilizer	26.39
Broadcast seed (clover)	15.02
Pesticide application	
Spray (excluding material)	16.85
Nitrogen application	
Sidedress N—corn	16.90
Topdress N—wheat	13.94
Combine	
Corn	59.95
Soybeans	59.63
Wheat	55.55
Postharvest	
	\$ $\%^{-1}$ kg^{-1}
Corn drying	0.0015
	\$ kg^{-1} km^{-1}
Grain hauling	0.003

† Pennsylvania Agricultural Statistics Service (1992–1993, 1993–1994, 1994–1995, 1995–1996, 1996–1997).

RESULTS AND DISCUSSION

Corn yields had tillage × rotation, tillage × management, and rotation × management interactions (Table 3). When averaged across years, first-year corn in soybean–corn–corn (8.9 Mg ha^{-1}) and corn in soybean–corn and soybean–wheat/red clover–corn rotations (8.7 Mg ha^{-1}) under high chemical management yielded greatest in chisel tillage. In moldboard plow tillage, corn in the soybean–wheat/red clover–corn rotation under high (9.6 Mg ha^{-1}) and low (9.2 Mg ha^{-1}) chemical management and corn in the soybean–corn rotation under high chemical management (9.3 Mg ha^{-1}) yielded greatest. In ridge tillage, first-year corn in soybean–corn–corn (8.2 Mg kg^{-1}) and corn in soybean–corn and soybean–wheat/red clover–corn rotations under high chemical management yielded the greatest (8.2 and 8.0 Mg ha^{-1}, respectively). Corn yields in this experiment averaged 10 to 25% greater, depending upon tillage, rotation, and management systems, than typical farmer yields during the same 5-yr period (New York State Dep. of Agriculture and Markets, 1998).

Tillage, rotation, and management systems affected

Table 3. Corn, soybean, and wheat (155, 130, and 135 g kg^{-1} moisture content, respectively) yields, averaged across the 1993 to 1997 growing seasons, in continuous corn (C–C), soybean–corn (S–C), soybean–corn–corn (S–C–C) and soybean–wheat/red clover–corn (S–W/RC–C) rotations under three tillage systems and two management systems at Aurora, NY.

	Management	
Tillage/crop	High chemical	Low chemical
	Mg ha^{-1}	
Chisel		
C–*C*†	7.5	6.2
S–*C*	8.9	7.9
S–*C*–C	8.9	7.3
S–C–*C*	7.6	5.9
S–W/RC–*C*	8.7	8.3
LSD 0.05‡	0.5	
S–C	2.5	2.3
S–C–C	2.7	2.5
S–W/RC–C	2.7	2.3
LSD 0.05	0.2	
S–*W*/RC–C	3.7	3.2
Plow		
C–*C*	7.9	5.9
S–*C*	9.3	8.5
S–*C*–C	9.1	8.3
S–C–*C*	8.2	6.4
S–W/RC–*C*	9.6	9.2
LSD 0.05	0.5	
S–C	2.4	2.5
S–C–C	2.6	2.7
S–W/RC–C	2.5	2.5
LSD 0.05	0.2	
S–*W*/RC–C	4.0	3.6
Ridge		
C–*C*	7.5	5.4
S–*C*	8.1	6.3
S–*C*–C	8.2	6.9
S–C–*C*	7.6	5.4
S–W/RC–*C*	8.0	6.9
LSD 0.05	0.5	
S–C	2.0	1.8
S–C–C	2.1	2.0
S–W/RC–C	2.2	2.1
LSD 0.05	0.2	
S–*W*/RC–C	3.7	3.3

† Italics indicate the phase of rotation.
‡ LSD 0.05 compares means among different rotation–management systems within a tillage system for corn and soybean.

soybean yields, but there was a tillage × management interaction (Table 3). Soybeans yielded greatest under high chemical management in chisel and ridge tillage (2.6 and 2.1 Mg ha^{-1}, respectively) when compared with low chemical management (2.4 and 2.0 Mg ha^{-1}, respectively). Soybeans, however, yielded the same under high and low chemical management in moldboard plow tillage (2.5 Mg ha^{-1}). Soybean yields in this experiment averaged the same as typical farmer yields in chisel and moldboard plow tillage, but averaged about 20% less in ridge tillage (New York State Dep. of Agriculture and Markets, 1998). The lower yields in ridge compared with chisel and moldboard plow tillage can be attributed in part to 0.76 m row spacing in ridge compared with 0.38 m row spacing in chisel and moldboard plow tillage, because narrow-row soybeans yield more in northern latitudes (Leuschen et al., 1992; Cox et al., 1999). Martin et al. (1991) reported greater soybean yields in a soybean–wheat–corn rotation compared with a soybean–corn rotation in Indiana, whereas Lund et al. (1993) reported similar soybean yields between the two rotations in Wisconsin. When averaged across tillage and management systems, soybeans in the soybean–corn–corn and soybean–wheat/red clover–corn rotations (2.4 Mg ha^{-1}) yielded greater than soybeans in the soybean–corn rotation (2.3 Mg ha^{-1}).

Tillage and management systems affected wheat yields, and there was no tillage × management interaction (Table 3). When averaged across years and management systems, wheat yielded greatest under moldboard plow (3.8 Mg ha^{-1}) compared with chisel and ridge tillage (both 3.5 Mg ha^{-1}). After soybean harvest, wheat plots in moldboard plow and chisel tillage received the same single disc–cultipacker operation before planting. Consequently, tillage operations that occurred in the soybean and corn phases of the rotation must have contributed to the difference in wheat yield between chisel and moldboard plow tillage. Wheat yielded greatest under high chemical management (3.8 Mg ha^{-1}), which received a topdressing rate of 67 kg N ha^{-1}, compared with low chemical management (3.4 Mg ha^{-1}), which received 33 kg N ha^{-1}. In a previous study, Cox et al. (1989) reported that 67 kg N ha^{-1} was the optimum N rate for wheat when following oats in the rotation under the environmental conditions of this study. Evidently, 67 kg N ha^{-1} is close to optimum when wheat follows soybean in the rotation. Wheat yields in ridge and chisel tillage averaged about the same as typical farmer yields, but yields averaged about 10% greater in moldboard plow tillage during the 5-yr period (New York State Dep. of Agriculture and Markets, 1998).

Continuous corn under high chemical management had total production costs of about \$900 ha^{-1} in chisel and moldboard plow tillage and \$865 ha^{-1} in ridge tillage (Tables 4, 5, and 6). Production costs for ridge tillage were less in part because of \$20 to \$25 ha^{-1} less machinery costs, which is consistent with studies in Iowa in the 1980s (Chase and Duffy, 1991) and the early 1990s (Liu and Duffy, 1996). Net returns for continuous corn under high chemical management averaged \$48 ha^{-1} in moldboard plow, \$33 ha^{-1} in ridge, and \$12 ha^{-1} in chisel tillage (Tables 4, 5, and 6). In a previous study on New York farms, Cox et al. (1992) reported similar net returns in continuous corn between moldboard plow and ridge tillage systems. Chase and Duffy (1991), however, reported greater net returns in continuous corn for moldboard plow compared with ridge tillage systems, but similar net returns between moldboard plow and chisel tillage systems. The relatively low net returns for continuous corn under high chemical management, a common practice for New York cash crop producers because of the demand for corn by the dairy industry, indicate that continuous corn may not be a sustainable cropping system once government support payments are terminated.

Total production costs for rotated corn (soybean–*corn*, soybean–*corn*–corn, and soybean–wheat/red clover–*corn*) exceeded production costs for continuous corn under high chemical management in all tillage systems because of greater drying and hauling costs associated with greater yields (Tables 4, 5, and 6). Nevertheless, net returns for rotated corn under high chemical management greatly exceeded net returns for continuous corn under high chemical management, except for corn in the soybean–wheat/red clover–corn rotation in ridge tillage, because of much greater gross returns. In ridge tillage, corn in the soybean–wheat/red clover–corn rotation compared with continuous corn had slightly

Table 4. Production costs, gross returns, and net returns, averaged across the 1993 to 1997 growing seasons, for the corn phase within four crop rotations under high and low chemical management in chisel tillage.

	Continuous *corn*†		Soybean–*corn*		Soybean–*corn*–corn		Soybean–corn–*corn*		Soybean–wheat/red clover–*corn*	
Production costs	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
	\$ ha^{-1}									
Machinery‡	185	194	185	194	185	194	185	194	191	208
Seed	69	69	69	69	69	69	69	69	69	69
Fertilizer	144	100	144	100	144	100	144	100	144	100
Pesticides	116	25	116	25	116	25	116	25	148	63
Drying and hauling	182	147	212	190	213	175	183	142	209	199
Interest on operating capital	29	24	29	24	29	24	29	24	31	24
Crop insurance	30	30	30	30	30	30	30	30	30	30
Land rent	148	148	148	148	148	148	148	148	148	148
Total	903	737	933	780	934	765	904	732	970	841
Gross returns	915	738	1063	954	1067	876	910	710	1047	997
Net returns	12	1	130	174	133	111	6	−22	77	156

† Italics indicate the phase of rotation.
‡ Machinery expenses calculated using custom rates.

Table 5. Production costs, gross returns, and net returns, averaged across the 1993 to 1997 growing seasons, for the corn phase within four crop rotations under high and low chemical management in moldboard plow tillage.

	Continuous *corn*†		Soybean–*corn*		Soybean–*corn*–corn		Soybean–corn–*corn*		Soybean–wheat/red clover–*corn*	
Production costs	High	Low	High	Low	High	Low	High	Low	High	Low
	$ ha^{-1}									
Machinery‡	177	186	177	186	177	186	177	186	177	186
Seed	69	69	69	69	69	69	69	69	69	69
Fertilizer	144	100	144	100	144	100	144	100	144	100
Pesticides	116	25	116	25	116	25	116	25	116	25
Drying and hauling	190	138	222	203	219	198	196	154	230	220
Interest on operating capital	29	24	29	24	29	24	29	24	29	24
Crop insurance	30	30	30	30	30	30	30	30	30	30
Land rent	148	148	148	148	148	148	148	148	148	148
Total	903	720	935	785	932	780	909	736	943	802
Gross returns	951	695	1112	1017	1098	995	985	771	1155	1102
Net returns	48	−25	177	232	166	215	76	35	212	300

† Italics indicate the phase of rotation.
‡ Machinery expenses calculated using custom rates.

less net returns because the additional $45 ha^{-1} in pesticide and $15 ha^{-1} in machinery costs for the herbicide application to kill clover exceeded its greater gross return. Liu and Duffy (1996) reported greater returns for corn following soybean compared with continuous corn, although not as great nor as consistent a response across tillage systems as in this study. Singer and Cox (1998) also reported much greater net returns for corn in soybean–corn and soybean–wheat/red clover–corn rotations compared with continuous corn under chisel and moldboard plow tillage on four New York farms. The much greater net returns for rotated compared with continuous corn indicate that New York cash crop producers should seriously consider rotating fields out of corn, despite the demand for corn by the dairy industry.

Total production costs of corn averaged $120 to $210 ha^{-1} less under low vs. high chemical management in all tillage–rotation systems because of less fertilizer and pesticide costs as well as less drying and hauling costs (Table 4, 5, and 6). Machinery costs for corn, however, averaged close to $10 ha^{-1} greater for low vs. high chemical management in chisel and moldboard plow tillage because cultivation costs exceeded spray application costs by about $10 ha^{-1}. In ridge tillage, machinery costs averaged close to $10 ha^{-1} less under low vs. high chemical management because spray application costs in high chemical management exceeded the additional cultivation costs (in 3 of the 5 yr) in low chemical management.

Net returns for continuous corn and the second-year corn phase of the soybean–corn–corn rotation under high chemical management exceeded net returns under low chemical management in all tillage systems because greater gross returns under high chemical management exceeded the savings in production costs under low chemical management (Tables 4, 5, and 6). In contrast, net returns for rotated corn under low chemical management exceeded net returns under high chemical management by $45 to $90 ha^{-1} in moldboard plow and chisel tillage, except for first-year corn in the soybean–corn–corn rotation in chisel tillage. Furthermore, net returns for rotated corn under low chemical management exceeded net returns for continuous corn under high chemical management by $170 ha^{-1} or more in moldboard plow and $120 ha^{-1} or more in chisel tillage. In ridge tillage, however, net returns for rotated corn differed by only about −$15 to $30 ha^{-1} between low and high chemical management because of relatively low yields and thus low gross returns for rotated corn under low chemical management. Apparently, growers who use moldboard plow or chisel tillage can greatly improve corn profitability while greatly reducing chemical inputs by substituting soybean–corn or soybean–

Table 6. Production costs, gross returns, and net returns, averaged across the 1993 to 1997 growing seasons, for the corn phase within four crop rotations under high and low chemical management in ridge tillage.

	Continuous *corn*†		Soybean–*corn*		Soybean–*corn*–corn		Soybean–corn–*corn*		Soybean–wheat/red clover–*corn*	
Production costs	High	Low	High	Low	High	Low	High	Low	High	Low
	$ ha^{-1}									
Machinery‡	159	151	159	151	159	151	159	151	169	169
Seed	69	69	69	69	69	69	69	69	69	69
Fertilizer	144	100	144	100	144	100	144	100	144	100
Pesticides	109	25	121	25	121	25	121	25	157	73
Drying and hauling	179	129	193	151	196	175	183	128	191	166
Interest on operating capital	27	21	27	21	27	21	27	21	27	21
Crop insurance	30	30	30	30	30	30	30	30	30	30
Land rent	148	148	148	148	148	148	148	148	148	148
Total	865	673	891	695	894	719	881	672	973	779
Gross returns	898	646	971	759	982	830	917	643	959	833
Net returns	33	−27	80	64	88	111	36	−29	24	54

† Italics indicate the phase of rotation.
‡ Machinery expenses calculated using custom rates.

Table 7. Production costs, gross returns, and net returns, averaged across the 1993 to 1997 growing seasons, for the soybean and wheat phases within four crop rotations under high and low chemical management in chisel tillage.

	Corn–*soybean*†		Corn–corn–*Soybean*		Corn–*soybean*–wheat/red clover		Corn–soybean–*wheat*/red clover	
Production costs	High	Low	High	Low	High	Low	High	Low
	$ ha^{-1}							
Machinery‡	176	176	176	176	176	176	137	137
Seed§	51	51	51	51	51	51	109	109
Fertilizer	0	0	0	0	0	0	89	68
Pesticides	128	64	128	64	128	64	0	0
Hauling¶	13	12	13	12	13	11	19	18
Interest on operating capital	21	18	21	18	21	18	21	20
Crop insurance	20	20	20	20	20	20	15	15
Land rent	148	148	148	148	148	148	148	148
Total	557	489	557	489	557	488	538	515
Gross returns	550	514	579	537	594	495	496	430
Net returns	−7	25	22	48	37	7	−42	−85

† Italics indicate the phase of rotation.
‡ Machinery expenses calculated using custom rates.
§ Seed costs include seed innoculant for soybean and clover seed in wheat.
¶ Soybean and wheat crops did not incur drying charges.

wheat/red clover–corn rotations under low chemical management for continuous corn under high chemical management.

Total soybean production costs under high chemical management averaged about \$550 ha^{-1} in moldboard plow and chisel tillage, but only about \$470 ha^{-1} in ridge tillage because of \$40 ha^{-1} less machinery costs and \$30 ha^{-1} less pesticide costs in ridge tillage (Tables 7, 8, and 9). Chase and Duffy (1991) reported about \$30 ha^{-1} less machinery costs, but about \$25 ha^{-1} greater pesticide costs for soybeans in ridge compared with chisel and moldboard plow tillage in an Iowa study. Liu and Duffy (1996), however, reported that soybean growers in Iowa had less pesticide costs in ridge tillage. Total soybean production costs did not differ much among rotations within tillage systems because all rotations received the same inputs (Tables 7, 8, and 9). Consequently, net returns of soybean under high chemical management in the soybean–corn–corn and soybean–wheat/red clover–corn rotations exceeded net returns of soybean in the soybean–corn rotation because of greater yields and thus gross returns. In fact, soybean production in the soybean–corn rotation under high chemical management was not profitable in any tillage system. In another study in New York, however, soybeans in a soybean–corn rotation under high chemical management had net returns of \$135 ha^{-1} (Singer and Cox, 1998).

Total soybean production costs under low vs. high chemical management in chisel and moldboard plow tillage averaged about \$65 ha^{-1} less because of less pesticide costs (Tables 7 and 8). In ridge tillage, low vs. high chemical management had about \$40 ha^{-1} less production costs because the \$65 ha^{-1} less pesticide costs were offset somewhat by an additional \$25 ha^{-1} in cultivation costs (Table 9). Soybean net returns under low chemical management, which ranged from \$55 to \$95 ha^{-1} in moldboard plow, \$10 to \$50 ha^{-1} in chisel, and −\$30 to \$30 ha^{-1} in ridge, exceeded net returns under high chemical management. Apparently, soybean growers under the environmental conditions of this study can increase net returns by reducing herbicide rates, which is consistent with the results from an Indiana study (Martin et al., 1991).

Total production costs in wheat averaged about \$540 ha^{-1} under high chemical management in chisel and moldboard plow tillage and averaged \$525 ha^{-1} in ridge tillage (Tables 7, 8, and 9). Total production costs under high chemical management averaged about \$15 ha^{-1}

Table 8. Production costs, gross returns, and net returns, averaged across the 1993 to 1997 growing seasons, for the soybean and wheat phases within four crop rotations under high and low chemical management in moldboard plow tillage.

	Corn–*soybean*†		Corn–corn–*soybean*		Corn–*soybean*–wheat/red clover		Corn–soybean–*wheat*/red clover	
Production costs	High	Low	High	Low	High	Low	High	Low
	$ ha^{-1}							
Machinery‡	168	168	168	168	168	168	137	137
Seed§	51	51	51	51	51	51	109	109
Fertilizer	0	0	0	0	0	0	89	68
Pesticides	128	64	128	64	128	64	0	0
Hauling¶	11	11	12	13	12	12	20	20
Interest on operating capital	21	18	21	18	21	18	21	20
Crop insurance	20	20	20	20	20	20	15	15
Land rent	148	148	148	148	148	148	148	148
Total	547	480	548	482	548	481	539	517
Gross returns	524	534	559	577	551	536	532	484
Net returns	−23	54	11	95	3	55	−7	−33

† Italics indicate the phase of rotation.
‡ Machinery expenses calculated using custom rates.
§ Seed costs include seed innoculant for soybean and clover seed in wheat.
¶ Soybean and wheat crops did not incur drying charges.

Table 9. Production costs, gross returns, and net returns, averaged across the 1993 to 1997 growing seasons, for the soybean and wheat phases within four crop rotations under high and low chemical management in ridge tillage.

	Corn–*soybean*†		Corn–corn–*soybean*		Corn–*soybean*–wheat/red clover		Corn–soybean–*wheat*/red clover	
Production costs	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
	$ ha^{-1}							
Machinery‡	129	154	129	154	129	154	111	111
Seed§	51	51	51	51	51	51	127	127
Fertilizer	0	0	0	0	0	0	89	68
Pesticides	97	32	97	32	97	32	0	0
Hauling¶	9	9	10	9	10	10	19	18
Interest on operations capital	18	15	18	15	18	15	20	19
Crop insurance	20	20	20	20	20	20	15	15
Land rent	148	148	148	148	148	148	148	148
Total	472	429	473	429	473	430	525	502
Gross returns	431	399	456	426	495	458	496	437
Net returns	−41	−30	−17	−3	22	28	−29	−65

† Italics indicate the phase of rotation.
‡ Machinery expenses calculated using custom rates.
§ Seed costs include seed innoculant for soybean and clover seed in wheat.
¶ Soybean and wheat crops did not incur drying charges.

less in ridge compared with moldboard plow and chisel tillage because of \$30 ha^{-1} less machinery costs, which were offset somewhat by an additional \$15 ha^{-1} in seed costs. Wheat had negative net returns under all tillage and management systems, which is consistent with a previous study in New York (Singer and Cox, 1998). Wheat in New York, however, is generally a profitable crop because most growers bale and market the straw to local dairy producers, which results in an additional \$180 ha^{-1} in net returns (Singer and Cox, 1998). Wheat had less net returns under low vs. high chemical management in all tillage systems because the \$25 ha^{-1} reduction in fertilizer costs did not offset the \$50 to \$65 ha^{-1} loss in gross returns. In contrast, Munn et al. (1998) reported \$19 ha^{-1} greater net returns for wheat, which did not receive topdress N or herbicides, compared with wheat, which received 62 kg N ha^{-1} and postemergence herbicides in a 5-yr study in Ohio.

Net returns for crop rotations had tillage × rotation and rotation × management interactions (Table 10). Continuous corn had the least net returns among rotations in chisel and moldboard plow tillage systems. In chisel tillage, the soybean–corn rotation had the greatest net returns, which is consistent with the findings of Chase and Duffy (1991). The soybean–corn rotation had \$39 ha^{-1} greater net return under low vs. high chemical management (\$100 ha^{-1} vs. \$61 ha^{-1}, respectively) because the reduction in production costs, associated with less fertilizer and pesticide costs in corn and less herbicide costs in soybean, offset less gross returns. Consequently, growers who use chisel tillage under similar environmental conditions of this study can greatly reduce chemical inputs while maximizing profits by adopting a soybean–corn rotation under low chemical management.

The soybean–corn, soybean–corn–corn, and soybean–wheat/red clover–corn rotations had the greatest net returns in moldboard plow tillage. Nevertheless, the soybean–corn rotation under low chemical management had the greatest net returns (\$143 ha^{-1}) among all rotation–management systems in moldboard plow tillage. Consequently, growers who use moldboard plow tillage can greatly reduce chemical inputs while maximizing profits by adopting a soybean–corn rotation under low chemical management. Growers, however, should also consider the soybean–wheat/red clover–corn rotation under low chemical management because they can increase net returns in this rotation by an additional \$60 ha^{-1} by baling and marketing the wheat straw (Singer and Cox, 1998). Consequently, the soybean–wheat/red clover–corn rotation under low chemical management has the potential to be the most profitable rotation–management system in moldboard plow tillage.

The soybean–corn–corn rotation had greater net returns when compared with the soybean–wheat/red clover–corn rotation and continuous corn in ridge tillage. Ridge compared with moldboard plow tillage had less net returns, especially in soybean–corn, soybean–corn–

Table 10. Production costs, gross returns, and net returns for continuous corn (C–C), soybean–corn (S–C), soybean–corn–corn (S–C–C) and soybean–wheat/red clover–corn (S–W/RC–C) rotations in three tillage systems under high and low chemical management, averaged across the 1993 to 1997 growing seasons, using the average yield and the average weighted marketing year price over the 5-yr period for each crop.

	Chisel		Plow		Ridge	
Rotation	**High**	**Low**	**High**	**Low**	**High**	**Low**
	$ ha^{-1}					
	Gross returns					
C–C	916	738	952	695	898	646
S–C	806	734	818	775	701	579
S–C–C	852	708	880	781	785	633
S–W/RC–C	713	641	746	708	650	576
	Production costs					
C–C	903	737	903	720	865	673
S–C	745	634	741	633	682	562
S–C–C	798	662	796	666	749	606
S–W/RC–C	688	615	677	600	645	570
	Net returns					
C–C	13	1	49	−25	33	−27
S–C	61	100	78	143	19	17
S–C–C	54	46	84	115	36	26
S–W/RC–C	24	26	69	108	5	6
LSD 0.05†	23		23		23	

† LSD compares rotation–management means within each tillage system.

corn, and soybean–wheat/red clover–corn rotations under low chemical management. Consequently, ridge tillage may not be the best tillage system to use for sustainable cropping systems, which emphasize crop rotations and the reduction of chemical inputs, under the environmental conditions of this study. Smolik et al. (1995) also suggested that a corn–soybean–spring wheat rotation under ridge tillage may not be sustainable in northeastern South Dakota. Ridge tillage, however, had the greatest crop residue on the surface among tillage systems in all years of the study (Katsvairo, 2000), which could result in less sediment pollution. The soybean–corn–corn and soybean–corn rotations in ridge tillage under low chemical management had similar net returns as continuous corn under high chemical management. Consequently, growers who use ridge tillage under the environmental conditions in this study can greatly reduce chemical inputs while maintaining similar net returns by substituting either rotation under low chemical management for continuous corn under high chemical management.

CONCLUSION

Continuous corn under high chemical management, which has been a common cropping system for New York cash crop producers because of demand for corn by the dairy industry, resulted in the least net returns in chisel and moldboard plow tillage. New York cash crop producers who use moldboard plow and chisel tillage should eliminate continuous corn because it is the least profitable and has the greatest potential for environmental degradation associated with fertilizer N and pesticide use. A soybean–corn rotation under low chemical management resulted in the greatest net returns in chisel and moldboard plow tillage. Growers who use moldboard plow and chisel tillage should substitute a soybean–corn rotation under low chemical management for continuous corn under high chemical management, which could reduce starter fertilizer use by 50%, N fertilizer use by about 70%, herbicide use by about 60%, and insecticide use by 100%. Growers who use moldboard plow tillage should also consider the soybean–wheat/red clover–corn rotation under low chemical management because this cropping system may result in the greatest profitability if the growers bale and market the wheat straw, a common practice in New York. Also, the soybean–wheat/red clover–corn rotation adds a green manure crop and more crop diversity to the rotation, which may improve soil quality (Karlen et al., 1992) and reduce potential pest problems, particularly corn rootworm (*Diabrotica* spp.), which has become adapted to the soybean–corn rotation in parts of the midwestern USA.

Ridge tillage had much less net returns when compared with moldboard plow tillage, especially in soybean–corn, soybean–corn–corn, and soybean–wheat/red clover–corn rotations under low chemical management. Nevertheless, ridge tillage had the greatest residue on the surface among tillage systems, which makes it the best adapted tillage system on highly erodible lands. The soybean–corn–corn and soybean–corn rotations under low chemical management had the same net returns as continuous corn under high chemical management in ridge tillage. Growers who use ridge tillage can thus maintain net returns by substituting either rotation under low chemical management for continuous corn under high chemical management, which would reduce starter fertilizer use by 33 to 50%, N fertilizer use by about 60 to 70%, herbicide use by about 60%, and insecticide use by 67 to 100%.

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