Runoff, Soil, and Dissolved Nutrient Losses from No-Till Soybean with Winter Cover Crops

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ABSTRACT

Soils are more vulnerable to erosion following cropping to soybean (*Glycine max* [L.] Merr.) than corn (*Zea mays* L.). This has been attributed to lower dry matter production, less residue cover, and soil-loosening action by soybean roots. To augment soil cover, common chickweed (*Stellaria media* L.), Canada bluegrass (*Poa compressa* L.), and downy brome (*Bromus tectorum* L.) were grown as winter cover crops with no-till soybean on natural rainfall erosion plots located on a poorly drained Mexico claypan soil (Udollic Ochraqualf). No-till soybean without a cover crop served as the check. Winter cover crops significantly increased soil cover by 30 to 50% during the critical erosion period of late spring to early summer. Compared to the check, mean annual soil losses from the chickweed, downy brome, and Canada bluegrass were decreased by 87, 95, and 96%, and runoff was reduced 44, 53, and 45%, respectively. Dissolved NH_4^+ concentration in runoff from cover crops was 1.61 to 3.72 times more, and dissolved PO_4^{3-} was 1.61 to 2.86 times more than that of the check. However, runoff from the check plots had 96 to 117% greater concentration of dissolved NO_3^- than cover crop plots. Mean annual dissolved nutrient losses were decreased 7 to 77% by using winter cover crops. Thus, winter cover crops were very effective in reducing soil erosion and dissolved nutrient losses from no-till soybean.

SOYBEAN is a major economic crop in many areas of the world. Research has indicated that soil erosion and runoff losses are greater from soybean than corn and also greater when the proceeding crop is soybean rather than corn. Laflen and Moldenhauer (1979) concluded from analysis of 7 yr of water and soil loss data from natural rainfall erosion plots in Iowa that annual soil loss from corn following soybean was significantly higher ($P < 0.10$) than the loss from soybean following corn or corn following corn. Alberts et al. (1985) reported that average annual soil losses from soybean were 3.4 and 2.0 times that from corn for conventional and no-till systems, respectively ($P < 0.01$). Buyanovsky and Wagner (1986) suggest that the difference in erosion arise because of the enhanced soil-loosening action of soybean roots and lower dry matter production (with less soil surface residue) for soybean than for corn. Alberts et al. (1985) reported that the measured annual C factor in the Universal Soil Loss Equation (USLE) was about two times higher for continuous soybean among tillage methods than for continuous corn.

Differences in soil loss have also been related to the effects of cropping systems on soil aggregate stability. The mean weight diameter (MWD) of dry-sieved soil aggregates of Clarion clay loam and Monona silt loam (both are Typic Hapludolls) subjected to continuous soybean and corn cropping systems for four consecutive years (Alberts and Wendt, 1985) did not differ between soybean and corn in early summer but was significantly lower for soybean ($P < 0.05$) than for corn in late fall. Quantity and quality of organic material incorporated into the soil influences soil aggregate stability. Gantzer et al. (1987) observed that incubation with soybean residue resulted in 5 to 10% greater single-drop soil splash than incubation with the same amount of corn residue, indicating differences in stability are related to residue quality.

McDowell and McGregor (1980) reported both concentration and loss of soluble N and P in runoff water from no-till managed soybean in northern Mississippi on a Providence silt loam (Typic Fragiudalf) were significantly greater than from conventionally tilled soybean. In Missouri, about 30% of the total annual precipitation occurs from March to May, but as much as 44 to 77% of the annual runoff is concentrated in the same period (Scrivner et al., 1972). Generally, no crop canopy is available to protect the soil surface during this period. Thus, soil erosion could be very serious if vegetative material or residue cover on the soil surface is sparse.

Cover crops have been used for many years: to fix soil N, to improve soil structure and tilth, and to reduce runoff and soil loss. Many studies have reported on winter legumes rather than grasses as living mulches for corn (Mitchell and Teel, 1977; Ebelhar et al., 1984; and Frye et al., 1985). Cover crops are seldom used in modern row-crop systems, however, and most cover crops have to be killed with herbicides before maturity to minimize water and light competition.

Few studies have been conducted to find a winter cover crop for no-till soybean. Elkins et al. (1982, 1983) studied soybean yield with two grasses on four

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soils but no soil erosion or runoff data were reported. The objectives of this study were to evaluate the effectiveness of selected nonleguminous winter cover crops grown with no-till soybean in reducing runoff and soil loss, and to investigate the influence of winter cover crops on dissolved N and P levels transported in runoff.

MATERIALS AND METHODS

The study was initiated in the fall of 1984 on eight natural rainfall erosion plots located at the USDA-ARS Midwest Claypan Exp. Farm near Kingdom City, MO on a Mexico silt loam (fine, montmorillonitic, mesic Udollic Ochraqualf). A 0.3- to 0.6-m thick argillic horizon (claypan), located about 0.25 m below the soil surface, contains more than 40% clay. Soil organic matter concentration of the Ap horizon was 2.6%. The average annual precipitation and runoff in the study area are 996 and 288 mm, of which about 29% of the precipitation and 66% of the runoff are concentrated from March to May, respectively.

Plots were 3.2 by 27.4 m and were instrumented with two volumetrically calibrated, covered tanks for collection of runoff and sediment. Plots were oriented parallel to the slope. Slopes of all plots were 3%. Adjacent plots were separated by 2.1-m borders, which were also planted to soybean. An earthen berm at the upper end of each plot prevented any extraneous water from entering the plots.

All plots were reshaped to reestablish slope uniformity in 1978 and managed uniformly after that. All plots were moldboard plowed and cropped with soybean in the spring of 1984. Three cover crops were hand-spread into the plots prior to a rain in mid-September before soybean harvest to assure a good germination and cover crop stand. The winter cover crops were allowed to reseed by themselves in the following years. Four treatments with two replicates in a completely randomized design were used. Treatments consisted of winter cover crops of: (i) CB-Canada bluegrass (*Poa compressa* L.), a perennial; (ii) CW-common chickweed (*Stellaria media* L.), a winter annual which is very common in Missouri and matures in late April to early May, just before the time of soybean planting; (iii) DB-downy brome (*Bromus tectorum* L.), also a winter annual; and (iv) CK-no cover crop. Cover crop selection was based on the following criteria: (i) The time of physiological maturity must be early and senescence or dormancy being reached by late spring; (ii) The plant must be a prolific seed producer to aid in reseeding; and (iii) The plant should have short growth pattern to minimize light competition or interference to emerging soybean.

Soybean was seeded in the spring of 1985 by either direct drilling, or no-till planting, into the cover crops. Four rows were planted in 0.76-m row spacings within each plot area at a rate of 5×10^5 seed ha^{-1}. Two buffer rows of the same width were planted in the area between the individual plots. A 6-10-20 ratio (6% total N, 10% available P, and 20% water-soluble K) fertilizer was applied in the amount of 246 kg ha^{-1} at the time of soybean planting. In 1985, soybean was seeded on 10 May for CK and CW, and 21 May for CB and DB. Soybean for all plots was seeded on 7 May in 1986 and on 29 May in 1987. All farming operations were conducted up and down slope using common farm equipment.

Weeds were controlled chemically. After soybean seeding but prior to emergence, paraquat (1,1-dimethyl-4,4-bipyridinium ion) or glyphosate [*N*-(phosphonomethyl) glycine] were used at 2.4 L ha^{-1} to kill invading grasses and weeds in the CK plots. While soybean were growing, sethoxydim {2-[1-(ethoxyimino) butyl]-5-[2- (ethylthio)pro-pyl]-3-hydroxy-2-cyclohexen-l-one}, a selective grass herbicide was used at the rate of 2.4 L ha^{-1} when needed for all plots. Soybean residue was uniformly spread across each plot after harvest by hand to increase the uniformity of cover.

Runoff was collected and measured after each event. Sediment was suspended by vigorous stirring immediately before obtaining sediment concentration samples. Additional samples were collected, immediately filtered, and refrigerated for analyses of dissolved N and P concentrations. Dissolved NO_3^-, NH_4^+-N, and PO_4^{3-}-P concentrations in runoff were determined using colorimetric methods (Technicon Industrial system, 1978a,b; Olsen and Sommers, 1982).

Soil surface cover, including the soybean and cover crop canopies and plant residues, were measured using the meterstick method described by Colvin and Gilley (1987). Measurements were made weekly during the growing season and monthly during the rest of the year. The annual mean surface cover value was calculated as the weighted average over time. Data other than surface cover were calculated as means-by-treatment and cropstage periods. Cropstage periods are defined by Wischmeier and Smith (1978) as follows: Period SB (seedbed period) is from seeding until the crop has developed a 10% canopy cover for the no-till treatment; Period 1&2 (establishment period) is from the end of SB until crop has developed a 75% canopy cover; Period 3 (maturing crop period) starts from the end of Period 2 until crop harvest; and Period 4 (residue or stubble period) is from harvest to new seeding. Statistical analyses were conducted using a one-way analysis of variance with single degree of freedom *F* tests (SAS Institute Inc., 1985).

RESULTS AND DISCUSSION

Soil Cover

Yearly distribution patterns of soil cover are depicted in Fig. 1. All cover crop treatments provided significantly greater soil cover than the CK. Annual averages were 71, 92, 99, and 99% for CK, CW, CB, and DB, respectively. Cover crops provided 30 to 50% more cover during the critical erosion period of late spring from mid-March to May (Fig. 1). Because Canada bluegrass is a perennial and downy brome grew rapidly during winter and early spring, soil surfaces were completely covered most of the year for these treatments. Chickweed began to cover the soil completely by late March to early April until it matured before soybean planting in May. Although the time-weighted average annual soil surface cover of CW was significantly less than that of CB and DB, it still provided 20% greater soil surface cover than CK throughout the year.

Runoff

Most runoff occurred during Period 4, harvest to new seeding (Table 1). Significantly more runoff oc-

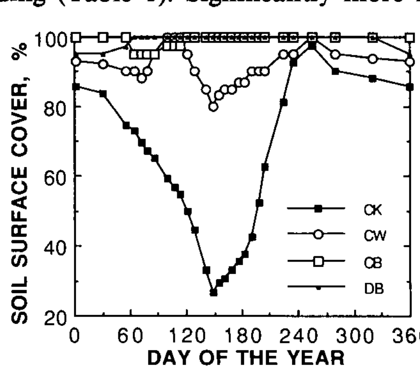

Fig. 1. Variation in soil surface cover over time for selected cover crop treatments during 1986–1987. Treatment abbreviations are: no-till soybean with chickweed, CW, Canada bluegrass, CB; downy brome, DB; and no cover crop, CK.

Table 1. Runoff losses from soybean cover crop treatments by cropstage period and annually for 3 yr.

Cropstage†	CK‡	CW	CB	DB
	mm			
	1985			
SB	4	0	0	0
1&2	53	31	34	25
3	3	0	0	0
4	258	156	180	136
Annual§	311	213	217	200
	1986			
SB	10	1	0	0
1&2	1	0	0	0
3	7	1	0	0
4	92	15	26	15
Annual	151	52	67	31
	1987			
SB	2	0	0	0
1&2	33	8	0	0
3	0	0	0	0
4	57	36	20	36
Annual	74	34	12	23

† SB = seedbed period; 1&2 = establishment period; 3 = maturing crop period; 4 = residue or stubble period.
‡ CK = no cover crop; CW = common chickweed (*stellaria media* L.); CB = Canada bluegrass (*Poa compressa* L.); and DB = downy brome (*Bromus tectorum* L.).
§ Annual values represent losses for the January through December period, while the crop year is from seeding to new seeding so that total values for stages and annual do not correspond.

Table 2. Probabilities of greater F values for comparisons of cover crop effects on runoff for different cropstage periods and annually for 3 yr.

Cropstage period†	Comparison: CK‡ vs. All	Comparison: CW vs. CB + DB	Comparison: CB vs. DB
		1985	
SB	0.001	1.000	1.000
1&2	0.014	0.810	0.161
3	0.027	0.795	1.000
4	0.019	0.952	0.187
Annual§	0.035	0.905	0.644
		1986	
SB	0.004	0.475	1.000
1&2	0.156	0.648	1.000
3	0.001	0.116	1.000
4	0.001	0.554	0.214
Annual	0.008	0.915	0.145
		1987	
SB	0.004	1.000	1.000
1&2	0.001	0.001	0.550
4	0.027	0.412	0.117
Annual	0.007	0.498	0.983

†,‡ See Table 1.
§ Annual values represent losses for the January through December period, while the crop year is from seeding to new seeding so that total values for stages and annual do not correspond.

curred from the CK than the cover crop treatments for each of the 3 yr (Table 2). Cover crop treatments reduced annual runoff from 30 to 36% as compared to the CK in 1985 and even more during subsequent years. Annual runoff was reduced by 56, 66, and 79% for the treatments of CB, CW, and DB vs. CK, respectively, in 1986; and by 54, 69, and 84% for CW, DB, and CB vs. CK in 1987 (Table 1). It should be pointed out that precipitation in 1985 (1209 mm) was 21% more and precipitation in 1986 (884 mm) and 1987 (792 mm) was 11 and 20% less than the normal (996 mm). No differences in runoff among cover crop treatments were found ($P > 0.10$, Table 2).

Soil Loss

Annual soil losses in 1985 from CW, DB, and CB were 83, 90, and 92% below the CK (Table 3). Soil loss from CW was significantly decreased by 92% in 1986 and 1987 compared to the CK. Little measurable soil loss occurred in CB and DB after the first year of the study (1985). No significant differences in soil loss were found among the cover crop treatments of CW, CB, and DB during any year (Table 4).

The greatest impact of cover crops on reducing soil loss was observed in period SB to Period 1&2 (Table 3). Measurable soil loss after these stages was observed only in 1987 for CW, CB, and CK plots. These results were similar to those of Kramer (1986), who reported that the greatest effect of tillage on runoff and soil loss in Missouri was during cropstage SB when there is little plant canopy to protect the soil.

Annual soil loss was highly correlated to annual runoff ($r = 0.96$). Runoff and soil loss were both negatively correlated ($r = -0.98, -0.99$, respectively) with soil cover. Based on results from a number of experiments, Wischmeier and Smith (1978) reported about 20% reduction in soil loss for each 10% increment of soil cover. Our results showed a 33% decrease in soil loss for each 10% increase of soil cover when cover crop treatments were compared to the CK.

Dissolved Nutrient Losses

Dissolved nutrient concentrations and losses in runoff averaged for 1985 and 1986 are presented in Table 5. Dissolved NH_4^+-N and PO_4^{3-}-P concentrations from cover crop plots were higher than those from the CK, but the total amount of losses were lower from the cover crop treatments. Runoff from the CK treatment was higher in NO_3^--N than runoff from cover crop treatments. The annual mean NO_3^- concentrations in runoff were 1.86, 1.92, 2.06, and 4.04 mg kg^{-1} for treatments CW, CB, DB, and CK, respectively.

Concentrations of NH_4^+-N in runoff from CW, CB, and DB were 1.61, 2.33, and 3.72 times that of the CK, respectively. The PO_4^{3-}-P concentrations were increased 61, 86, and 186% for the CW, DB, and CB treatments, respectively, in comparison to the CK. However, the NO_3^--N concentrations were 49, 52, and 54%, respectively, less from DB, CB, and CW, than the CK. The highest concentrations of NO_3^--N, NH_4^+-N and PO_4^{3-}-P, were in runoff from CK, DB, and CB, respectively. No significant differences in dissolved nutrient concentrations were found among the three cover crop treatments (Table 6). The NO_3^--N concentrations in runoff from the cover crop plots were about 50% lower than that from the CK.

The general hypothesis that higher nutrient concentration would lead to greater nutrient losses was not true in this study (Table 5). Dissolved NO_3^--N losses were highly correlated with runoff concentrations ($r = 0.95$) for the 2-yr data, but runoff losses of NH_4^+-N and PO_4^{3-}-P were poorly correlated with concentra-

Table 3. Soil losses from soybean cover crop treatments by cropstage period and annually for 3 yr.

Cropstage†	CK‡	CW	CB	DB
	kg ha^{-1}			
		1985		
SB	336	0	0	0
1&2	1984	381	168	213
3	0	0	0	0
4	0	0	0	0
Annual§	2454	420	185	235
		1986		
SB	562	45	0	0
1&2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
Annual	562	45	0	0
		1987		
SB	217	0	0	0
1&2	1317	125	0	0
3	0	0	0	0
4	111	52	6	0
Annual	1534	125	0	0

†,‡ See Table 1.
§ Annual values represent losses for the January through December period, while the crop year is from seeding to new seeding so that total values for stages and annual do not correspond.

Table 4. Probabilities of greater *F* values for comparisons of cover crop effects on soil loss for different cropstage periods and annually for 3 yr.

Cropstage period†	Comparison: CK‡ vs. all	Comparison: CW vs. CB + DB	Comparison: CB vs. DB
		1985	
SB	0.001	1.000	1.000
1&2	0.001	0.259	0.741
Annual§	0.001	0.258	0.739
		1986	
SB	0.015	0.771	1.000
Annual	0.012	0.758	1.000
		1987	
SB	0.001	1.000	1.000
1&2	0.001	0.237	1.000
4	0.037	0.199	0.870
Annual	0.001	0.206	1.000

†,‡ See Table 1.
§ Annual values represent losses for the January through December period, while the crop year is from seeding to new seeding so that total values for stages and annual do not correspond.

tions ($r = -0.54$ and -0.47, respectively). Other factors such as total volume of runoff and soil cover should be related to the total nutrient losses by runoff water. Because runoff was a function of soil surface cover, variables which correlated with soil cover should be highly correlated with the total amount of runoff as well.

Results show total NO_3^-–N loss was highly correlated with soil cover and runoff volume ($r = -0.96$, 0.94, respectively). Less soil cover and greater runoff resulted in greater nutrient losses in the CK. Since dissolved nutrient losses were influenced more by soil surface cover and runoff volume than concentration, nutrient losses were reduced with cover crops. The annual NO_3^-–N losses were 0.77, 0.84, 0.88, and 3.36 kg ha^{-1} yr^{-1} from treatments of CW, DB, CB, and CK, respectively. Cover crop treatments decreased NO_3^-–N losses by 74, 75, and 77% for treatments of CB, DB, and CW, respectively, vs. the CK ($P < 0.05$). Losses of NH_4^+–N were also reduced by 35, 35, and 41%; and PO_4^{3-}–P losses were decreased by 63, 41, and 7% for treatments of CW, DB, and CB, respectively, in comparison to the CK. The differences, however, were not significant (Table 6).

Barisas et al. (1978), observing nutrient losses from simulated rainfall erosion plots planted to corn on three Iowa soils (Ida silt loam, Tama silty clay loam, and Kenyon sandy loam), reported that soluble nutrient concentrations were positively correlated with the amounts of soil residue cover; and that conservation tillage systems were ineffective in reducing the loss of soluble nutrients. Our results show that although dissolved PO_4^{3-}–P and NH_4^+–N concentrations from the cover crop treatments were higher than those from CK, differences were not significant. The CK plots, however, had a greater concentration of NO_3^-–N in runoff than did the cover crop treatments. The largest quantity of NO_3^-–N, NH_4^+–N, and PO_4^{3-}–P losses were from the CK; and the lowest were from CW, CB, and CW, respectively (Table 5). Lower dissolved nutrient losses with the cover crop treatments are attributed to the reduction in runoff. Except for NO_3^-–N, total nutrient losses were not highly correlated with concentration. Both nutrient concentration and total losses were associated with soil surface cover and runoff volume (Table 7).

Table 5. Mean annual dissolved nutrient concentrations and losses from soybean cover crop treatments (2 yr, 1985 and 1986, means).

Treatment	Runoff concentrations: NO_3^-	NH_4^+	PO_4^{3-}	Runoff losses: NO_3^-	NH_4^+	PO_4^{3-}
	mg kg^{-1}			kg ha^{-1} yr^{-1}		
CK†	4.04	0.18	0.28	3.36	0.17	0.46
CW	1.86	0.29	0.45	0.77	0.11	0.17
CB	1.92	0.42	0.80	0.88	0.10	0.43
DB	2.06	0.67	0.52	0.84	0.11	0.27

† See Table 1.

Table 6. Probabilities of greater *F* values for comparisons of cover crop effects on dissolved nutrients for cropstage periods and annually for 2 yr.

Comparison effect	Concentrations: NO_3^-	NH_4^+	PO_4^{3-}	Losses: NO_3^-	NH_4^+	PO_4^{3-}
	Significance level					
CK† vs. all	0.159	0.178	0.088	0.043	0.157	0.587
CW vs. CB+DB	0.936	0.284	0.305	0.947	0.922	0.479
CB vs. DB	0.932	0.289	0.174	0.976	0.903	0.492

† See Table 1.

Barisas et al. (1978) and McDowell and McGregor (1980) compared nutrient losses in runoff and sediment and concluded that nutrient losses in runoff were relatively small and sediment was the major carrier of nutrients. Since soil loss was reduced in the cover crop treatments and total dissolved nutrient loss in runoff was less, total (solution plus sediment) nutrient losses would also be less. Thus, surface water quality should be better after using any of the reported winter cover crops with no-till soybean.

Soybean yields for the 3-yr average of 1985, 1986,

Table 7. Coefficient of determination (r^2) of dissolved nutrient losses with runoff volume and soil surface cover for the 2-yr average (1985–1986).

Correlation function with	Coefficient of determination					
	Concentrations			Losses		
	NO_3^-	NH_4^+	PO_4^{3-}	NO_3^-	NH_4^+	PO_4^{3-}
	r^2					
Soil cover	0.73	0.53	0.88	0.93	0.69	0.37
Runoff	0.68	0.71	0.78	0.89	0.64	0.52
Concentration	1.00	1.00	1.00	0.91	0.29	0.22

and 1987 were 451, 1031, 1537, and 2177 kg ha^{-1} for treatments of CB, DB, CW, and CK, respectively. Due to the competition for soil water (Zhu, 1988), soybean yields were significantly decreased 53, and 79%, by DB and CB ($P < 0.01$). Soybean yield in CW was 29% lower than CK but the difference was not statistically significant ($P = 0.16$). Since runoff, soil, and dissolved nutrient losses from CW were significantly reduced in comparison to the CK, CW seems to be the best candidate as a winter cover crop with no-till soybean. However, more research is needed to understand how competition can be reduced by management of winter cover crops in no-till soybean.

SUMMARY AND CONCLUSIONS

Winter cover crops increased average soil cover by 31 to 40% in comparison to the no-till check. Soil surface cover in the cover crop plots was over two times that of the CK during the early growth stages. Soil loss with CB, DB, and CW was only 4, 5, and 13% of that from CK. Both runoff and soil loss were significantly correlated with the degree of soil cover ($r = -0.98$ and -0.98, respectively). Runoff from CK had the highest concentration of NO_3^-–N. Although concentrations of NH_4^+–N and PO_4^{3-}–P from the cover crop treatments were about 1.61 to 3.72 that of CK, nutrient losses were decreased by 74 to 77% for NO_3^-–N, by 35 to 41% for NH_4^+–N, and by 7 to 63% for PO_4^{3-}–P from the cover crop treatments due to runoff volume reduction. Soil and dissolved nutrient losses from no-till soybean can be reduced by using a winter cover crop. However, average soybean yields were decreased 53 and 79%, by DB and CB. Although CW reduced soybean yield by 29% as compared to CK, the difference was not statistically significant. Thus, CW seems to be more suitable as a winter cover crop with no-till soybean than CB and DB. More studies are needed on the management of winter cover crops so as to minimize the soil water competition and yield-reducing effects.

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