WIND AND WATER EROSION

Cover crop effects on soil erosion by wind and water

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A principal function of cover crops is to prevent land degradation by wind and water erosion. Available conservation tillage technology to manage cover crops prior to the late 20th century was elementary, but the practice of green manuring is very ancient. The Greeks turned under broadbeans (*Vicia faba* L.) about 300 B.C. *(40)*. Cropping strategies for soil improvement were also a common practice for early Roman and Chinese empires. Many 20th century land stewardship initiatives accompany successful cover crop strategies.

Long-term benefits of cover crops extend beyond the published definitions in a holistic sense *(18, 52)*. Crop residue rather than cover crop management becomes important on water deficient soils (xeric climate) where cover crops cannot be grown successfully between periods of regular crop production. Similar scenarios can be used for soils developed in boreal climates. In this chapter, we will focus on the protective value of plant vegetative and residue cover for controlling soil erosion.

In addition to providing resistance to soil particle detachment and transport as described by wind *(68)* and water *(66)* models, decomposing plant materials give rise to other hallmark functions. These functions, which contribute to the maintenance of dynamic soil organic matter levels, are inherently related to soil erosion control because of increased rainfall capture and retention *(6, 36)*.

Accelerated soil erosion is often associated with deficient vegetative land cover, and may be partially responsible for societal failures *(19, 26)*. In colonial North America, considerable land degradation occurred because of the abundance of land accompanied with soil stewardship illiteracy. European people migrated to North America with little agricultural experience to deal with a high-rainfall, erosive climate. Ruffin *(47)*, Hilgard *(17)*, and Trimble *(56)* documented accelerated soil erosion following European settlements. Bennett *(5)*, Lowdermilk *(26)*, Jenny *(19)*, and Barnett *(3)* described some human misery associated with about 200 years of continuous land degradation into the 20th century. The first U.S. legislative action mandating research for control of soil erosion was authorized by the 1928 Buchanan Amendment to the Agricultural Appropriation Bill *(58)*. Bennett's passionate soil conservation leadership also continued to arouse the stewardship conscience of the nation during the dust bowl era.

Williams et al. *(63)* summarized the results of the early soil erosion research activities. Positive soil erosion control results were associated with cover crop treatments used in our first national environmental research thrust. Conservation technology developed in the 1930s and 1940s to derive the universal soil loss equation (USLE) *(67)* C and P factors as well as the Conservation Reserve Program (Soil Bank), authorized in Title I of the Agricultural Act of 1956, all served to significantly decrease off-site sediment damage *(56)*. Sedimentation rates decreased 73% from 1939 to 1967 (107 to 29 acre-feet/year) in some northern Georgia reservoirs *(2, 60)*.

Increased export market opportunities for U.S. soybean

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and wheat farmers during the 1970s and early 1980s significantly expanded monocropped, conventionally tilled acreage *(59, 61)*. The diminished use of cover crops during this era degraded U.S. agroecosystems significantly *(12, 63)*. The recent low-input sustainable agriculture thrust and ground water quality initiatives are currently serving to provide more cover crop opportunities for American agriculture. In this chapter, we will describe the importance of cover crops for protecting U.S. agroecosystems through soil erosion control.

Soil surface management with cover crops on dominant soil orders of the United States

Ultisols. Because of Ultisol formation processes in udic thermic climates, cover crop management on these soils in the southeastern United States *(7, 53)* tends to be more inextricably related to the USLE C factor *(65, 67)*. This climate regime permits vigorous growth of many cool-season cover crops. For soil erosion control purposes, cropping stages SB, 1, and 2 of an annual C factor are highly dependent upon the cool-season crop. Sojka et al. *(54)* demonstrates this in a review. When clover and perennial grasses were included in a conventional tillage system on Paleudult soils of the Atlantic and Gulf Coastal Plains, C factors declined 38% *(55)*. These values are relatively high because bare fallow and intensive crop rotating plots were used to calculate the soil loss ratios. However, generalized annual C factors associated with a conventional, monocropped tillage system are usually greater than 0.30 on both Hapludult and Paleudult soils.

Considerably more cover crop soil erosion research has been accomplished on Hapludult soils of the Southern Piedmont than on other Ultisols. Conventionally tilled cotton (*Gossypium hirsutum* L.) farming in the Southern Piedmont has caused soil losses averaging at least 20 tons/acre/year *(8, 10)*. This continuous row-crop management system was used as a standard for comparison with other tillage and cropping systems. Beginning in the early 1930s, warm-season annual and perennial cover crops, such as lespedezas (*Lespedeza cuneata* L. and *stricta* L.), alfalfa (*Medicago sativa* L.), and kudzu (*Pueraria thumbergiana* L.), were used to effectively reduce soil losses well below an accepted soil loss tolerance (T) value *(10, 16, 39)*. Most cover crop research during the 1930s used annual rather than seasonal rotations. Only conventional-tillage technology was available to plow-down these annual cover crops. Acceptance of cool-season cover crops came only with successful mulched tillage procedures developed during the 1940s and 1950s *(4)*. Mulch tilling corn (*Zea mays* L.) into vetch (*Vicia villosa* Roth), rye (*Secale cereale* L.), and crimson clover (*Trifolium incarnatum* L.) was compatible. Cover crops decreased soil losses on these runoff plots 62% (Table 1). In addition to improving soil characteristics for erosion control, a biological nitrogen (N) supply was available for each corn crop.

Concomitant tillage and herbicide development during the 1970s and early 1980s provided the first technology for using conservation tillage to plant summer annual row crops into cool-season cover crops *(14, 42, 57, 59)*. A long-term soil erosion data set *(25, 35)* from a Southern Piedmont watershed was chosen to represent this era (Table 2). These multiple crop systems tend to mimic forest systems studied by Copley et al. *(10)* during the 1930s. These data express the long-term value of a cool-season leguminous cover crop for soil erosion purposes in the Southern Piedmont.

Alfisols. Alfisols are found most extensively in humid and subhumid temperate regions *(7)*. The presence of winter cover crops on these soils has proved to be effective in

Table 1. Reduction of average annual runoff and soil loss with cool-season cover crops on USLE runoff plots.*

Location	Slope (%)	Cropping System	Average Annual Runoff (inches)	Average Annual Soil Loss (tons/acre)
Clemson, South Carolina	8	Continuous corn	6.0†	3.4†
		Corn with vetch & rye	1.7†	1.4†
Baton Rouge, Louisiana	4	Continuous corn	11.5	7.3
		Corn with winter cover	9.5	7.3
		Continuous cotton	14.6	4.8
		Cotton with winter cover	14.1	2.2
Tyler, Texas	9	Continuous cotton	12.1	60.7
		Cotton with vetch	10.7	57.7
State College, Mississippi	3-13	Cotton-cotton-corn	3.5	10.0
		Cotton-cotton-corn with winter cover	2.6	6.4

*After Wischmeier *(64)*.
†Corn growing season only.

Table 2. Annual stochastic soil loss comparisons expressing the value of cool-season crop in conservation tillage systems on an Ultisol*.

		Soil Loss by Exceedance Probability			
Tillage	Cropping System	0.2	0.4	0.6	0.8
		tons/acre			
Conventional	Fallow/soybean	22.30	17.40	13.80	10.70
Conservation	Wheat/soybean	0.05	0.02	0.01	0.01
Conservation	Crimson clover/grain sorghum	0.04	0.00	0.00	0.00

*After Mills et al. *(35)*.

Table 3. Soil erosion losses on Alfisols in systems including cover crops compared to no cover crop systems.

Summer crop	*Winter Cover Crop*	*Tillage System*	*Soil Loss (tons/acre)*	*Location and Reference*
Soybean	No cover	No-till	1.09	Missouri (69)
	Chickweed	No-till	0.19	
	Canada bluegrass	No-till	0.08	
	Downy brome	No-till	0.10	
Soybean	No cover	Conventional	3.34*	Tennessee (48)
	Wheat	Conventional	0.75*	
	No cover	No-till	0.05*	
	Wheat	No-till	0.04*	
Soybean	No cover	Conventional	4.04	Kentucky (45)
	Wheat	Conventional	0.51	
	No cover	No-till	0.19	
	Wheat	No-till	0.12	
Cotton†	No cover	No-till	8.93	Mississippi (37)
	Weeds	No-till	8.21	
	Hairy vetch	No-till	1.03†	
Cotton§	No cover	Conventional	0.45‡	Mississippi (37)
	Weeds	No-till	0.58‡	
	Hairy vetch/wheat	No-till	0.40	
Cotton#	No cover	Conventional	33.35	Mississippi (37)
	Weeds	Conventional	32.90	
	Hairy vetch/wheat	Conventional	9.11	

*Mean soil loss associated with soybean cropping/tillage systems during April-July study periods. Mean of 17 storms of high intensity that occurred in 1980-1986 that included natural storms and simulated rainfall.
†Following reduced tilled soybean.
‡One year of data.
§Following no-till soybean-wheat double-cropped.
#Following 11 years of conventional tilled corn/soybean.

reducing soil erosion. Recent studies on a Udollic Ochraqualf in Missouri *(69)* compared no-till soybean plots seeded to cover crops with a check-treatment without cover crops. Mean annual soil losses from chickweed (*Stellaria media* L.), Canada bluegrass (*Poa compressa* L.), and downy brome (*Bromus tectorum* L.) treatments were decreased 87%, 95%, and 96%, respectively, compared with the check plot with no cover crop (Table 3).

Studies conducted in western Kentucky on a Typic Fragiudalf soil showed an 88% (Table 3) reduction of soil erosion for conventionally tilled soybeans planted following double-cropped wheat compared with conventional tillage without a cover crop. In the no-till system, soil losses were small for treatments with and without cover crops. But, there was less soil erosion on plots planted to a wheat cover crop.

Studies on a Typic Paleudalf soil in western Tennessee *(48)* measured soil losses from 0.25-acre runoff plots, where soybeans were grown with different cropping systems. These systems included wheat planted as part of a double-crop system with conventional tillage and no-till and the same tillage comparison without a cover crop. The data in table 3 represent mean soil loss measured during April-July study periods. During this period, 17 high-intensity storms occurred in 1980-1986. Most of this was natural rainfall, however, supplemental events using a rainfall simulator were included. These findings were similar to those observed in western Kentucky. With conventional tillage, soil losses were significantly greater for single-crop soybeans without a cover crop than for treatments seeded to a wheat cover crop (Table 3). The no-till treatment showed no significant advantage of wheat as a cover crop as part of a wheat/soybean double-crop system compared with no-till without a cover crop.

Mutchler et al. *(38)* and Mutchler and McDowell *(37)* showed that conservation-tilled cover crops reduced soil erosion 47% and increased seed cotton yield 20% on a Providence silt loam (Typic Fragidulf) soil in Mississippi. Their use of vetch and winter wheat cover crops with conventionally tilled cotton was beneficial in reducing soil loss, but not sufficient for acceptable soil erosion control. With no-till, the cover crop contribution toward reducing soil erosion depends on the quantity of residue and its distribution on the soil surface. For some conservation tillage systems, residue of the previous year's crop may be sufficient to provide effective erosion control.

Mollisols. USLE research in the 1930s and 1940s established the role of meadow rotations for controlling soil erosion on midwestern soils (Table 4). Interest in growing cover crops for soil erosion control, especially following soybeans, was renewed with findings by Laflen and Moldenhauer *(23)*. They reported that between 1963 and 1969, soil loss from a Grundy silt loam (fine, montmorillonitic, mesic Aquic Argiudoll) was 35% greater for corn following soybeans than for either soybeans after corn or a continuous corn rotation. They attributed the increased soil erosion following soybeans to lower dry matter production, less residue cover, and soil-loosening action of soybean roots. These data compare favorably with a generalized meadow-rotation/cover crop soil erosion hazard (Table 5) developed by Miller et al. *(34)*.

When mean annual precipitation decreases from more than 40 inches on midwestern Mollisols to less than 12 inches on the western edge of the Great Plains, vegetative cover is a cardinal rule for controlling wind and water erosion *(9, 29)*.

For more northern locations, however, Karlen *(20)* recently reported that a major need in conservation tillage research was to develop cropping strategies and management schemes that make cover crops more compatible with common crop rotations. Power *(42)* also identified improving shade and cold tolerance of legume cover crop germplasm as a major research need for the Midwest.

An on-farm study recently demonstrated that the combination of ridge-tillage, cover crops, and manure applications significantly decreased runoff from a Clarion (fine-loamy, mixed, mesic Typic Hapludoll) hillside soil *(46)*. This was attributed in part to higher earthworm populations that were probably enhanced by overseeded cover crops because of increased protection during the fall and winter months *(51)*.

Model development for cover crop management

Historical perspective. National research needs for water and wind erosion control became highly visible with the dust bowl era *(5)*. A national research thrust to control soil erosion began during the early 1930s *(62)*. Wind *(68)* and water *(66)* models that assimilated the long-term national data sets for management planning were initially published during the early 1960s. These models, with revisions and their crop residue requirements, were published in a review format during the 1970s *(15, 49, 50)*. The water erosion model was referred to as the universal soil loss equation (USLE), and the wind erosion model as the wind erosion equation (WEQ). These and other selected soil erosion models, which include a cover crop management component, are discussed herein.

Universal soil loss equation. A data set that includes 8,000 runoff-plot years from 21 states was used to develop the USLE *(66)*. By analysis of this data set, Wischmeier *(66)* concluded that seeding vetch and ryegrass in cotton or corn plots before harvest and plowed-down the following spring was effective erosion control (Tables 1 and 4). These cover crops reduced soil erosion during winter months, as well as the following crop year *(44)*. For USLE crop stage 1, corn plots without winter cover had a soil loss ratio of 36%, while those with winter crop cover had a ratio of 22%. For USLE crop stage 2, soil-loss ratios were 63% and 46%, respectively.

The USLE data set included six research sites (Table 4) with meadow rotation treatments and four (Table 1) with winter cover crop treatments. The meadow rotation treatment reduced average annual runoff 31% to 65% and accompanying soil losses 42% to 92% . Winter cover crop treatment produced similar results. Plot slope and row direction also significantly influenced runoff and soil losses *(8, 10)*. Beale et al. *(4)* and Bruce et al. *(6)* described other factors and mechanisms that explain the effects of cool-season cover crops on soil erosion.

Wind erosion equation. Skidmore and Siddoway *(50)* demonstrated the paramount importance of crop residues for controlling wind erosion. The data set assembled in this review publication accompanies the WEQ *(68)* to provide wind erosion control technology on about 74 million acres of the nation's land resource area *(60)*. Additional literature review only creates redundancy, so only research associated with the WEQs vegetative components since 1978 follows herein.

Lyles and Allison *(27, 28)* reported the protective role of crop residue and range grasses as flat small-grain equivalent of the form:

$$SGE = ax^b \quad [1]$$

where SGE is flat-small-grain equivalent (pounds/acres), x is the quantity of residue or grass to be converted, and a and b are experimentally determined regression constants. The flat-small-grain equivalent is converted to the vegetative factor that is needed to estimate wind erosion by the Woodruff and Siddoway *(68)* procedure.

Woodruff and Siddoway *(68)* graphically demonstrated the relationship between flat-small-grain equivalent (SGE) and vegetative factor (VE). Williams et al. *(62)* fit an equation to the graphical relationship to give:

$$VE = 0.253\,(SGE)^{1.363} \quad [2]$$

Until recently, all small-grain equivalence data have been limited to dead crop residue or dormant grass. Armbrust and

Table 4. Reduction of average annual runoff and soil loss with meadow rotations on USLE runoff plots.*

Location	Slope (%)	Cropping System	Average Annual Runoff (inches)	Average Annual Soil Loss (tons/acre)
Bethany, Missouri	8	Continuous corn	8.2	50.9
		Corn-wheat-clover & timothy	4.9	9.1
LaCrosse, Wisconsin	16	Continuous corn	9.9	111.7
		Corn-barley-clover	5.8	27.8
Clarinda, Iowa	9	Continuous corn	5.6	37.8
		Corn-oats-meadow	2.7	11.7
Tifton, Georgia	3	Continuous corn	2.9	1.2
		Corn-oats-meadow-meadow	2.0	0.7
Guthrie, Oklahoma	8	Continuous cotton	4.1	24.2
		Cotton-wheat-clover	2.7	5.9
Ithaca, New York	19	Continuous corn	6.5	6.6
		Corn-oats-meadow	2.3	0.6

*After Wischmeier, *(64)*.

Table 5. Relative erosion hazard of selected crop sequences (continuous corn = 100) on Mollisols.*

Crop Sequence†	*Relative Erosion Hazard*
Fallow	256
C-Sb	131
C-C-Sb	120
Continuous corn	100
C-C-C-Ox	74
C-C-Ox	64
C-Ox	46
C-C-C-O-M	49
C-C-O-M	36
C-C-O-M-M	28
C-C-O-M-M-M	26
C-O-M	18
C-C-O-M	15
C-C-O-M-M	13
C-C-O-M-M-M	10
Continuous cover	-

*After Iowa State Extension Services, Ames, Iowa, Miller et al. (*34*).
†C-corn; Sb-soybeans; O-oats; Ox-oats with green manure crop; M-meadow.

Lyles *(1)* reported flat-small-grain equivalents for growing corn, cotton, grain sorghum [*Sorghum bicolor* (L.) Moench], peanuts (*Arachis hypogaea* L.), and soybeans [*Glycine max* (L.) Merr.],

$$SGE = a_1 R_w^{b1} \quad [3]$$

where Rw is the aboveground dry weight of the crop to be converted (pounds/acre), and a_1 and b_1 are constant coefficients for each crop. They found that if only rough estimates of SGE are needed, an average coefficient could be used. An average equation determined from pooling all crop data with rows running perpendicular to wind direction yielded 8.9 and 0.9 for a_1 and b_1, respectively.

Cover crops, where they can be grown, give effective wind erosion protection. They are especially applicable in regions more humid than the semiarid lands of the historical dust bowl. Their protective value at a specific growth stage for use in the Woodruff and Siddoway *(68)* wind erosion prediction method, and variations thereof, can be estimated by using equation 3.

In the developing the "Wind Erosion Prediction System" *(13)*, crop growth is simulated by a generalized growth model, CROP, which calculates potential growth of leaves, stems, yield, and root components. The potential growth is modified by stresses of temperature, fertility, and water. The CROP submodel, using biomass as an independent variable, also predicts distributions of leaf and stem silhouette area with height, canopy height, canopy cover, and flat biomass cover. That information, along with other pertinent information, then is input into an EROSION submodel for computing soil loss from wind.

Erosion-productivity impact calculator. The Erosion-Productivity Impact Calculator (EPIC) was originally designed to determine the relationship between soil erosion and soil productivity in the 1985 Soil and Water Resource Conservation Act (RCA) Analysis *(43)*. The model has been adapted for solving numerous agricultural management problems. A recent adaptation of that model was motivated by the need to determine the effects of winter cover crops on ruoff and soil erosion. Data sets from three small watersheds near Riesel, Texas, were used for testing purposes (Table 6 and 7). These Vertisol watersheds are dominated by Houston Black (fine,

Table 6. Observed and EPIC-simulated flume yields from three watersheds during a cover crop period, October-May.

	Oat Cover Crop				*Fallow*			
	Runoff		*Sediment*		*Runoff*		*Sediment*	
Watershed	*Observed*	*Simulated*	*Observed*	*Simulated*	*Observed*	*Simulated*	*Observed*	*Simulated*
	inches		*tons/acre*		*inches*		*tons/acre*	
No. 1	3.35	3.11	0.29	0.27	4.29	3.82	0.85	0.87
No. 2	5.24	4.13	0.21	0.17	3.66	4.02	0.63	0.67
No. 3	2.95	4.13	0.09	0.15	5.98	5.79	1.43	1.19

Table 7. EPIC-simulated (20 years) watershed flume yields associated with fallow, wheat, and clover cover conditions.

		Cotton/Grain Sorghum		*Cotton/Wheat/Grain Sorghum*		*Cotton/Clover/Grain Sorghum*	
Month	*Rainfall (inches)*	*Runoff (inches)*	*Sediment (tons/acre)*	*Runoff (inches)*	*Sediment (tons/acre)*	*Runoff (inches)*	*Sediment (tons/acre)*
January	1.50	0.16	0.01	0.12	0.00	0.16	0.00
February	2.17	0.28	0.05	0.20	0.01	0.24	0.00
March	2.20	0.20	0.03	0.08	0.01	0.12	0.01
April	3.50	0.71	0.12	0.47	0.02	0.51	0.03
May	4.37	1.10	0.18	0.91	0.06	0.87	0.07
June	2.83	0.35	0.02	0.31	0.02	0.31	0.02
July	1.85	0.08	0.01	0.08	0.01	0.08	0.01
August	1.89	0.12	0.01	0.12	0.01	0.12	0.01
September	2.32	0.32	0.03	0.31	0.01	0.32	0.01
October	3.58	0.63	0.10	0.59	0.07	0.63	0.06
November	3.82	0.59	0.06	0.47	0.01	0.51	0.01
December	3.66	0.63	0.08	0.43	0.01	0.51	0.01
Annual	33.70	5.16	0.69	4.13	0.21	4.37	0.22

montmorillonitic, thermic Udic Pellusterts) soils. Watershed areas ranged from 16.3 to 20.8 acres, with average slopes ranging from 1.88% to 3.21%. The 3-year crop-rotation consisted of cotton, grain sorghum, and oats (*Avena sativa* L.). A winter cover of oats occurred on each watershed every third year. Oats were planted about October 15 and harvested about June 1 each year. Table 6 presents both observed and simulated runoff and sediment yields for the cover crop period (October-June). EPICs prediction efficiency averages 93% for runoff and 83% for sediment.

To accommodate leguminous, cereal grain, and fallow cover between corn crops, a 16.3-acre watershed with 2.24% slope for a 20-year simulation without crop rotation was assumed. Three simulations were performed using identical weather generated by EPIC. Table 7 provides simulated average monthly and annual rainfall, runoff, and sediment yield for the three simulated cover conditions. Based on these results, cool-season cover crops appear to provide a distinct soil erosion protection value, even on Vertisols formed on slopes averaging less than 4.0%.

Revised universal soil loss equation. The USLE has been revised to accurately estimate soil loss from both crop and rangeland. This revision incorporates technology developed since the 1978 version of the USLE *(67)*. The result is the revised universal soil loss equation (RUSLE) *(32)*. The basic structure of the USLE has been retained, but the algorithms used to calculate the individual factors have been changed significantly. One important change is in the computerization of the technology. This allows computation of the soil-loss ratio by 15-day intervals rather than by longer crop stage periods as in the USLE. This improves estimates of the factors affecting the soil loss ratio, such as surface roughness, crop growth, and residue decomposition. Another change is in use of a time-variant soil erodibility factor, which reflects winter freeze-thaw effects and the consolidating effect of moisture extraction by a growing crop during the summer months. New slope-length and steepness relationships were developed from plot data and detachment theory *(30, 31, 33)*. The relationships consider the relative susceptibility of the soil to rill versus interrill erosion. Separate relationships were developed specifically for the freeze-thaw-affected dry-farmed cropland region of the Pacific Northwest.

The cover-management factor is perhaps the most important factor of either the USLE or the RUSLE because it represents conditions that can be managed most easily to reduce erosion. The soil-loss ratio (SLR), which is weighted by the annual erosivity distribution to produce the cover-management factor, is calculated as a product of four subfactors by Laflen et al. *(22)*, as follows:

$$SLR = PLU \times CC \times SC \times SR \quad [4]$$

where PLU is prior land use, CC is crop canopy, SC is surface or ground cover, and SR is the surface roughness. The soil-loss ratio is far more sensitive to surface cover than to other factors. The effect of surface cover on soil erosion is given by a negative exponential relationship:

$$SC = e^{-bm} \quad [5]$$

where m is the fraction of the land area covered by plant material and b is a regression coefficient. Laflen et al. *(24)* and Laflen and Colvin *(21)* found b values ranging from 3.0 to 7.0 for row crops, while Dickey et al. *(11)* found b values of 2.4 to 3.2 in a rainfall-simulation study on small grains. In the Pacific Northwest, where much of the annual erosion is in the form of rills caused by snowmelt or rainfall on thawing soil, data from runoff plots on a Palouse silt loam (fine-silty, mixed, mesic Pachic Ultic Haploxeroll) near Pullman, Washington (Table 8), indicates a b-value greater than 5. Slopes at this study site ranged from 19% to 26% and soil losses from bare fallow plots often exceed 65 tons/acre/year. Winter wheat and spring dry peas (*Pisum sativum* L.) provide residue cover ranging from 11% to 96%. However, recommendations for b-values for use in RUSLE are 2.5 with interrill erosion (such as rangeland) and 3.5 for cultivated cropland conditions *(41)*. The data set presented herein suggests that specific technology associated with the RUSLE model is important for managing crop residues to control severe soil erosion of the Pacific Northwest.

Conclusion

Wise use of cover crop technology is essential to accomplish sustainable agriculture objectives. Sustainable agriculture must control soil erosion by both wind and water. Some 20% of the 420 million acres of cultivated cropland in the United States also requires soil productivity restoration. Use of cover crops in conservation tillage systems may offer sustainable solutions to best accomplish both goals. An assessment of more than 50 years of cover crop research in soil erosion control suggests their essential role on the nation's cultivated landscape.

Dominating Ultisol, Alfisol, and Mollisol soil orders received extensive cover crop attention in soil erosion control and restoration studies. We associate most of these research

Table 8. Relationship of RUSLE's surface cover (SC) subfactor to percent crop residue cover on a Palouse silt loam soil.*

Tillage	*Cropping System*	*Surface Residue (%)*	*Surface Cover (SC) Subfactor*
Conventional†	Fallow	0	1.0
Conventional‡	Summer fallow/winter wheat	11	0.57
Conventional‡	Wheat§/winter wheat	42.5	0.22
No-till seeded	Spring peas/winter wheat	58.0	0.073
No-till seeded	Wheat§/winter wheat	96.5	0.0050

*Data set includes 1978/1979 through 1983/1984 winter erosion seasons.
†Tillage to maintain bare fallow conditions.
‡Tillage representative of the Palouse Soils Resource Area (*11, 53, 58*).
§Rotating spring and winter wheat.

activities with a long-term conservation tillage evaluation. Cover crops are best adapted to conservation tillage efforts for Ultisols and Alfisols. However, different research approaches were more discretely associated with soil resource areas within soil orders. We attribute this to cover crop species adaptation to climate and soil formation processes. Because of the xeric and boreal climate association of Mollisols, meadow rotations serve as the best vegetative cover. Conservation tillage technology has only recently approached a threshold to capitalize on the beneficial functions of cover crops for soil erosion control. Because of fragmentation of research efforts, as well as the short-term economic policy structure of American agriculture, cover crop use is prohibitive on much of the nation's landscape. Cover crop discouragement on Ultisols was exhibited only recently in the Conservation Reserve Program of the 1985 Food Security Act.

Hydrologic models that include vegetative parameters for soil conservation purposes may enhance the importance of cover crops for soil erosion control. Current model development for agroecosystems has also experienced a long-term evaluation process. Those models that appear most applicable for managing cover or meadow crops for soil erosion control herein are the USLE, WEQ, EPIC, and RUSLE. This model diversity is similar to the different cover crop management requirements for the nation's diverse soil family and series association. These soil erosion control tools may serve to stimulate best management of our most important renewable natural resource—crop vegetation—in an economical and environmental manner.

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Effects of crop residue and tillage practices on water infiltration and crop production

George C. Naderman

In a 3-year study on sloping, crust-prone soils of the North Carolina Piedmont, Wagger and Denton *(2)* found that no-till corn and soybean yields were 32% and 43%, respectively, greater than on conventionally tilled plots. Measurements indicated that soil moisture in the upper 6 inches was greater in the no-till plots on several dates. They believed this was due to reduced runoff and increased water infiltration by the soil. However, in a coarser textured soil of the Coastal Plain, yield differences due to tillage practices were less prominent.

Methodology

In this study we measured water intake as influenced by tillage and surface residue effects using a sprinkling infiltrometer. The type of oscillating nozzles and resulting droplet characteristics were similar to those reported by Meyer and Harmon *(1)*. The equipment was modified by suspending nozzles on rails that extended from the transport trailer over the study area. We made one 39-minute run in each plot of the experiment. Infiltration was measured in two adjacent, bordered 11-square-foot areas.

Water that failed to infiltrate and collected in low areas was removed by vacuum and measured periodically. The data reported include actual water intake by the soil. We determined the application rate with collection trays just after each run. Corn was grown and infiltration measurements were conducted late in the season. We cut plants at about the 6-inch height and removed them from the study area.

We conducted the experiments at two locations during 1989 and 1990. The soils are Craven fine sandy loam (Clayey, Mixed Aquic Hapludult) and Wickham fine sandy loam (Fine Loamy, Mixed Typic Hapludult). Both locations are nearly level. In 1989, there were four replicates on the Craven soil and five on the Wickham soil. In 1990, there were eight replicates on both sites.

On the Craven soil, we established an oat cover crop with shallow tillage in the preceding fall each year. For treatments with no residue, the cover crop was destroyed by shallow tillage in February or March. On the Wickham soil, no cover crop was established either year. In each experiment one or more treatments involved no-till planting into the cover crop or previous crop residue. We applied common burn-down herbicides to all plots.

The tillage practices compared are listed in tables 1 and 2. On the Craven soil, the ParaTil system, a product of the Tye Company, was included each year. This uses special "legs," originally used on the Howard Paraplow, except that these were mounted further apart at a 38-inch spacing. The system involves a trash-cutting coulter ahead of the shank, mounted such that the soil is loosened to about a 16-inch depth beneath each row. We attached the planter to the unit, which allowed row tillage, band fertilization, and herbicide application in one pass. The Beasley unit used in 1989 is a modified no-till planter that uses short shanks with pressure and closure wheels, preparing about an 8-inch wide seedbed zone. In 1990, the "Farm for Profit" (FFP) microbial inoculum product was applied to the surface and incorporated by cultivation.

On the Wickham soil, residue cover in the no-till treatment at the time of infiltration studies in 1989 was generally 60% to 90%. This residue was mainly from wheat, because the preceding soybean crop had been no-till planted into heavy wheat straw. In 1990, the no-till plots had 30% to 60% residue cover, primarily from the preceding corn crop. In the treatment involving cultivation, we used a small rotary garden tiller. In 1989, the bedding treatment used a double-disk bedder without ripper, with a formed-metal bed shaper. In 1990, we used a powered rotary tiller with levelling board to form a wide, low bed. In both years, the chisel plow/plant treatment involved planters mounted onto the chisel plow, with no

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Table 1. Water intake from 39-minute application of 1.3-inch simulated rainfall on Craven Fine Sandy Loam.

Treatment	Water Intake (inches) 1989	1990
No-till, oat residue	0.62	0.79
ParaTil-no-till, oat residue	0.62	1.09
Beasley no-till	0.62	
Disked, no residue	0.45	
Disk + paraTil, no residue	0.58	
Disk + rip/bed, no residue	0.57	
Field cultivator*-FFP†, no residue		0.61
Field cultivator, no residue		0.52
Field cultivator + paraTil, no residue		0.60
Field cultivator + rip/bed, no residue		0.61

*Field cultivator, "S" tine with rolling crumbler.
†FFP is a proprietary soil inoculant product, not marketed in North Carolina.

Table 2. Water intake from 39-minute application of 1.3-inch simulated rainfall on Wickham Fine Sandy Loam.

Treatment	Water Intake (inches) 1989	1990
No-till, wheat/soybean residue	0.65	
No-till, corn residue		0.75
Disk* + chisel plow† + disk	0.52	0.58
Disk + chisel plow + disk + cultivator	0.45	
Disk + bedder/shaper‡	0.49	
Disk + chisel plow/planter§	0.56	0.60
Disk	0.50	
Disk + chisel plow + disk-FFP#		0.59
Disk + chisel plow + disk + rotary tiller/ bedder/shaper		0.53
No disk + chisel plow/planter		0.85

*Disked once or twice.
†Chisel plow about 9 inches deep.
‡Double-disk bedder followed by metal bed-shaper.
§Chisel plow with planters attached; one-pass chisel/plant.
#FFP is a proprietary soil innoculant, not marketed in North Carolina.

secondary tillage or wheel compaction between tillage and planting. The planters followed in positions between the chisel tines.

Results

On the Craven soil in 1989, all treatments having little disturbance of the surface residue had equal water intake, about one-third greater than the disked treatment. ParaTil in the absence of surface residue increased water intake to almost equal that of the no-till treatments. But ParaTil did not increase intake in the presence of surface residue. The rip/bed treatment also increased infiltration.

In the Craven soil in 1990, the results were quite different. There was no significant difference among any of the no-residue treatments. The effect of ParaTil was significant in the presence of residue but not apparent in the absence of residue. Water intake on no-till-alone plots was significantly greater than on any of the clean-tilled plots.

For the Wickham soil in 1989, only the no-till treatment showed greater water intake than the others. The cultivated treatment allowed greater soil crusting. In 1990, water intake again was greater on the no-till plots than any of the clean-tilled treatments. There was no significant reduction in water intake by the rotary-tilled treatment, compared to the various treatments involving chiseling and disking. However, water intake on the no-disk, chisel/plant treatment was greater than for the no-till treatment alone (significant at 10%). The FFP treatment was not significantly different from the comparable tillage treatment in either soil.

We took standard soil bulk density measurements adjacent to the infiltration studies for the Wickham soil (Table 3). Also included was a nearby long-term, no-till field on the same soil series. These results show significantly higher bulk density in the no-till plots. The long-term, no-till field was not different in density from the 2-year, no-till plots.

Corn yields in the Craven soil in 1989 were correlated with measured water intake, ranging from 119 bushels to 143 bushels/acre. However, in 1990 there was almost no rainfall during June and July, and all treatments yielded 55 bushels to 60 bushels/acre. On the Wickham soil, there was moderate drought stress in 1990 but no significant differences related to treatments.

Table 3. Soil bulk density, surface 3 inches for the Wickham soil.

Treatment	1989	1990*
	gm/cm³	
No-till, 2 years	1.58†	
Disk + chisel plow + disk	1.46‡	1.21
Disk + chisel plow/planter	1.24‡	1.21
No-till > 10 years	1.53§	
No-till, corn residue		1.52
Disk + chisel plow + disk + FFP		1.21
Disk + chisel plow + disk + rotary tiller/ bedder/shaper		1.17
No disk + chisel plow/planter		1.29

*For 1990 each value is mean of eight replicates.
†Mean of 20 samples.
‡Mean of 10 samples.
§Mean of 8 samples.

Conclusions

Surface residue, either from cover crops or previous wheat or corn crops, can increase potential water intake as measured by this type of infiltrometer. Water intake on standard coulter, no-till planting treatments was 25% to 50% greater than for shallow, conventionally tilled plots.

ParaTil and rip/bed treatments may increase potential intake somewhat, but effects were varied. This was probably due to differing early season rainfall patterns.

Infiltrometer measurements of this type probably closely predict yield responses due to water intake differences on crusting, sloping soils. However, on nearly level soils, measured differences probably exceed actual yield responses due to differing runoff rates from rainfall events.

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ERRATUM: This sheet replaces pages 25 and 26 in *Cover Crops for Clean Water* and corrects typographical and data conversion errors in tables 1, 3, and 4. SWCS regrets the errors.

Soil surface condition effects on runoff and erosion on selected vineyard soils

P. J. E. Louw and A. T. P. Bennie

Formation of a seal or crust at the soil surface, mainly as a result of the drop impact from rain and sprinkler irrigation, is a common feature in many soils, particularly in arid and semiarid regions *(6)*. Crust formation reduces water infiltration, increases runoff and soil erosion potential, and reduces seedling emergence *(4)*. In arid and semiarid climates, reducing runoff will increase profile soil water *(5)*.

On a bare soil surface, crust formation is caused by two mechanisms: (a) breakdown of the soil aggregates by drop impact and (b) a physicochemical dispersion of the soil clays, which can then migrate into the soil with the infiltrating water and clog the pores immediately beneath the surface, thereby creating the "washed-in" zone *(5)*. Soil crusting is affected by texture, clay type, organic matter, and sesquioxide content of the soil. Crop and tillage history, as well as climate, also play a role in crust formation *(2)*. Where the chemical dispersion of clay is predominant in crust formation, stabilization of soil aggregates by phosphogypsum or other chemical substances may prevent crust formation *(5)*. One cannot protect the soil chemically against the beating action of raindrops, which is the main agent in crust formation. But, by covering the soil with plant residues one can usually prevent crust formation.

The detrimental effect of clean tillage on overall vineyard performance was proven for both dryland and irrigated vineyards *(7, 8)*, but its effect on runoff and erosion has as yet not been studied in the vineyards of South Africa. Scientific evidence is needed to quantify the dangers of injudicious cultivation practices to the soil and environment. Herein, we report on studies performed to quantify runoff and erosion under different soil management practices.

Methodology

Field trial. The field trial included six treatments (B1 - B6, table 1), replicated four times in a randomized block design on an Avalon sandy loam soil *(3)* with an average slope of 6.7% near Stellenbosch, Republic of South Africa, which is situated in a winter rainfall region. We separated plots (43 square feet) with asbestos sheeting. We collected and measured runoff from each plot after each rain event. Table 1 shows treatments, with the amendments applied to the soil surface.

Laboratory trial. We used a rotating disc type rain simulator as described by Agassi and Du Plessis *(1)*. We packed soil 0.8 inch deep in trays (12 x 20 inches) over a coarse sand layer. Each of the six treatments was replicated four times (see above). A slope of 5% and a rain intensity of 1.8 ± 0.03 inches/hour was used. The electrical conductivity of the applied water was 1.4 ± 0.06 mho/foot. Six different soils with different crusting potentials were investigated (Table 2).

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Results and discussion

In the field trial, the 3.8-ton/acre phosphogypsum treatment resulted in a runoff loss of 11% of the total 23.5-inch rainfall, whereas the corresponding value for the bare soil surface (control) was 27%. In the laboratory, the phosphogypsum could only prevent crust formation at the beginning of a simulated rainstorm. Crust formation due to accumulation of kinetic droplet energy resulted in a final infiltration rate comparable to that of the control (Table 3), with only the Estcourt, Avalon, and Clovelly soils showing a significant increase in final infiltration rate with the 4.5-ton/acre phosphogypsum treatment. In some instances, we found erosion from the phosphogypsum treatments under the rain simulator was even higher than that of the control (Table 4), possibly due to the presence of gypsum in the sediment. The field trial did not show the same tendency regarding erosion, although the runoff water from the phosphogypsum plots settled out cleanly, thus indicating a presence of salts. Therefore, both trials indicated erosion of applied phosphogypsum from the soil. This fact has environmental implications that need further investigation.

On both the Clovelly and Glenrosa soils, the final infiltration rate with 3.6 tons/acre of straw mulch under the rain simulator was comparable to the application rate, and thus, almost no runoff occurred. For the other soils, the same straw mulch treatment resulted in a final infiltration rate of more than 0.39 inches/hour, which is more than the application rate of most irrigation systems on vineyard soils. However, partial covering of the soil surface, e.g., 0.9 ton/acre straw mulch under the rain simulator, resulted in a rapid decrease in

Table 1. Treatments used in the study.

Field Trial	*Laboratory Trial*
B1 = Control-no amendments	Control-no amendments
B2 = Straw mulch (3.3 tons/acre)	PG (2.2 tons/acre)
B3 = Cover crop (Triticale)	PG (4.5 tons/acre)
B4 = PG* (2.2 tons/acre)	Straw mulch (0.9 ton/acre)
B5 = Polyacrylamide (4.5 pounds/acre)	Straw mulch (3.6 tons/acre)
B6 = PG (3.8 tons/acre)	PG (2.2 tons/acre) + straw mulch (0.9 ton/acre)

*PG = Phosphogypsum

Table 2. Properties of the soils investigated.

Soil name	*Sand*	*Silt*	*Clay*	*Texture*	*Dominant Clay Mineral*
		%			
Estcourt	53.97	25.06	20.32	Sandy clay loam	Kaolinite
Dundee	43.24	39.84	16.34	Loam	Illite
Avalon	65.09	19.34	15.52	Sandy loam	Kaolinite
Katspruit	58.92	32.57	8.31	Sandy loam	Kaolinite
Clovelly	46.92	28.96	22.38	Loam	Kaolinite
Glenrosa	59.23	27.29	14.71	Sandy loam	Kaolinite

Soil names from MacVicar and Soil Survey Staff (3).

Table 3. Average final infiltration rate on six different soils as measured with a rainfall simulator in the laboratory.

Treatment	Final Infiltration Rate by Soil Type (inches/hour)					
	Estcourt	*Dundee*	*Avalon*	*Katspruit*	*Clovelly*	*Glenrosa*
Control	0.07a*	0.12a	0.09a	0.10a	0.11a	0.12a
PG (2.2 tons/acre)	0.10ab	0.11ab	0.18b	0.12a	0.19bc	0.23a
PG (4.5 tons/acre)	0.13b	0.11ab	0.24c	0.14a	0.23c	0.26a
Straw mulch (0.9 ton/acre)	0.08a	0.08b	0.13ab	0.10a	0.15ab	0.17a
Straw mulch (3.6 tons/acre)	0.41c	0.50	1.17d	0.78b	1.75d	1.66b
PG (2.2 tons/acre) + Straw mulch (0.9 ton/acre)	0.17d	0.17	0.47e	0.27c	0.50e	0.43c
Coefficient Variation (%)	8.45	8.81	5.52	9.13	5.15	14.07

*Values in the same column designated by the same symbol do not differ significantly (P = <0.05) for each treatment.

Table 4. Average cumulative soil erosion from six different soils after a 2.5-inch water application as measured with a rainfall simulator in the laboratory.

Treatment	Cumulative Soil Erosion by Soil Type (tons/acre)					
	Estcourt	*Dundee*	*Avalon*	*Katspruit*	*Clovelly*	*Glenrosa*
Control	1.66	1.99	0.99	1.08	0.77	1.38
PG (2.2 tons/acre)	1.69	2.22	0.67	1.32	0.75	0.54
PG (4.5 tons/acre)	1.01	3.25	0.81	1.06	0.37	0.37
Straw mulch (0.9 ton/acre)	0.95	0.96	0.33	0.48	0.18	0.37
Straw mulch (3.6 tons/acre)	0.29	0.40	0.14	0.11	0.00	0.03
PG (2.2 tons/acre) + Straw mulch (0.9 ton/acre)	0.61	0.83	0.22	0.30	0.10	0.20

infiltration rate, with the final infiltration rate never significantly higher than that of the control. A straw mulch of 3.3 tons/acre was consistently the best treatment in the field trial and resulted in only 4% runoff of the total rainfall (Figure 1). Erosion was significantly lower than that of the control and phosphogypsum treatments, both in the field and in the laboratory. High runoff occurred from the cover crop treatment (B3, figure 1) while the seedlings were still too small to cover the soil completely. Complete covering of the surface, thus, is necessary to prevent crust formation on these soils.

A 1.6-inch irrigation in the field resulted in almost no runoff from the straw mulch (B2) and cover crop (B3) treatments, while runoff from the control was 29%. The cover crop thus showed comparable results to the straw mulch under irrigation and also during winter rainfall (Figure 1) and effectively prevented soil erosion. A cover crop grown in situ provides an economically favorable alternative to the more expensive straw mulch, which we grew elsewhere and brought into the vineyard. Combining a straw mulch and phosphogypsum showed a strong synergistic effect under the rain simulator (Table 3). This combination may be important in the field as the phosphogypsum may prevent crust formation to a certain extent during germination of the cover crop and until the seedlings cover the soil completely.

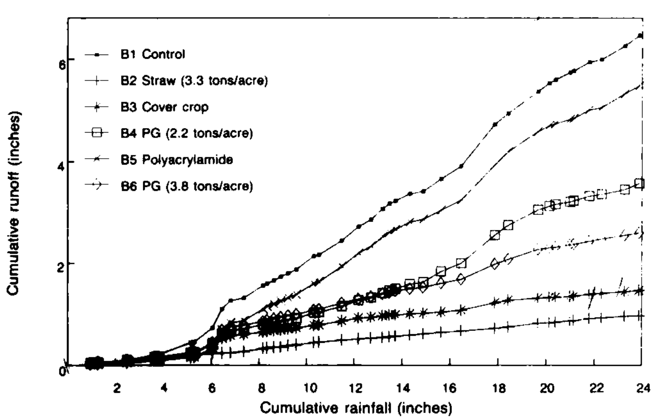

Figure 1. Average cumulative water runoff from an Avalon soil at Nietvoorbij, Stellenbosch, South Africa, April-October, 1989.

Covering the soil by either a straw mulch or a cover crop proved to be the most effective way to prevent runoff and erosion from vineyard soils, with the cover crop probably the most economical alternative. Growing a cover crop has the added advantage that it can effectively prohibit the growth of weeds during the summer months *(7)*; thus, one can eliminate the use of preemergence herbicides that have a potential environmental hazard.

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Cover crop experience in South Coastal British Columbia

Geoff A. Hughes-Games and Ron A. Bertrand

The South Coastal region of British Columbia is climatically unique to agricultural areas of North America and possibly the world. Mild temperatures and heavy precipitation during the winter months result in serious soil degradation, caused either by human activity or natural processes. Soil erosion by wind or water is the major degradation problem, but compaction and nutrient leaching are also serious problems throughout the region *(3)*. Many attempts have been made over the history of agriculture in the region to reduce the occurrences of and damage caused by soil degradation. Cover crops have been studied by several researchers and agriculture extension agencies as one means of controlling some of these processes *(2, 7)*. Over the years, the use of cover crops in farming operations for erosion control and organic matter accumulation has been intermittent, but recently their use has increased.

Although we often associate cover crops with water management for erosion control in South Coastal British Columbia, water management, through subsurface drainage, is essential for the survival of overwintering crops. This is particularly true in the lowland and poorly drained upland areas, where water may remain ponded on the soil surface for extended periods.

With some 200 soil series present in the region, understanding soil-crop interactions becomes a formidable task *(4, 6)*. Figure 1 shows the location of four communities within the agricultural areas of the Lower Fraser Valley portion of South Coastal British Columbia. In the Abbotsford area, generally well-drained, highly erodible loess or glacio-marine surface layers overlay gravelly glacial till or outwash in the uplands. The soils in the upland areas are very susceptible to water erosion and, partially due to their porosity, groundwater pollution from nitrates has occurred. In the lowlands, poorly drained, fine-textured floodplain and lacustrine soils are present. Fine-textured marine and deltaic soils, which are poorly drained and susceptible to soil compaction, dominate the Delta-Ladner area. There are two large areas of poorly drained organic soils to the east and northeast of Delta-Ladner, one of which is important for vegetable production. Large areas of poorly drained glacial outwash and organic soils are found in the Pitt-Polder area. Soils in the Chilliwack area, known for its dairy and vegetable production, are predominantly formed on poorly drained lacustrine and local stream deposits of silts and sands. The area between Chilliwack and Abbotsford is very susceptible to wind erosion during arctic air outflow conditions. All lowland areas are subject to intermittent flooding or ponding during winter storm events and/or the Fraser River freshet.

The mean daily temperatures for all four communities range from a low of about 35.0° F in January to a high of about 63.0° F in July *(1)* (Table 1). Due to the moderate temperatures at Ladner-Delta, snow cover is rare. Chilliwack, on the other hand, experiences a wider range of temperatures that often result in winter snow cover and summer drought *(1)*. The frost-free period for the region ranges from 180 to 210 days *(4)*. Annual precipitation ranges from a low of 35 inches at Delta-Ladner to a high of 90 inches at Pitt-Polder *(1)* (Table 2). Annual precipitation at Abbotsford and Chilliwack is 60 and 74 inches, respectively. This high number of frost-free days and the annual precipitation distribution are very significant when we consider cover crop use.

Discussion

Because of the mild winter in the South Coastal region of British Columbia, it is important that producers have a clear understanding of their goal when considering a cover crop. Spring cereals, some small seeded legumes, winter cereals, forage brassicas, and annual grasses all perform well in this climate. An early seeded spring cereal, such as barley, will give excellent growth and, therefore, is useful as an erosion control crop. However, in most years the top of the plants winterkill and these crops cannot be used for forage production. The spring cereals are used extensively in the interrow area of small fruit fields, especially raspberries (*Rubis idaeus* L.). Spring cereals are also used in areas where vegetable production occurs on organic soils. In both cases, the producer's goal is to have rapid growth that will protect the soil from erosion. The purpose of the cover crop in the organic soil/vegetable production areas is twofold. The first is to protect against surface-soil-structure degradation—puddling—because these areas often remain flooded during the winter. The second is to prevent wind erosion during periods when these soils are frozen. The small fruits are generally grown in upland areas where water erosion is prevalent. The spring cereal usually mats down after the first killing frost, providing erosion control and increased trafficability, which allows for winter

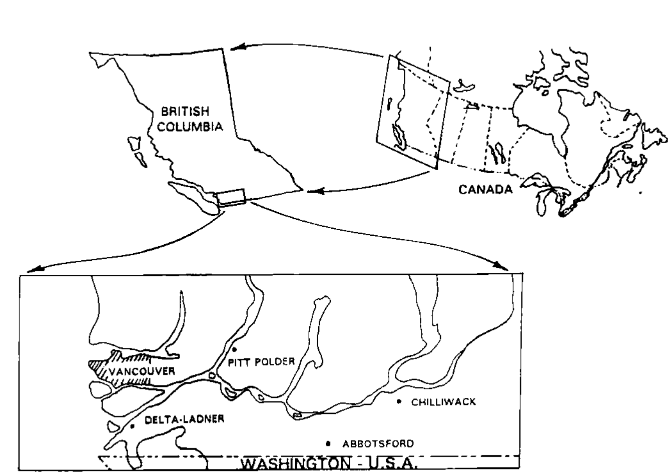

Figure 1. Lower Fraser River Valley portion of South Coastal British Columbia.

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pruning. A complete water-control system in the form of surface and subsurface drainage works, along with a cover crop, is essential in most of the upland areas. We measured soil erosion rates of 17.9 tons/acre/year where no erosion control system is in place compared with 0.3 ton/acre/year where one type of system was used *(8)*.

Cereal cover crops, particularly fall rye and spring barley, have historically been used in bulb production areas for soil erosion control and organic matter incorporation. Recently, nursery tree and shrub producers have begun to use annual grasses and cereals in the interrow areas of field-grown stock. These cover crops not only reduce soil loss, but aid in trafficability of the fields during fall and spring digging operations.

We must consider several factors prior to planting a cover crop in the region. If the cover crop is going to be used for the capture of nutrients, in particular nitrogen (N), then it must either be planted between late August and early September, or it must be capable of a good flush of fall growth. If the crop is to be grown strictly as a cover to reduce the potential for wind and/or water erosion, then it must have the ability to produce sufficient cover before the heavy rains of late October begin or to withstand the desicating winds of late January. If the crop is to be grown only as a spring forage, then the maximization of fall growth is not that important. For forage production, a healthy crop is more important. Species, seeding rate, mixture of species, and date of seeding are critical factors. Cover crops grown for harvest of grain require an intensive cereal management program in order to maximize yield potential. An intensive cereal management program requires specific seeding dates, seeding rates, and nutrient levels and may not produce sufficient crop growth for either erosion control or the capture of leachable nutrients.

The largest increase in cover crop use in the region in the past few years has been in the area of double-cropping for forage production in the dairy industry. Dairy farmers have begun to plant annual forages after the mid-fall harvest of silage corn. The annual forage grasses in use are winter wheat and Italian ryegrass, planted alone or in combination with one or more annual legumes such as Austrian winter peas or hairy vetch. Fall rye has been used, but due to the aggressive nature of the spring growth in our climate, its use is no longer recommended. Use of the annual legumes is not recommended because they are not competitive with weeds and the risk of winterkill is relatively high.

Forage brassicas (especially cultivar Typhon) are a new crop that have been introduced to the area, but their use is not wide spread (personal communication, S. Bittman, Agriculture Canada, Agassiz, British Columbia). The main advantages of the forage brassicas are that they can be planted alone and they continue to grow later into the winter. For good dry matter content in a spring forage, the brassicas should be planted with a grass species.

The growing season for silage corn is about 150 days, leaving a 50-day growing season for the production of a cover crop or second forage crop in any given year. This second crop provides many benefits to the dairy producer. The risk of soil erosion and degradation processes that lead to soil compaction are reduced. Depending on the planting date and the crop species grown, the cover crop will provide a trap for leachable nutrients, such as N. If a legume is included in the mix, soil N levels after plowdown are elevated. This is important because soil nitrate-N (NO_3-N) levels in the spring approach zero in the region. Control of winter annual weeds through competition is another tangible benefit the overwintering annual forage provides.

We found three options available to producers who use an overwintering cereal *(2,7)*. The first is to use the crop as an early spring silage or plowdown prior to planting corn. This use of the cover crop as a winter annual forage yields an average of 2.5 tons/acre with 14% protein and 60% total digestible nutrient. The second is to harvest the forage in midsummer as a hay or mature silage prior to seedbed preparation for a late-summer-seeded perennial grass crop. The third option is to harvest the mature crop for grain and straw if winter wheat was planted alone as the cover crop.

Seeding rates for the cover crops used as winter annual forages are generally as follows: Winter wheat or Italian rye grass alone, 100 to 110 pounds/acre and winter wheat or Italian rye grass in a mixture with an annual legume, 75 to 85 pounds/acre; Austrian winter peas, 15 to 25 pounds/acre; and hairy vetch, 5 to 15 pounds/acre.

The most common mixture is 80 pounds winter wheat (cultivar, 'Monopol') + 15 pounds Austrian winter peas + 5 pounds of hairy vetch/acre. The following are the best

Table 1. Total monthly precipitation for four locations within South Coastal British Columbia.

	Monthly Precipitation (inches)												
Location	*January*	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*December*	*Total*
Delta-Ladner	4.65	3.62	2.76	1.85	1.54	1.57	1.02	1.46	2.05	3.66	5.00	5.43	34.61
Pitt Polder	11.89	9.45	8.11	5.98	4.09	3.82	2.56	3.19	5.35	9.49	11.81	14.21	90.00
Abbotsford	8.23	6.26	5.47	4.02	3.07	2.56	1.61	2.20	3.54	6.02	7.56	8.98	59.53
Chilliwack	10.39	7.68	6.93	4.96	3.86	3.07	1.86	2.56	4.45	7.32	9.41	11.61	74.05

Table 2. Mean daily temperatures for four locations within South Coastal British Columbia.

	Mean Daily Temperature (°F)												
Location	*January*	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*December*	*Year*
Delta-Ladner	36.3	40.1	42.8	47.8	54.3	59.2	62.8	62.2	57.4	49.3	42.4	38.5	49.5
Pitt Polder	34.9	39.4	41.7	47.1	53.8	59.0	63.0	62.4	57.6	49.8	41.5	37.6	48.9
Abbotsford	34.9	39.9	42.1	47.7	58.5	53.6	62.6	62.4	58.1	50.2	42.1	37.8	49.1
Chilliwack	34.7	40.5	43.0	49.1	55.4	60.4	64.8	64.2	60.1	51.8	43.0	38.0	50.4

cultural practices for this mixture when used as fall-seeded annual forage. The first is to plant around September 25, just after the harvest of an early maturing silage corn hybrid. The second is a two-pass seeding operation, including an initial pass with a tandem disk and a final pass with a grain drill. Using a grain drill ensures that the seed will be at an optimum seeding depth and will only germinate when adequate soil moisture is present. The crop should receive about 50 pounds/acre of N fertilizer in March to gain maximum dry matter yield for the forage crop. This fertilizer is not necessary if the crop is to be plowed-down as a green manure. The forage is generally harvested by early May in order to allow for field preparation and corn planting before June.

All of the above-mentioned cultural practices are important, but providing adequate surface and subsurface drainage of the soil throughout the winter is essential if the crop is to be grown for any use other than a simple cover crop in the lowland areas. Many researchers have demonstrated this need for adequate drainage. Work on intensive cereal management and winter annual forages by researchers at the University of British Columbia (UBC) and the British Columbia Ministry of Agriculture, Fisheries and Food (BCMAFF) has shown that surface ponding and high water tables at any time during the winter will significantly reduce the vigor and survival of winter annual cereal crops.

At the Boundary Bay Water Control Project, an applied research site operated by the BCMAFF Soils and Engineering Branch, we carried out work on drainage and subirrigation of a wide variety of crops. The soil is a silty clay loam deltaic soil of the Ladner soil series. This soil is one of our most poorly drained soils, with a high water table or surface ponding common during the winter months. Installation of a subsurface drainage system, using 4-inch polyethylene drain pipe spaced at 46 feet and at a depth of 3.6 feet, has provided excellent drainage. The outlet-ditch water level is controlled by a pump because regional drainage is poor.

We have grown winter wheat (cultivar Monopol) on the site for 3 years to demonstrate the need for winter water control, that is, drainage, to produce a winter cereal grain crop. Table 3 presents the grain and straw yields for these crops *(5)*. In all 3 years, there was very little measurable grain yield from the undrained sites. Fertilizer and pesticide inputs were minimal in comparison to the intensive cereal management work being carried out by Temple and Bomke *(7)*, yet yields were within the average for intensive cereal management yields in 1988. Because we allowed the cover crop of winter wheat to mature to grain, subirrigation was applied to one plot area. This resulted in increased yields of both straw and grain.

It should be noted that a site in Delta, near the Boundary Bay Project, set the Canadian grain yield record of 6.2 tons/acre (13.5% moisture grain, cultivar Monopol) in 1988.

Although water management and cover cropping are important management practices for reducing soil erosion and nutrient leaching, they are also critical for reducng soil compaction. Soil compaction is a serious management problem facing all commodities with soil-bound production systems in the region. One method of reducing the negative impacts of soil compaction is to reduce the amount of traffic in the field at periods when the soil-moisture levels are suboptimum. The use of cover crops as overwinter forages or as grain crops allows the producer to move field operations out of the wetter periods into the season when the soil is in a more trafficable state.

Table 3. Winter wheat yields.*

	Winter Wheat Yields (tons/acre)					
	Drained		Subirrigated		Undrained	
Year	Grain	Straw	Grain	Straw	Grain	Straw
1986	3.7	5.1	3.9	5.8	0.4	0.4
1988	3.4	5.7	4.4	7.7	0.2	0.3
1989	2.1	2.9	3.3	3.7	0.0	0.0

*Grain weight based on 13.5 percent moisture grain. Straw weight field dry weight.

Conclusions

South Coastal British Columbia has a unique climate that requires high levels of management in order to produce crops. Cover crops are useful soil management tools that are being put to use in a wide array of crop production systems. However, water management is a key to the survival and beneficial use of cover crops for erosion control, nutrient capture, and reduction in soil compaction.

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Oat cover cropping in sugarcane for weed and erosion control in Hawaii

Carl I. Evensen and Robert V. Osgood

Cover crops are being studied by Hawaii's sugar industry to improve soil erosion control. As described by the Soil Conservation Service, a cover crop is planted primarily to provide soil protection and can be a sod-forming grass, a small grain crop, or a legume *(5)*. Average annual erosion rates in sugarcane fields are thought to be relatively low and generally below soil loss tolerance limits set by the U.S. Department of Agriculture *(1)*. However, soil erosion in sugarcane fields can be serious from planting to the closing-in of the canopy, usually at 4 to 6 months *(3)*. During this period of early crop growth, the soil is unprotected and intense rainfall can cause severe erosion.

Cover cropping studies at the Hawaiian Sugar Planters' Association (HSPA) have shown that oats (*Avena sativa* L.) is the best cover crop for unirrigated sugarcane (*Saccharum officinarum* L.), owing to its rapid growth, drought tolerance, and inexpensive seed *(2)*. Hamakua Sugar Company, a plantation on the island of Hawaii, began testing oat cover cropping on a production scale in 1990, and HSPA developed and is testing a prototype oat cover crop planter *(4)*. The planter broadcasts and incorporates oat seeds into the soil and applies an 18-inch band of herbicide over the sugarcane rows. Because between-row spacing is 4.5 feet, we apply only one-third of the usual amount of preemergence herbicide. Personnel from Hamakua Sugar Company raised concerns about the oat cover crop, including the possibilities of inadequate weed control and competition of the oats with sugarcane.

Materials and methods

We began an experiment in July 1990 at Hamakua to study crop competition and weed control. We compared the standard plantation practice of one premergence and two postemergence herbicide applications to oat cover cropping with zero, one, or two postemergence applications. We applied diuron + atrazine (3 + 3 pounds/acre) at planting in the plantation practice-treatment and at 8 and 17 weeks after planting for first and second postemergence applications, respectively. We banded only one-third of this rate (1 + 1 pounds/acre) over sugarcane rows at planting in the cover crop treatments. But the full rate was broadcast for the first and second postemergence applications. In an additional treatment, we cut sugarcane and oats as forage to a 7-inch stubble height at 12 weeks We followed this with an application of herbicide. At this writing, we had not evaluated the effects of the second postemergence application, so those data are not presented.

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Results and discussion

The plantation practice treatment provided good weed control, but weed populations increased with the oat cover crop (Figure 1). Grass and broadleaf weeds were both problems in the treatment in which no postemergence herbicide was used (No Post); however, this treatment provided the most dense canopy cover. Broadleaf weeds were controlled well with one postemergence spraying (1 Post and Forage treatments), but grasses were not, probably owing to incomplete spray coverage (Figure 1). The forage yields at 12 weeks were 1,420 pounds dry matter/acre for oats and 1,260 pounds dry matter/acre for sugarcane, and canopy cover was reduced after removal of this material.

Sugarcane tillering was not significantly affected, but stalk height at 16 weeks after planting was slightly greater with the presence of the oat cover crop (No Post), as compared to plantation practice (Table 1). We minimized competition between sugarcane and oat plants by the 18-inch-wide band of preemergence herbicide applied over the sugarcane rows. We

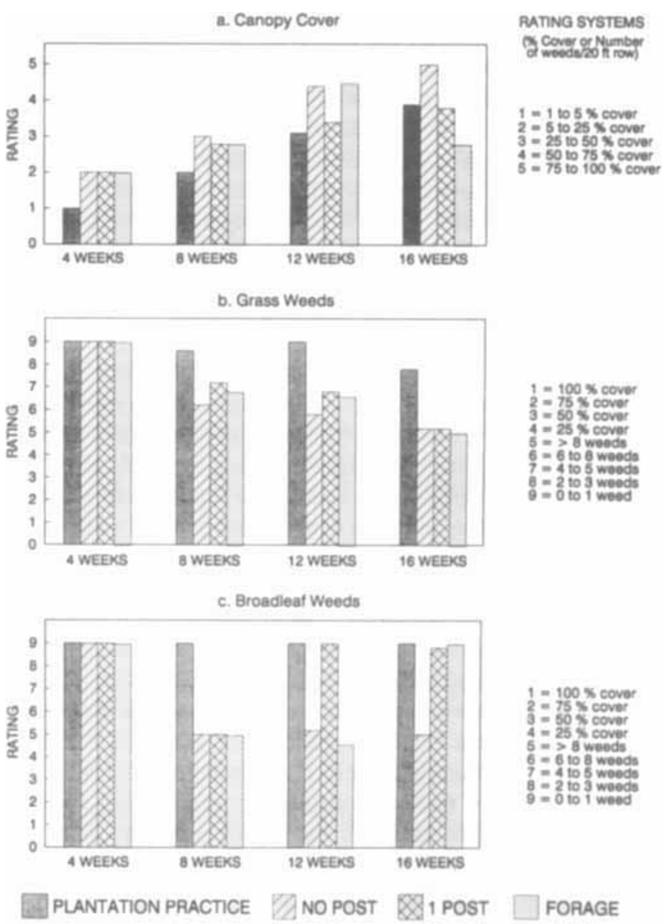

Figure 1. Treatment effects on weed control and canopy cover.

Table 1. Sugarcane and oat cover crop growth at 8 and 16 weeks after planting.

	Growth at 8 Weeks			*Growth at 16 Weeks*		
	Sugarcane			*Sugarcane*		
Treatment	*Tillers per 20 Feet*	*Height to TVD* (inches)*	*Oat Plants per Square Yard*	*Tillers per 20 Feet*	*Height to TVD* (inches)*	*Oat Plants per Square Yard*
Plantation practice	51	9	0	67	38	0
No post	52	9	41	54	42	23
One post	42	9	50	61	36	4
Forage	58	9	43	62	12	0
LSD (0.05)	ns	ns	16	ns	3	4
Coefficient of variation (%)	28	8	33	18	7	47

*TVD is top visible dewlap (top of the stalk).

controlled oats by applying postemergence herbicide (Table 1), but canopy cover was greater if the oats were not killed (Figure 1). The high coefficients of variation for tiller and plant counts reflect variability in mechanical planting of both sugarcane and oat seed. Overall, oat cover cropping improved ground cover with minimal competition to sugarcane but adequate weed control requires further study.

In addition to reducing soil erosion, oat cover cropping in sugarcane has the potential to reduce herbicide use and planting costs. Because we applied only one-third the standard amount of postemergence herbicide at planting, this provides a cost savings that offsets the cost of planting the oat crop. Jakeway *(4)* found that total planting costs were 30% lower for the oat cover crop than for plantation practice. However, he indicated that subsequent weed control costs may be higher than usual. As yet, we do not know whether postemergence herbicide applications can be reduced or eliminated. In addition, we need to conduct research on optimal seeding rates for oats, effects of fertilizing the oats, monitoring rat populations, and improvements in planting equipment.

Oat cover cropping has potential for providing major benefits to Hawaii's sugar industry through improved compliance with the conservation provisions of the 1985 Farm Bill. SCS is currently considering revision of the crop and management (C) factor in the universal soil loss equation to provide a significant conservation credit for planting an oat cover crop with sugarcane. Information collected at Hamakua Sugar Company will prominently affect that decision. If approved, oat cover cropping would become an alternative conservation practice that may reduce costs of conservation compliance to Hawaii's sugar plantations. In addition, potential reductions in herbicide use would increase water quality protection by reducing leaching and runoff losses.

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Permanent cover crops for vineyards

Frederick B. Gaffney and Martin van der Grinten

All grape growers would like to save about $50/acre in production costs. This may be possible by using permanent cover crops, as indicated by a recent study conducted by the U.S. Department of Agriculture's (USDA), Soil Conservation Service (SCS) and Taylor Wine Company. We began the study to find a vegetative management system, which when used in conjunction with soil conservation practices, would provide an economical, manageable, and effective permanent cover crop in the vineyard aisle. Our objective was to find a desirable management system of grasses and legumes that has the potential as a permanent sod cover in vineyards.

Temporary cover crops planted in late August are commonly used. Frequently, only every other aisle is seeded and then the cover is disked into the soil the following spring. This leaves a bare ground situation, allowing continued soil erosion.

A manageable cover cropping system would increase organic matter, improve soil structure and tilth, increase water infiltration, improve trafficability of equipment, lower labor input for maintenance, reduce soil surface crusting to allow better aeration, and maintain productivity of the vineyard by controlling erosion of soil and nutrients *(1, 2)*.

Study methods

In May 1980, SCS and Taylor Wine Company began a cooperative study to test the performance of selected grasses in vineyards. We selected three sites in the Taylor Wine Company vineyards near Hammondsport and Dresden, New York. We seeded four replicated plots at each location, comparing the winter cover crop/cultivation (control plot) with perennial cover crop management systems. Just prior to seeding, we disked each site twice and broadcasted 500 pounds/acre of 5-10-10 (N-P_2O-K_2O) fertilizer. We planted permanent cover seedings using a Brillion1 seeder/cultipacker, and we seeded the oats and rye with an Ontario drill.

Selecting a permanent cover

In selecting the grasses and legumes, we needed to meet certain criteria (a) to provide a permanent sod cover in the 4- to 5-foot-wide vineyard aisle; (b) to be cost effective; (c) to be less competitive for nutrients and water through late summer, but then to be aggressive in late fall to aid in vine hardening; (d) to be low-growing so as not to interfere with harvesting and pruning practices; (e)to provide erosion control, but not to increase the incidence of frost damage; (f) to provide weed control; and (g) to be adaptable to small, as well as large, vineyard operations.

Based on these criteria, we selected two cool-season grasses: red fescue (*Festuca rubra* L.) and perennial ryegrass (*Lolium perenne* L.). These low-growing grasses have the characteristic of growing in the cool temperatures of spring and fall and are dormant during the hot summer months, minimizing any competition with vine and fruit production. We included the legumes, white clover (*Trifolium repens* L.) and birdsfoot trefoil (*Lotus corniculatus* L.), in mixes for their nitrogen (N)-fixing value. The 'Aroostook' rye (*Secale cereale L.*) and oats (*Avena sativa* L.) are temporary cover crops frequently used by growers.

Common seeding rates in pounds/acre are Dutch white clover, 8; 'Pennlawn' red fescue, 15; 'Empire' birdsfoot trefoil, 8; 'Linn' perennial ryegrass, 5; Aroostook rye (temporary clover), 100; and oats (temporary cover), 80.

We seeded oats and Aroostook rye annually in August and disked the following spring and summer. We seeded the permanent cover crop plots on May 7, 1980, and once established, we managed them with an occasional mowing to maintain a low-grass height. All other management (fertilizing, spraying, pruning, and harvesting) was the same as the control plot. We conducted this study in vineyards of 'Ives,' 'Delaware,' and 'Castel' cultivars.

Evaluation and results

We evaluated the cover crops at the three sites for 4 years (1980-1984). We measured the present cover of each species in relation to the total area of the aisle in 1984 (Table 1). To determine the effect of the cover crops on vine growth and yield, we labeled 15 plants in the center row of each plot for data collection. We sampled petioles and tested for nutrient levels to ensure adequate nutrients for normal growth. At harvest, we collected yield information (Table 2). Pruning weight is a measure of how soil properties and amendments

Table 1. Percent cover of cover crops on August 13, 1984.*

	Total Aisle Area in Cover Crop		
Cover Crop	*Delaware*	*Ives*	*Castels*
		%	
Oats	-	24	22
Ryegrass	93	89	96
Red fescue	88	97	97

*Rye cover crop plots were not seeded.

Table 2. Four-year average of grape harvest weights of balanced-pruned grapevines.

	Cluster Weights of 15 Vines (pounds)		
*Cover Crop**	*Delaware*	*Ives*	*Castels*
Oats	16.23	13.93	13.38
Ryegrass	12.25	13.25	14.55
Red fescue	14.36	13.13	10.10
Rye	17.16	15.47	10.71

*Duncan's multiple range test showed no significant differences between cover crops.

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Table 3. Four-year average pruning weights.

	Weight of Cane Prunings per Vine (pounds)		
*Cover Crop**	*Delaware*	*Ives*	*Castels*
Oats	2.56	3.00	2.42
Ryegrass	2.27	2.32	2.39
Red fescue	2.33	3.19	1.96
Rye	2.59	2.59	2.01

*Duncan's multiple range test showed no significant differences between cover crops.

affect vine performance (Table 3).

After 4 years, we found that the permanent cover crop Pennlawn red fescue and Linn perennial ryegrass performed the best, providing an average of 88% to 97% cover in the vineyard aisles. Due to the annual N fertilization program in the vineyard, the grasses out-competed the clover and trefoil, resulting in little to no stands of these legumes. Red fescue and perennial ryegrass have consistently provided excellent cover at all sites. The grape-leaf petiole tests indicated no element was limiting grape production in any of the treatments of grape cultivars. We evaluated the harvest yields by cluster weights from 15 vines per treatment. We obtained no overall significant difference in grape harvest weights and pruning weights between the permanent cover and the temporary cover (control plots).

Conclusions and economic analysis

A permanent cover crop in vineyards is both culturally and economically feasible and is easily implemented in current management systems. Red fescue and perennial ryegrass have provided excellent cover (88%-97%) in this 4-year study. We raised questions about how the permanent cover crop would affect vine growth and yield. Petiole tests, harvest yields, and pruning weights indicate there is no significant difference between the permanent cover and temporary cover.

We conducted an economic analysis on various vineyard-management methods using New York average grape yield (4.1 tons/acre) production costs and the value of grapes produced. The vineyard management system with the highest net return (or profit) is the permanent cover crop system. The economic advantages to the grower include reduced labor requirements, improved efficiency of management practices, and decreased input of supplies and materials.

Vineyard managers noted additional benefits from the permanent cover crops. During wet periods, the sod vegetation allowed tractors and harvesters to continue operations without causing ruts or getting bogged down in mud. At harvest time, the mechanical harvesters can move steadily in aisles with sod cover. There were fewer problems from weeds under the trellis because the sod cover prevented weeds from growing and spreading their seeds. With fewer weeds, less hand-labor is required to weed under the trellis. The initial cost of establishing the vegetative cover is low and can be accomplished with equipment available in vineyards in little time. Once established, maintenance costs are lower because of only having to mow the vineyard aisles a few times in a season. With belly-mounted tractor mowers, this is accomplished simultaneously with the spraying operation.

A permanent cover crop system is very attractive and can be easily adapted to vineyards in New York. Besides the economic benefits, these cover crops provide organic matter, reduce soil nutrient loss, improve water infiltration, require lower labor inputs for maintenance, and maintain the vineyard productivity by controlling soil erosion.

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Conservation of soil and water by using a new tillage system for row crops

Manfred Estler

Recently, soil and water conservation has become a worldwide goal among farm operators. In middle Europe and Germany, under existing climate and soil conditions, common farming systems and preferred row crops are experiencing two problems: soil erosion, mainly water erosion of row-crop farming in sloping regions, and leaching of chemicals used at plant protection operations and of nitrogen (N) from application of liquid manure. For these reasons, there is danger of environmental contamination. We need to establish new mechanization and farm organization systems to diminish or limit these problems.

Erosion control in row crops

Soil erosion causes loss of precious arable land, the threat of leaching fertilizer and chemicals (herbicides), and obstruction of waters. Therefore, at the Institute of Agricultural Engineering we developed and tested different implements and farming systems for controlling water runoff and diminishing soil erosion in row crops.

The major result of our research was the development of the mulch planting systems, which can guarantee successful erosion control and diminish water runoff.

The operation of this special row-crop farming system begins just after harvest of winter barley (an early harvested small-grain crop) or after winter wheat. After deep plowing and preparing a normal seedbed, special cover crops (e.g., white mustard, *phacelia, engl.raygrass*) are planted. The crops grow fast in the fall and produce good root systems. Some of these cover crops are killed by frost in the winter, others must be killed with herbicides in early spring before planting the next row crop. Cover crop residues remain on the soil surface and guarantee excellent soil protection during winter months and also during the next farming season. (In Germany these cover crop residues are called mulch).

In spring, row crops (corn, sugarbeets, sunflower, or others) can be planted into cover crops. Farmers may use different implements and operations (Figure 1). Figures 2 through 6 show a select number of combination planting implements.

These implments are used to prepare seedbeds of the total soil surface or of narrow strips of soil (3- to 10-inch widths) where corn or sugarbeet plants could grow promptly and undisturbed. In addition, seedbed preparation has a mechanical weed control effect. However, the erosion-control effect is slightly reduced, especially for soil preparation of the total soil surface. Therefore, mulch-planting-systems have not been used with seedbed preparation for sloping areas.

Planting implements with disk coulters in front of the furrow opener or the spite planters guarantee the best soil-protecting and erosion-control effect. The undamaged cover crop residues also prevent water evaporation, which can be important for areas with dry conditions in spring and early summer. Seasonal warming and drying of the seedbed layer can be slightly delayed, therefore, row crop planting dates can

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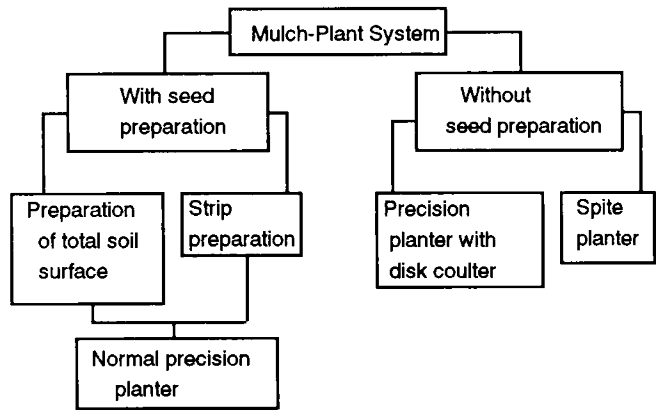

Figure 1. Implements needed for systems with and without seed preparation.

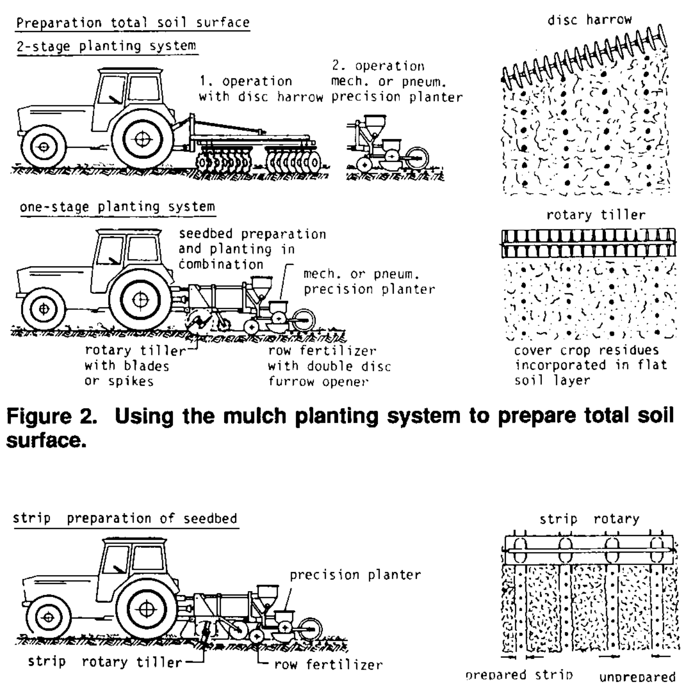

Figure 2. Using the mulch planting system to prepare total soil surface.

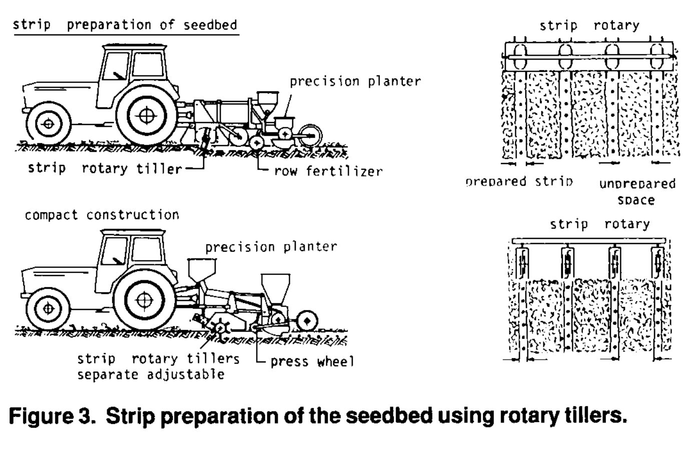

Figure 3. Strip preparation of the seedbed using rotary tillers.

be some days later than normal.

Results of field experiments using a rainfall simulator and also under practical conditions show that use of cover crops and special planting implements can reduce soil erosion and soil loss to 2.4% of that under conventional tillage and planting systems. This also reduces the danger of leaching fertilizer and herbicides (Figure 7).

Diminishing nitrogen leaching

Under German farming and climatic conditions, there are different reasons for N leaching into deeper soil layers and, perhaps, also into groundwater:

1. A high rainfall rate in spring and early summer.
2. Corn is planted at row width of about 2.5 feet.
3. Corn root growth is very slow in the first 2 to 3 months after planting.
4. Liquid manure (slurry) is an important fertilizer for farmers. Normally, it is applied just before seedbed preparation and spring planting. In warm climates, mineralization of ammonium N starts very rapidly.

The slow development of row-crop root systems, a high-rainfall rate in that period, and a high amount of water soluble N cause an increasing danger of N leaching into deeper soil layers. Normally, two problems can occur. First, in the early growing season between April and late July, root growth is slower and the uptake rate is lower than the amount of N from liquid manure and mineral fertilizer. During wet weather conditions and high rainfall intensity, N leaching is faster than root growth of row-crop plants. Second, later in the growing season (August-October), N uptake rates decrease, but the amount of N from fertilizer and mineralization of organic material in the soil is still high. There is a big difference between need of N by row-crop plants and amount of fertilizer and soil. If high-rainfall rates occur in the same season, there is a high danger of N leaching into groundwater.

The latest results of our research and experimental work show two main possibilities for decreasing these problems. First, the danger of N leaching in the early growing season of row crops can be reduced by splitting slurry application into two or three dates. Before corn planting, apply only half of the final slurry amount and Nrate. Then, apply the remaining N laterally between rows of corn with special tube applicators. In that way, the uptake and amount of N can be adjusted. Second, N supplies can only be reduced in the fall if you grow plant material with high N requirments and a high input rate exists in the fields at the same time (Figure 8).

To solve these problems, we tested special cover crop mixtures. These cover crops have a high N consumption rate at the same time when the uptake rate of corn plants is decreasing considerably. We planted the cover crops in two growing stages for corn.

By using a changed normal drilling machine, we planted three rows of cover crop in the space between the corn rows. Corn plant growth may not be more than the three- to four-leaf stage. For this operation, only slow growing seeds and cultivars should be used, otherwise the cover crop will outflank corn growth and yield.

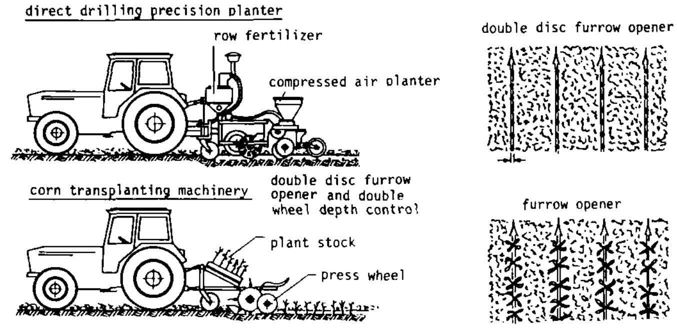

Figure 4. Double-disc furrow openers provide the best soil protection.

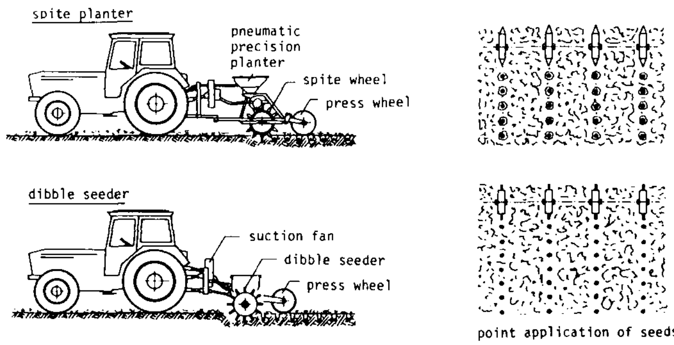

Figure 5. Point application of seeds using the spite planter or dibble seeder.

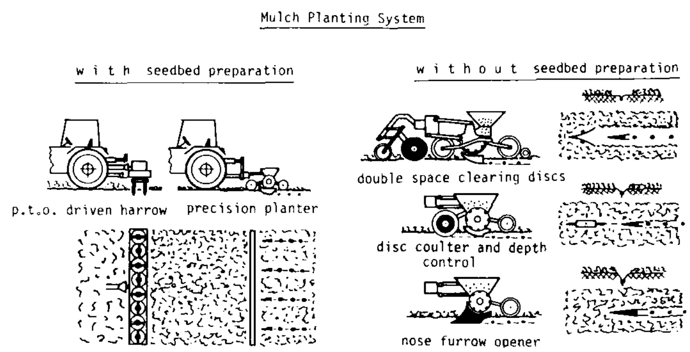

Figure 6. Using different implements to plant sugarbeets with the mulch planting system.

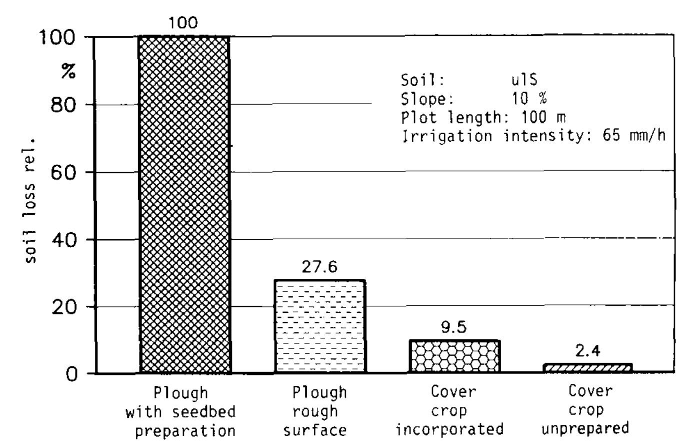

Figure 7. Use of cover crops can reduce soil loss by 2.4 percent in comparison with conventional row-crop farming.

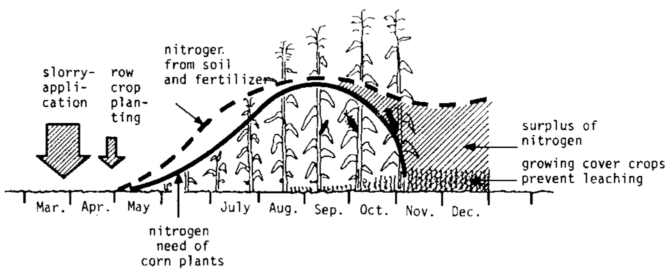

Figure 8. Growing cover crops in late fall can prevent leaching of surplus nitrogen.

Another option is to plant seeds when the corn is 20 to 24 inches in height. We performed this planting operation with wide-spreading fertilizer broadcasters. We used mechanical weed control implements to improve field emergence.

These cover crops will grow fast in the fall. Because the cover crops are not killed by frost, they can store N from early fall, during the winter, to the next spring. Nitrogen leaching is prevented until the next planting season.

Summary

Under German climatic and farming conditions, two main problems exist for farming row crops: (a) soil erosion, especially in sloping areas, which results in the loss of precious, arable land, and (b) N leaching to deeper soil layers, which occurs when liquid manure and mineral fertilizer are applied. For these reasons, environmental problems are increasing.

To decrease soil erosion problems, we developed and tested a new planting system. Using the mulch planting system, we planted cover crops after harvest of early small grains (i.e., winter barley). The following spring, we planted row crops into the faded cover crop residues with special planting implements. We reduced soil loss by 2.4% compared with conventional row-crop farming, without decreasing yields.

We can reduce N leaching to deeper soil layers by using special mixtures of cover crops. During corn growing season, we planted these cover crops between corn rows. The cover crops grow fast in fall when there is a high amount of N from the soil and a low uptake rate of corn plants. These cover crops will prevent N leaching from fall to the following spring of the row-crop planting season.

Cover crops for wind erosion control in semiarid regions

J. D. Bilbro

About 4.2 million acres of land are damaged by wind erosion each year in the semiarid Great Plains region *(3)*. Much of this damage occurs in the cotton-growing area because there is little residue remaining after the crop is harvested in November or December, and the fallow period is characterized by low precipitation and high winds.

Various techniques are used for controlling wind erosion in this area, including tillage, annual and perennial windbarriers, and cover crops, singly and in various combinations *(1, 2, 5)*. Cover crops are an effective means of controlling wind erosion; the higher the percentage of the soil that is covered, the lower will be the wind erosion potential *(4)*. Because much of the rainfed cotton is grown in a skip-row pattern of two-planted, two-skipped rows (30- to 40-inch row spacing), planting cover crops in the blank areas in the fall appears to be a very good technique for controlling wind erosion during the subsequent fallow period. Objectives in this study were (a) to determine the percentage of ground cover produced over time by three fall-seeded crops grown singly with 5- and 10-inch row spacings and also grown in all possible combinations in alternate rows, spaced 5 inches apart, and (b) to show the effectiveness of the various treatments in reducing potential wind erosion.

Methodology

On September 11, 1989, I established the following nine treatments: three crops (at 1.0 to 1.5 seeds/inch) were planted with a double-disk-opener drill in two replicated plots 80 inches wide and about 400 feet long: 'Red Top Kandy' forage sorghum [*Sorghum bicolor* (L.) Moench], 'Chopper' spring barley (*Hordeum vulgare* L.); and 'Winter-more' rye (*Secale cereale* L.), all with row spacings of 5 and 10 inches. Combinations of forage sorghum and spring barley, spring barley and rye, and forage sorghum and rye were also planted in alternate rows spaced 5 inches apart.

I made ground cover measurements by centering a 10-inch by 10-inch wire grid with 100 intersections over one and two rows for the 5- and 10-inch rows, respectively, and taking a slide photo. The slides were projected and every intersection touched by a plant part was counted as 1% ground cover. I repeated measurements periodically in exactly the same places in the plots. To determine the rate of ground cover deterioration for killed rye plants (in case a farmer wanted to kill the plants to save soil water), on March 7, 1990, the plants were chemically killed in both row spacings in the photographed areas and about 25 feet on either side and ground cover mea-

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surements continued to be conducted.

To evaluate the various treatments for reducing potential wind erosion, we used the following technique to calculate the erosion values for each treatment. From the Soil Conservation Service handbook *(6)*, we determined the base erosion value for the test site to be 60 tons/acre/year when the erodibility index (I) is 86 tons/acre, the climatic factor (C) is 70, the roughness factor (K) is 1.0, the unsheltered length (L) is 3,000 feet, and the flat-small-grain-residue equivalent is zero. We determined the soil-loss ratio (SLR) for each treatment for each sampling date by using the relationship between percent soil loss and ground cover, established by Fryrear *(4)*:

$$SLR = 1.81e^{-0.072\,(GC)}$$

We used the average percent ground cover (GC) for each treatment in this equation to obtain the SLR for the respective treatments. We then multiplied this ratio by 60 (the base wind erosion factor) to determine the erosion for each treatment, corrected for ground cover.

On April 11, 1990, we disked all plots that did not have rye in them because weeds were beginning to emerge in significant numbers.

Results and discussion

Ground cover percentages. Figures 1 and 2 give the percentages of ground cover for the treatments and precipitation received. These are relatively self-explanatory, so we will discuss only the most significant points and the major anomalies.

The decline in ground cover of forage sorghum from 38 to 45 days after planting resulted from a 28° F temperature on October 18 that had killed some of the leaves. (Average date of first-killing fall temperature is about November 10.) The variations in ground cover after the plants were killed on December 7 (23° F) were the result of rearrangement of the ground cover by wind and rain and by natural deterioration.

The sharp decline in rye ground cover between 100 and 135 days after planting was probably the result of the unseasonably low temperatures from December 21-23 (0° to 40° F lows, and 17° to 37° F highs). We chemically killed the plants in the 5- and 10-inch rows 177 days after planting (March 7, 1990). Subsequently, the plants deteriorated rather rapidly, probably because they were very succulent following an extended rainy period. Previous work *(1)* has shown a much slower deterioration rate for less-succulent, small-grain plants chemically killed in January or February.

Forage sorghum and rye produced significantly more ground cover in the 5-inch rows than in the 10-inch rows. On the other hand, row spacing had little effect on the ground cover production of spring barley. The low temperatures of the December 21-23 period killed the spring barley plants.

Wind erosion potential. Figures 3 and 4 readily show the effectiveness of ground cover in reducing erosion. The horizontal line at 5 tons/acre/year is the tolerable amount of wind erosion for the soil at the site (Amarillo fine sandy loam).

Forage sorghum in 5-inch rows appears to be very effective in reducing the wind erosion value (Figure 3). It also performed well in alternate rows with rye. Forage sorghum and spring barley were not a good combination because both froze in December before adequate ground cover had been produced (Figure 4).

Because spring barley produced less ground cover than forage sorghum and deteriorated more rapidly than forage sorghum after death, spring barley was inferior to forage sorghum in reducing the erosion value (Figure 3). However, spring barley was better than the rye in 10-inch rows from about 45 to 165 days after planting.

Rye in 5-inch rows and in combination with either spring barley or forage sorghum provided adequate soil protection (Figure 4). The advantage of using rye is that it will continue to grow after a hard freeze, whereas forage sorghum will not. Rye will reach heights of up to 3 feet by maturity (depending upon soil water conditions) and therefore, would provide

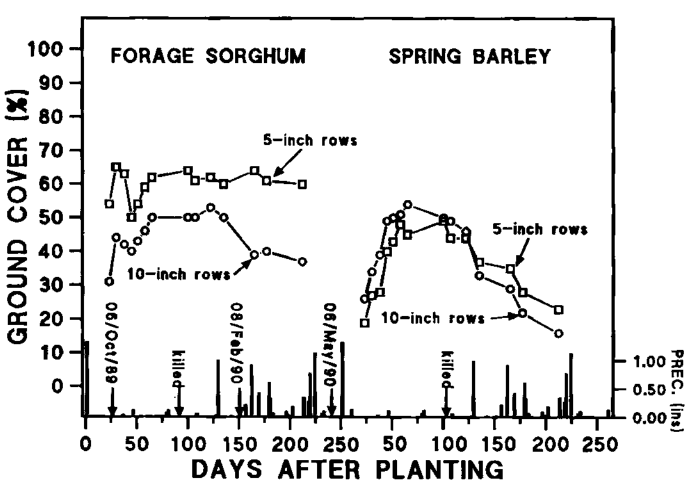

Figure 1. Percent ground cover (and precipitation) for forage sorghum and spring barley.

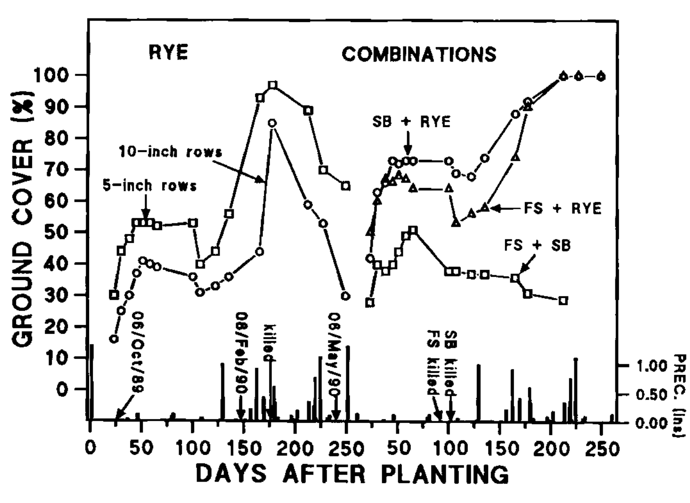

Figure 2. Percent ground cover (and precipitation) for rye and combinations of rye, forage sorghum, and spring barley.

adequate protection to cotton seedlings in adjacent rows if the producer chooses this alternative. The disadvantage of rye is that it can use soil water that subsequently could be used by cotton.

Conclusion

Possibly the safest technique to ensure adequate wind erosion protection with a minimum of soil-water usage would be to plant the forage sorghum and rye in alternate 5-inch rows. If the forage sorghum makes adequate ground cover before it is killed by low temperatures, then the rye could be chemically killed to stop water usage. On the other hand, if the forage sorghum had not made sufficient ground cover before it was killed, the rye could be allowed to grow to provide the needed ground cover. Then the rye could be chemically killed to minimize soil-water usage. Or if soil water is adequate, the producer could allow the rye to grow to the haying stage, or to maturity, depending upon his or her objectives.

A note of caution: If possible, the cover crops should be established in August, or no later than the first week in September, to better ensure that adequate ground cover will be produced before the highly erosive period begins in January.

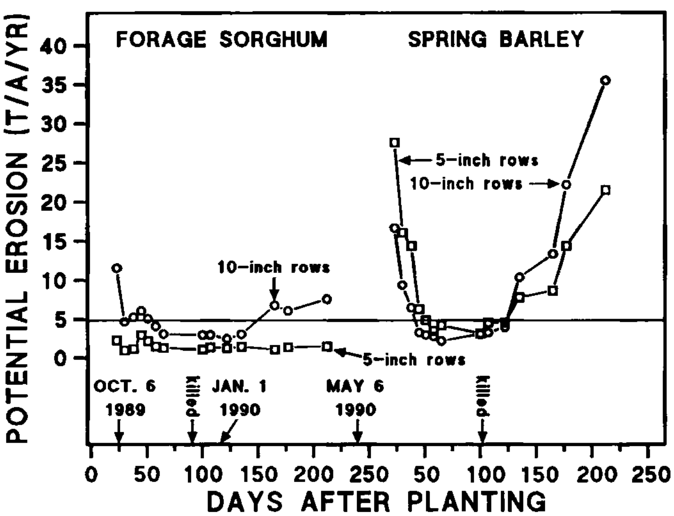

Figure 3. Potential wind erosion losses for plots of forage sorghum and spring barley.

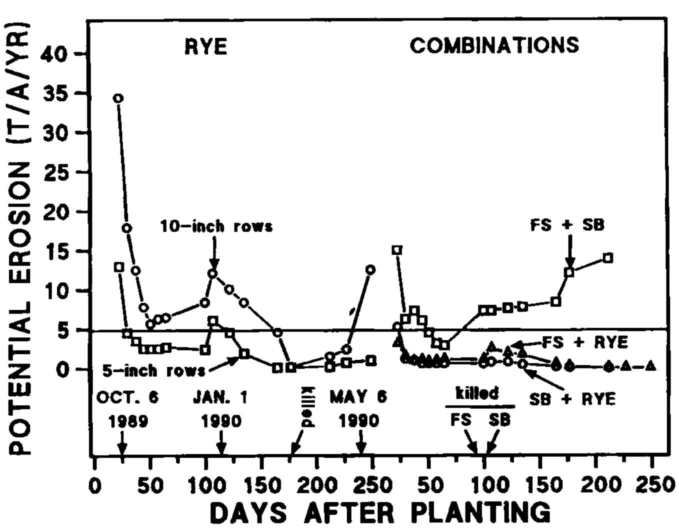

Figure 4. Potential wind erosion losses for plots of rye, and combinations of rye, forage sorghum, and spring barley.

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Measuring cover crop soil moisture competition in North Coastal California vineyards

Phillip Blake

Farmers in Napa County, California, have long-recognized the benefits of cover crops for vineyard floor management and soil improvement. Traditionally, winter green manure cover crops have been grown between vine rows to improve soil tilth, reduce compaction, and increase soil fertility.

For the most part, cover crop management has traditionally been passive. In a typical Napa Valley vineyard, resident cool-season annual forbs and grasses germinate and establish between vine rows with fall rains. Herbicides or french plows are used to control growth under the trellis wire in winter or early spring months. Spring cover crop growth is checked with mowing or chopping implements that also shred grapevine prunings. In most cases, disking follows this operation to prepare a smooth, vegetation-free floor during the spring frost-period and to return plowed soil to trellis berms.

In recent years, as available valley bottomlands have grown scarce, vineyard expansion has concentrated increasingly on hillside areas. New technologies, such as drip irrigation, and an ever-expanding demand for premium Napa Valley Appellation wines have helped to encourage development of vineyards on steep, erodible land. A study conducted by the local resource conservation district in 1985 found average soil erosion rates to be 14 tons/acre in these vineyards, 3 to 14 times the soil loss tolerance values.

Local fishery biologists, land use planners, and municipal water-supply officials have become increasingly aware of water quality problems associated with the erosion. In one recent case, a newly developed 30-acre hillside vineyard contributed an estimated 1,400 cubic feet of sediment to a small water-supply reservoir. In a 1985 report, the Soil Conservation Service (SCS) suggested that no-till cover crops provided the most cost-effective approach to controlling sheet and rill erosion and reducing downstream water quality impacts *(3)*.

The universal soil loss equation suggests that erosion in many Napa County hillside vineyards can be reduced within the assigned soil T value with the establishment of no-till annual cover crops. Field observations by SCS staff confirm the effectiveness of no-till versus conventional, spring tillage cover crop management. Reduction of visible in-field sedimentation, erosion rills, and pebble pedestalling have provided the main means of confirmation, as crop yield response to erosion is not readily apparent.

Although we can accrue a number of benefits to management of no-till cover crops, vineyard managers do not readily adopt the concept of eliminating tillage. Soil moisture conservation ranks high on grape growers' minds as a drawback to permanent sod. Irrigation water is in short supply in many hillside areas, where low-yielding wells and small runoff collection ponds are the main water sources. Whereas soil erosion concerns most growers, a measure of moisture competition between grapevines and cover crops is of immediate concern in the decision process.

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Field studies conducted

In 1981, Garlock *(2)* conducted initial field studies of cover crop soil moisture consumption using neutron probe instrumentation. In a study of vine vigor effects in nonirrigated Cabernet Sauvignon, Garlock found that tillage-control treatments actually showed slightly higher moisture consumption over the growing season, as compared with treatments of no-till 'Blando' brome cover, (7.9 versus 7.5). Garlock assumed that improved soil porosity in the Pleasanton loam (fine, loamy, mixed, thermic) cover treatments aided rainfall infiltration and that dead grass thatch reduced evaporative losses during hot summer months. In addition to moisture data, no significant differences were found in fruit production, including total vine yield, cluster weights, cluster counts, and overall yield per acre.

Bowker *(1)* conducted later studies of vineyard cover crop relations to grapevine yield and berry quality, using a plant-water status console (also known as a plant pressure bomb) on Guenoc clay loam soils (fine, kaolintic, thermic). Three years of data collection showed only minor differences in vine stress between tillage plots and resident annual cover, maintained only by mowing. Relative stress readings (in bars of pressure) rarely exceeded 2- 3-bars difference between plots in weekly readings on a total seasonal scale range of 4 bars (lowest stress reading) to a high of 17 bars. Readings were collected weekly, and generally varied less than 1 bar. Sod-plot stress readings were periodically lower than tillage plots.

Bowker noted that improved soil-pore structure in the upper 16 inches of soil appeared to benefit even soil-moisture distribution to the 3-foot depth in cover crop plots, where a plow pan evidenced at 18 inches of depth in the tillage plot appeared to impede full-profile moisture distribution. He also noted that sod plots contained a high percentage of grasses to broadleaf forbs, (two-thirds annual grasses, one-third forbs total composition) compared with a reverse percentage composition in tillage plots. He postulated that the combined factors of soil-profile-moisture-depth penetration and a preponderance of high moisture-consuming, taprooted forb weeds in tillage plots accounted, in part, for similar vine stress effects between treatments.

In addition to soil-moisture measurements, Bowker also noted that vine vigor was higher in tillage plots, as evidenced by higher pruning brush weights and visual appearance. Conversely, fruit yield tended to be slightly higher in sod plots as compared with tillage.

During the 1989 growing season, SCS and Napa County Resource Conservation District staff members conducted cover crop soil-moisture stress studies in three Napa Valley vineyards (data from SCS and Napa County Resource Conservation District unpublished field studies of plant pressure bomb readings at Beringer, Christian Brothers, and Cuvaison vineyards). We conducted studies using a plant pressure bomb apparatus between commencement of the vineyard irrigation season and harvest.

Readings taken on Bale clay loam soils comparing 'Zorro' annual fescue sod plots with a tillage control yielded only slight differences. First readings in June showed slightly more stress in sod plots (9.5 versus 8.8 bars), but a slight reversal of stress at veraision (fruit enlargement, development period) (6.8 bars for sod, 7.4 bars for tillage). By harvest, sod readings indicated slightly higher levels of stress over tillage. Although we did not collect yield data on each treatment, the grower indicated that yields were slightly lower in sod treatments, but not significantly.

A second vineyard on Pleasanton loam soils yielded negligible differences in stress readings comparing resident annual mown sod with tillage. Comparisons yielded only a 0.5-bar difference in June and nearly identical relative stress readings at veraision and harvest (<0.1 bars). No yield data were available on this vineyard.

Similar sod-tillage treatments yielded much more dramatic differences on Diablo clay soils in the Carneros region of the Napa Valley. In this study, Zorro annual fescue sod plots were compared with a tillage treatment. With the exception of lower stress levels prior to commencement of irrigation in June, sod treatments maintained consistently higher levels of stress than tillage treatments. Differences widened during critical growth periods in July and early August by as much as 2.2 bars, on a total scale range of 5 to 12.5 bars. Vines showed visible stress symptoms with decreased shoot growth and lower yields. Researchers believe that the shallower-rooting depths of these soils, due to high increases in clay in the subsoil, accentuated the effects of sod competition with the vines. A late spring mowing allowed a more vigorous annual ryegrass to dominate the fescue cover crop stand and may have contributed to vine stress.

Results and discussion

Cover crop studies conducted to date for North Coast vineyards indicate that no-till annual grass floor management produces slightly higher vine stress on selected valley and upland soil types. Effects are variable between soil types. Indeed, annual cover crops may actually benefit net soil moisture while generating small increases in stress. Increases in stress do not appear to necessarily bring about lowered grape yield or quality. Cover crop effects other than moisture competition may account for increased stress. Allelopathic cover crop exodates may represent a vine vigor inhibitor, warranting future study.

Clay soils or other soil types with limiting soil depth may have a greater tendency to accentuate vine stress in no-till floor management and warrant further study.

Where water quality impairment due to sheet and rill erosion is an issue in sensitive watersheds, the beneficial effects of cover crops should never take a back seat to grower concerns about moisture competition. Accommodation for additional irrigation water supply to offset vine stress should be considered in the vineyard development process if maximum vine vigor is of paramount concern.

REFERENCES

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