EXPECTATIONS

Expectations of cover crops for sustainable agriculture

R. Lal, E. Regnier, D. J. Eckert, W. M. Edwards, and R. Hammond

Sustainable agriculture implies "successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources" *(62)*. Agricultural sustainability is a dynamic concept that recognizes the future needs of improving production while preserving the quality of the environment and the productive capacity of land and water resources. The concept of sustainability addresses the issues of environmental quality while recognizing the need for maintaining an increasing trend in per capita productivity; reducing input while increasing the profit margin; intensifying production on prime agricultural land while restoring productivity of degraded ecosystems and taking marginal land out of production; and maintaining a balance between natural and agroecosystems while transforming resource-based subsistence agriculture into a science-based commercial enterprise. Sustainable agriculture, therefore, is not necessarily synonymous with low-input, organic or alternative agriculture. In some cases, lowering input may sustain profitable and environmentally compatible farming. In other cases, increasing off-farm input may be the only viable alternative to enhance production from prime agricultural land and take marginal land out of production.

Producers in the U.S. Corn Belt spend over $1 billion annually for weed control in corn and soybean production; nationwide, herbicides account for 85% of all pesticides used in crop production *(45)*. Potential herbicide contamination of surface water and groundwater, rotational crop injury due to excessive herbicide persistence, unknown long-term health effects of herbicides, and appearance of herbicide-resistant weeds have led to widespread concern about herbicide dependence. One reason for herbicide dependence is the adoption of reduced tillage, a practice that reduces erosive losses of topsoil, fertilizers, and pesticides, but relies heavily on herbicides to control weeds. Conversion to reduced tillage continues; projections of acreage in conservation tillage in the United States in the year 2010 range from 63% to 82% of the total planted cropland *(55)*. Simultaneously, economic problems and government programs have encouraged declines in crop rotation as a cultural weed control measure *(61)*, the loss of which has contributed to herbicide dependence.

Sustainable agriculture objectives (Figure 1) highlight the importance of reducing dependence on fossil fuel-based input, minimizing risks of soil and environmental degradation, and maintaining an increasing trend in per capita productivity. While the short-term objective may be to increase profitability, the long-term objective is to address land misuse, accelerated soil erosion, depletion of soil fertility and the decline in soil organic matter content, eutrophication and pollution of water resources, and excessive use of nonrenewable natural resources. Growing cover crops in association with grain crops, horticultural crops, and plantations, in appropriate sequence or combination and with judicious management, can help achieve objectives of sustainable agriculture.

R. Lal is an associate professor, E. Regnier is an assistant professor, and D. J. Eckert is an associate professor, Department of Agronomy, Ohio State University, Columbus, Ohio 43210; W. M. Edwards is a soil scientist, Agricultural Research Service, U.S. Department of Agriculture, North Appalachian Experimental Watershed, Coshocton, Ohio 43812; and R. Hammond is an associate professor, Department of Entomology, Ohio Agricultural Research and Development Center, Wooster, Ohio 44691-4096.

Cover crops

Cover crops are legumes, cereals, or an appropriate mixture grown specifically to protect the soil against erosion; ameliorate soil structure; enhance soil fertility; and suppress pests, including weeds, insects, and pathogens *(22, 46)*. Figure 2 outlines some principal benefits of cover crops. We do not grow cover crops for harvest, but rather to fill gaps in either time or space when cash crops would leave the ground bare. Most cover crops are grown during the cold season in northern latitudes and during the dry season in tropical climates. In northern latitudes, rye (*Secale cereale* L.), clover (*Trifolium* spp.), or vetch (*Coronilla* and *Vicia* spp.) are planted in the fall to specifically provide a winter cover. In addition, alfalfa (*Medicago sativa*) is also left in the field during winter months. In tropical climates, legumes, such as *Pueraria, Stylosanthes,* and *Centrosema,* and grasses, including *Brachiaria, Melinis,* and *Panicum,* are grown in the short, rainy season and left in the field throughout the dry season.

Management of cover crops involves two approaches: live or living mulches *(34)* and killed cover crops or dead mulches. The two approaches differ in the spring treatment of the cover crops. Living mulches remain wholly or partly alive during the row crop's growing season, while killed cover crops are chemically or mechanically killed when the row crop is planted. When we use plowing or disking practices, the cover crop is incorporated into the soil prior to planting. The live-mulch system works if the cover crop is not competitive for light, moisture, and nutrients. The approaches also differ in the desired growth characteristics of the cover crop, if the primary purpose of the cover crop is to provide weed control. Living mulches should have a low-growing, yet smothering, growth habit to minimize competition with the row crop but still provide complete ground cover to prevent weed emergence *(2)*. Killed cover crops can have a tall growth habit because they are not permitted to live during row-crop establishment. In the case of killed cover crops, it may be advantageous if they acquire as much biomass as possible in order to provide a thick mat of residue to suppress weeds.

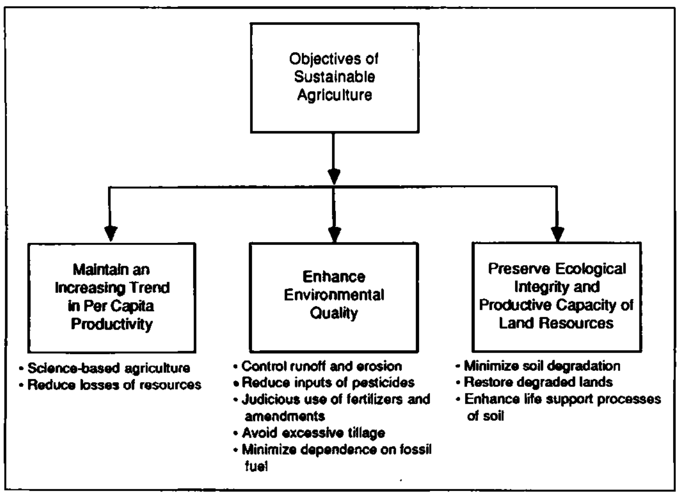

Figure 1. Objectives of a sustainable agricultural system.

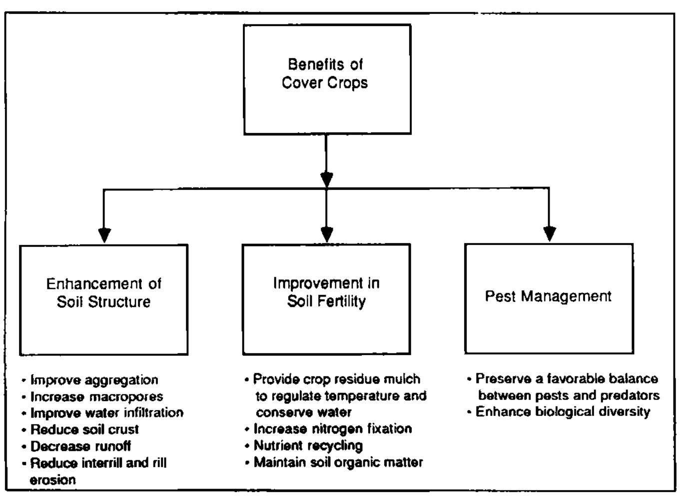

Figure 2. Potential benefits of cover crops.

Runoff and erosion management

Biological measures of erosion control, involving use of cover crops and vegetative hedges, are based on the principle of ameliorating soil structure, providing a continuous ground cover to protect soil against raindrop impact, and decreasing the velocity and carrying capacity of overland flow. Cover crops achieve these objectives by improving aggregation and enhancing soil structure. Wilson and Browning *(71)* and Wilson et al. *(72)* observed that continuous corn (*Zea mays*) had the smallest and continuous bluegrass (*Poa pratensis*) had the highest contents of aggregates greater than 0.1 inch. Low *(42)* studied the time required to improve soil physical condition of old arable land and old grassland. He observed that improvements in soil structure may take as long as 50 years for some clay soils and only 5 to 10 years on coarse sandy soils. As a consequence of improvement in soil structure, cover crops also increase water infiltration *(9, 36)*. Channels formed by decayed roots and enhanced earthworm activity are principal factors responsible for the increase in infiltration capacity.

Wadleigh et al. *(67)* reported a drastic reduction in runoff and soil erosion from plots with continuous grass cover and rotation pastures in long-term studies in Wisconsin. Browning *(9)* reported that perennial close-growing vegetation was effective in Oklahoma and Iowa. Shiflet and Darby *(56)* have also reported the potential benefits of cover crops in soil and water conservation. In Georgia, Hargrove et al. *(24)* and Langdale and Leonard *(39)* observed significant beneficial effects of winter cover crops in reducing erosion. They concluded that winter legumes may be more effective than small grains in increasing infiltration and reducing runoff. Hall et al. *(18)* reported that soil loss was 86% and 96% less in no-till corn with living mulch of birdfoot treefoil (*Lotus corniculatus*) or crownvetch (*Coronilla varia*), respectively, compared with conventionally tilled corn. Similar observations were made in Nigeria in a watershed grown to Mucuna *(35)*.

A pertinent example of the effects of winter cover crops on runoff reduction is evident from the data of 10 small watersheds at the North Appalachian Experimental Watershed in Coshocton, Ohio. These watersheds were farmed in a 4-year corn-wheat (*Triticum aestivum L.*)-meadow-meadow rotation for 28 years. Soon after every corn harvest, the crop residue was disked and winter wheat seeded. The wheat emerged in late October or early November and provided winter or dormant season cover to the 10% to 15% sloping Alfisols and Ultisols. For the entire dormant seasons of the wheat and meadow years of the rotations, the cover consisted of grass-legume mixture, either orchardgrass (*Dactylis glomerata* L.)-alfalfa, or timothy (*Phleum pratense* L.)-red clover (*Trifolium pratense* L.).

Table 1 shows average monthly runoff from each watershed for the 7 years that the winter cover was wheat and for the 21 years that the cover was meadow. The average dormant season runoff by months for all 10 watersheds under both covers is shown in figure 3.

Average runoff from the 10 watersheds (November-April) was 60% greater under wheat than under meadow (wheat, 1.7 inches; meadow, 1.0 inch). Under both covers, runoff was least in November and December, and greatest in March. Although long-term average rainfall in November is greater than in December, January, or February (Table 2), average November runoff is less than that of any other dormant season month because antecedent soil moisture is lowest at that time of year.

Later in the dormant season, difference in subsoil drainage characteristics affect the degree of profile saturation and, therefore, infiltration rate. The data in figure 4 compare runoff from two watersheds under winter wheat cover during a February 13, 1966, storm. Watershed 123 has restricted

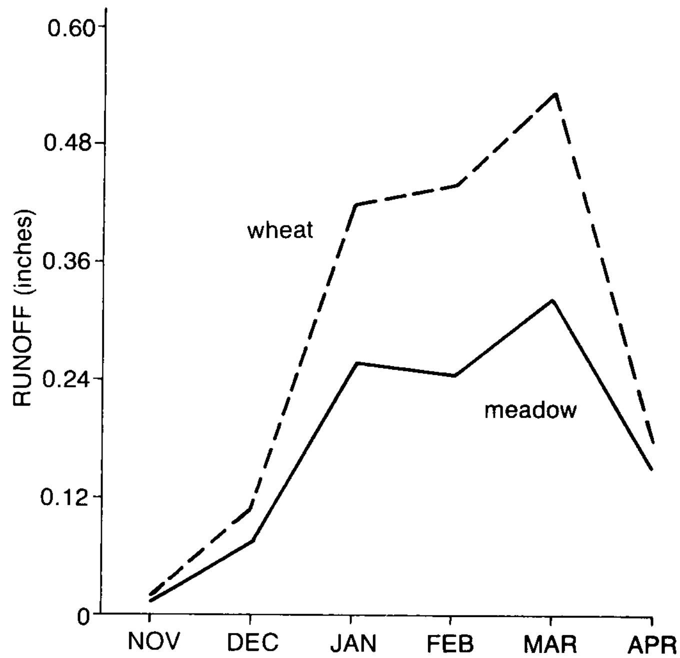

Figure 3. Average monthly runoff from 10 watersheds cropped with winter wheat (7 years) and meadow (21 years).

Table 1. Average dormant season monthly runoff from watershed cropped with winter wheat (7 years) and meadow (21 years).

	Dormant Season Runoff (inches)							
Crop and Watershed	*November*	*December*	*January*	*February*	*March*	*April*	*Total*	*Average*
Winter wheat								
103	0.053	0.166	0.638	0.563	1.087	0.060	2.565	0.430
106	0.006	0.045	0.299	0.129	0.461	0.382	1.320	0.220
109	0.001	0.044	0.080	0.398	0.067	0.002	0.591	0.099
110	0.037	0.214	0.544	0.355	0.981	0.013	2.143	0.357
111*	0.028	0.361	0.741	0.827	1.020	0.418	3.392	0.567
113	0.013	0.122	0.430	0.414	0.333	0.092	1.296	0.216
115	0.004	0.065	0.333	0.544	0.019	0.076	1.044	0.174
118	0.023	0.485	0.477	0.489	0.745	0.310	2.088	0.348
121	0.000	0.169	0.216	0.182	0.437	0.263	1.119	0.186
123	0.006	0.099	0.382	0.441	0.128	0.133	1.186	6.198
Average	0.017	0.107	0.414	0.434	0.528	0.175	1.675	0.280
Meadow								
103	0.004	0.075	0.273	0.286	0.453	0.289	1.375	0.229
106	0.032	0.095	0.241	0.363	0.193	0.066	0.989	0.165
109	0.000	0.002	0.053	0.023	0.143	0.028	0.249	0.041
110	0.011	0.062	0.143	0.166	0.167	0.112	0.662	0.110
111*	0.112	0.164	0.552	0.441	0.441	0.259	1.872	0.312
113	0.010	0.059	0.212	0.308	0.240	0.104	0.934	0.155
115	0.014	0.059	0.180	0.133	0.279	0.104	0.772	0.128
118	0.030	0.654	0.263	0.258	0.429	0.137	1.182	0.197
121	0.009	0.025	0.214	0.153	0.275	0.103	0.780	0.130
123	0.005	0.127	0.418	0.281	0.571	0.255	1.659	0.276
Average	0.013	0.073	0.255	0.241	0.320	0.145	1.048	0.175

*Watershed 111 had only 6 years winter wheat and 18 years meadow.

Table 2. Long-term distribution of total and intense precipitation at Coshocton, Ohio.

Rainfall	Precipitation by Month (inches)											
Type	*January*	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*December*
Total	2.50	2.20	3.25	3.43	3.93	4.28	4.43	3.21	2.88	2.33	2.75	2.44
Intense*	0.32	0.39	0.12	0.21	0.55	1.17	1.24	0.68	0.36	0.13	0.06	0.002

*Intense is the amount of precipitation falling at intensities greater than 1 inch/hour.

subsoil drainage and little unfilled porosity at that time of year. The well-drained watershed 109 had a lower degree of saturation at the start of the storm and produced only 20% as much runoff as did watershed 123. We can explain much of the variation in dormant-season runoff shown in table 1 by similar differences in internal drainage.

The available literature indicates decisive beneficial effects of cover crops in reducing runoff and conserving soil and water. The hydrologic benefits of cover crops are particularly important during the dormant season and in soils with restrictive subsoil horizons. However, in northern latitudes the dormant season runoff from a fall-seeded small-grain cover crop may be more than that from a well-established meadow crop because (a) the meadow uses more water at the time the cover crop is being established, which creates a drier profile under the meadow; (b) the heavier meadow vegetation offers better protection against soil freezing; or (c) tillage associated with establishing the fall-seeded cover crop (and possibly the previous crop) may leave a weakened or crusted surface with a low infiltration rate.

Soil fertility enhancement

The use of appropriate cover crops can reduce the use of chemical fertilizer and organic amendments, and yet produce yields equivalent to those produced with conventional fertilizer rates. But, annual cover crop influence on soil chemistry and fertility depends on a number of factors, including:

1. Soil and weather conditions present during development and decomposition of the cover crop.
2. Length of time that the cover crop is present and actively growing.
3. Quantity of biomass eventually produced by the cover crop.
4. Cover crop species.

Cover crop action on a particular chemical species relative to its existing status in the soil.

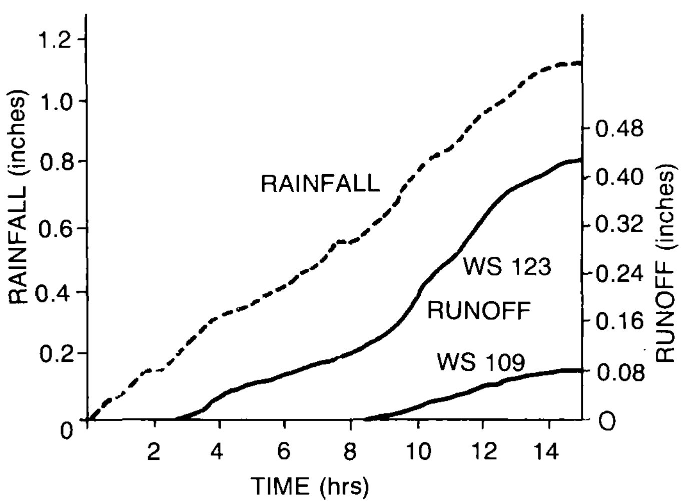

Figure 4. Cumulative rainfall and runoff from a well-drained (WS-109) and an imperfectly drained (WS 123) watershed under winter wheat cover, February 13, 1966.

The first three factors in particular are greatly influenced by climate and location. In northern areas, including much of the U.S. Corn Belt, cash crops may dominate fields for the majority of the available growing season. Cover crop establishment may not occur until near or after harvest in September or October. The cover crop will have only limited time to develop and cause effects before freezing temperatures arrive. Cash-crop planting may occur again before the cover crop makes significant spring growth. Under such conditions, potential cover crop effects might be small. In the South, however, cash crops may not utilize as much of the available growing season and winters may be quite mild, allowing more opportunity for cover crop development and effect.

Growers often plant winter cover crops, in an attempt to increase soil organic matter concentrations. While the cover crop will certainly add some biomass to the soil when it is killed or incorporated, the long-term changes in organic carbon (C) are often small or negligible. In Georgia, Hargrove *(21, 23)* found that the addition of winter legume cover crops to a no-till grain sorghum [*Sorghum bicolor* (L.) Moench] production system often merely slowed the decline in soil organic C concentrations seen in the study, while a winter rye (*Secale cereale* L.) cover crop had no effect on soil C concentrations. Eckert *(14)* found that adding a winter rye cover crop to no-till continuous corn (*Zea mays* L.), continuous soybean [*Glycine max* (L.) Merr.], and corn-soybean rotation systems had no effect on organic C concentrations, compared with the same cropping systems without rye on two Ohio soils (Table 3). The quantity of biomass produced by a cover crop is relatively small and is lessened considerably by the existing C content of the soil and any residue left after harvest of a grain crop. A permanent enhancement of soil C concentrations may not be possible with winter cover crops; but, the presence of extra mulch on the soil surface in the spring does deserve consideration as a potential sink for nitrogen fertilizers and pesticides.

Due to the relatively low C/N ratios of legume residues, decomposition of a legume cover crop usually releases inorganic N into the soil system. Recently, researchers have conducted extensive work at many locations to assess the ability of legume cover crops to supply available N to a succeeding grass crop, thus replacing a portion of the N normally applied to that crop as synthetic N fertilizer *(52)*. Such activity is driven by a number of factors, including concerns regarding the dependence of the N fertilizer industry on natural gas feedstocks. Studies have taken numerous forms but have often been evaluated in several common terms: (a) organic N produced in the cover crop residue; (b) quantity of inorganic N (either nitrate or ammonium plus nitrate) released into the soil following cover crop destruction; and (c) response of a test crop such as corn or sorghum to additions of N fertilizer when planted into the cover crop residue.

Because weather variables influence the growth of the cover crop and decomposition of the resulting residue, results of N-release studies often depend on the year and location of the particular study. The quantity of N fertilizer replaced by the legume residue can be quite variable from study to study. Several general factors affecting the N contributions of legume cover crops, however, do bear mention. Species should

Table 3. Effects of a rye cover crop in no-till cropping on several soil properties in Ohio, modified from Eckert (*14*).

					Exchangeable					
	Organic C		Bray-1 P		K		Ca		Mg	
Soil, Rotation, and Depth	*No Rye*	*Rye*	*No Rye*	*Rye*	*No Rye*	*Rye*	*No Rye*	*Rye*	*No Rye*	*Rye*
	%		ppm							
Canfield silt loam										
Continuous corn										
0-2 inches	1.93	1.82	77 *	60	141	149	652	628	111	104
2-4 inches	1.57	1.56	21	21	100	103	648	652	108	107
4-6 inches	1.42	1.56	16	19	81	90	652	647	111	113
6-8 inches	1.40	1.51	14	18	82	83	660	668	112	115
Continuous soybean										
0-2 inches	1.70	1.69	52	49	150 *	162	904	896	162	160
2-4 inches	1.43	1.37	15	13	80	83	880	876	162	159
4-6 inches	1.49	1.44	16	14	69	69	896	904	168	165
6-8 inches	1.36	1.37	13	13	65	66	840	876	166	167
Corn-soy rotation										
0-2 inches	1.70	1.76	54	57	159 *	174	872	848	150	143
2-4 inches	1.54	1.49	13	12	79	92	912	860	152	143
4-6 inches	1.57	1.52	12	11	72	74	964	900	163	151
6-8 inches	1.46	1.45	11	9	68	67	924	920	162	161
Hoytville silty clay										
Corn-soy rotation										
0-2 inches	2.42	2.50	121	111	347 *	387	2,930	2,890	446	442
2-4 inches	2.11	2.28	59	41	203	208	3,320	3,250	506	487
4-6 inches	2.12	2.22	33	34	183	183	3,320	3,270	502	492
6-8 inches	2.12	2.22	33	34	183	178	3,310	3,240	492	480

*Different at $P<.05$.

be adapted to the area in which they are to be planted. Legume cover crops planted out of their areas of adaptation produced low biomass and N yields *(47)*. This study also showed that the total quantity of N produced by a legume cover crop depended on both its biomass and the N concentration of its tissue. Covers with lesser concentrations of N provided as much N as those with greater concentrations, if the former produced more total biomass.

Once decomposition begins, the quantity of inorganic N released to the soil and the rate of release depends on the cover crop species *(12, 68)* and may also be affected by the timing of cover crop destruction and growing season *(68)* or legume crop management the previous year *(31)*. Wilson and Hargrove (70) also found that N release from crimson clover was slower under no-till conditions than when residue was incorporated. Such findings have implications for the use of legumes as an N source in no-till systems. Wilson and Hargrove concluded that N release under no-till conditions in Georgia was sufficiently rapid to provide benefit to a succeeding crop. Several studies in more northern states *(52, 63)* have indicated that legume residues decompose quickly enough to supply significant quantities of N to a succeeding crop under no-till conditions; however experience in Ohio in 1990 indicated that the quantity of N available to the succeeding crop can be affected by soil type and drainage, with availability being much greater on well-drained than poorly drained soils (J. W. Johnson and D. J. Eckert, 1990, unpublished data). We need to further examine the importance of soil characteristics and microclimate (as modified by tillage, drainage, etc.) on release and availability of legume-derived N.

The effects that inclusion of cover crops might have on soil chemical properties other than C and N status has received much less attention. Cover crops absorb nutrients while actively growing, and if significant biomass accumulation occurs, could affect such properties as the distribution and forms of nutrients in soils. Hargrove *(23)* found that including several cover crops in a continuous no-till grain sorghum system concentrated exchangeable potassium (K) into the upper 3 inches of the soil profile relative to a fallowed control. This K was apparently absorbed from deeper in the profile and deposited near the surface in the cover crop residue. Relatively immobile, the K remained near the surface. Eckert *(14)* found that a rye cover crop increased exchangeable K into the upper 2 inches of the soil relative to plots with no rye in several no-till cropping sequences (Table 3). The K was apparently transferred from a diffuse area in the soil profile because there was no significant decrease in exchangeable K at a depth of 2 to 8 inches. Neither investigator noted any effect of cover cropping on other exchangeable cations. The K effect is likely due to the relatively great amounts of K accumulated and translocated by the actively growing covers relative to the exchangeable K pool in the soil. The lack of effect on other cations would be due to relatively insignificant uptake relative to quantities in the soil. Both studies showed some tendency for cover crops to reduce available phosphorus (P) near the soil surface. Hargrove noted that the P effect was related to cover crop species, while Eckert found that effects with rye occurred only in continuous corn at one location (Table 3). We could speculate that available P was converted to organic forms not accessible to the soil test extractant upon absorption by the cover crop. Hargrove also noted that legume cover crops reduced soil pH and C/N ratio after 3 years relative to control plots. The reduced pH may have been due to nitrification of mineralized organic N from the cover crop residues.

In the tropics, leguminous cover crops have long been grown in association with plantation crops. The most commonly grown legumes for this purpose are *Calopogonium muconoides, Centrosema pubescens, Indigofera spictata, Pueraria pheseoloids, Stylosanthes guianensis, Dolichos hosel,* and *Glycine javanica.* Cover crops are also used as planted fallows to enhance fertility of soils of the tropics. The amount of N fixed by leguminous cover crops ranges from nothing to about 27 pounds/acre of plant-available N. *Psophoscarpus palustris, Centrosema pubescens, Mucuna utilis,* and *Crotolaria* usually fix plant available N from about 13 to 27 pounds/acre.

Weed suppression

Use of cover crops in row crop production represents a potential reduced herbicide technology for weed control in conservation tillage that incorporates short-term crop rotation. Cover crops are generally established in the fall to provide a dense cover by early spring that suppresses weed germination and establishment. Cover crops control weeds through competition, allelopathy, and/or physical effects, while maintaining surface residue. A potential disadvantage of using cover crops for weed control is the possibility that they may compete with row crops for light, water, and nutrients.

Researchers investigated living mulches for their potential for weed control in the 1950s in the midwestern United States *(54)* and more recently in Nigeria and the northeastern and north central United States *(1, 13, 25, 33, 53, 64, 66)*. Typically, in living mulch research, row crops, such as corn, soybeans, or vegetables, are seeded into a low-growing preestablished winter grain, perennial legume, or grass sod *(10, 13, 33, 66)*, or winter annual legume cover crop *(15)*. With few exceptions, these mulches have shown little selectivity; mulches effective in controlling weeds also tend to be effective in suppressing the row crop, and therefore, require management by herbicides, partial tillage, or mowing to reduce their interference with row-crop establishment, growth, and yield *(25, 33, 53, 66)*.

In a series of experiments in Pennsylvania, researchers examined no-till corn production in preestablished crownvetch (*Coronilla varia* L.) sod *(10, 25, 26, 41)*. They obtained corn yields comparable to the long-term average yields under conventional systems in crownvetch sods suppressed from 50% to 67% by various herbicide treatments *(26, 41)*. When crownvetch was unsuppressed, corn yields and weeds were significantly reduced over a 3-year trial *(10)*.

Researchers conducted studies with living mulches at Cornell University to reduce soil erosion and improve deteriorating soil properties caused by continuous vegetable cropping *(29)*. They encountered difficulty in initial trials with grassy covers in obtaining a herbicide rate at which the grasses would be suppressed but not killed. Spring-seeded oats (*Avena fatua* L.), rye, and perennial ryegrass (*Lolium perenne* L.) that remained unsuppressed by chemical treatment provided excellent broadleaf weed control compared to no-cover plots, but were too competitive for acceptable yields of cabbage (*Brassica oleracea capitara*) and beets (*Beta vulgarus*). Yields were acceptable only in severely stunted covers.

In chemically suppressed legume mulch plots established 1 year prior to sweet corn planting, yields were as good as or better than in no-cover clean-cultivated plots *(65)*. In unsuppressed mulch plots, corn yields were reduced. White clover and ladino clover suppressed weeds better than red clover or alfalfa.

Three perennial legumes showed promise as living mulches in maize production in Ibadan, Nigeria: wild groundnut (*Arachis repens*), centro (*Centrosema pubescens*), and wild winged bean (*Psophocarpus palustris*) *(3, 4, 1)*. No yield reduction was observed when maize was planted into preestablished legumes suppressed with banded paraquat (1,1-dimethyl-4,4-bipyridinium ion) applied over the crop rows, when compared with weed-free conventionally tilled no-cover plots. The legumes suppressed weed dry weight 88% to 93% compared with unweeded conventional no-cover plots. Corn yield was not improved by weeding the legumes. Live-mulch experiments conducted in Nigeria indicated severe yield reductions by unsuppressed climbing covers *(73)*. In contrast, with a low-growing nonclimber, favorable yields were obtained, even with mechanical suppression. Akobundu *(1)* also obtained favorable yields with low-growing and no-climber live mulches.

Robinson and Dunham (54) investigated winter wheat and winter rye as companion crops for weed control in soybeans. Rye and wheat were sown at the same time as soybeans, which were seeded in 15-inch rows. The soybeans yielded as well or better than the soybeans sown at the same row-spacing without a companion crop or any other form of weed control. Yields with rye or wheat were also comparable to soybeans in wider clean-cultivated rows. Wheat and rye gave excellent, but not complete, weed control, and rye was more competitive than wheat with both weeds and soybeans. The researchers favored spring seeding of rye and wheat due to the short growth habit and lack of influorescence of the winter grains when spring-seeded and their short life cycle; the grains began to senesce and cease competition with soybeans in July, when soybeans were growing rapidly.

In Illinois, spring-planted winter rye and wheat were studied for their potential as living mulches in soybeans *(53)*. The grains suppressed weeds more when established 4 and 2 weeks before soybeans were planted than when seeded at the same time as soybeans, and wheat was more suppressive than rye; weed dry weight reduction averaged over grain planting dates was 92% for wheat and 81% for rye. Preestablished grains also severely reduced soybean yield; yield was reduced 95% in rye seeded 4 weeks before soybeans were planted compared to 37% when rye was seeded when soybeans were planted. When researchers planted grains at the same time as soybeans, use of narrower soybean row-spacing improved both weed control and soybean yield; the highest soybean yield was obtained by planting soybeans in 7-inch rows in simultaneously established rye. However, this yield was still 28% less than weed-free soybeans grown at the same row-spacing without mulch.

Nicholson and Wien *(48)* screened 52 spring-planted grass and legume species for their potential as living mulches in New

York. White clover and turfgrasses were the lowest-growing and densest species, and gave the greatest weed suppression. Eight entries were selected from the original 52 for intercropping with sweet corn and cabbage: Chewings fescue (*Festuca rubra* L.), Kentucky bluegrass (*Poa pratensis* L.) and 'Kent' wild white clover (*Trifolium repens* L.) did not reduce crop yields. In Nebraska *(13)*, chemically suppressed Chewings fescue remained green during the growing season and gave good weed control, but it reduced field corn yield when precipitation was below normal.

Selection of a mulch with a winter annual life cycle gave researchers promising results in weed control and corn yield in New Jersey *(15)*. This 3-year study showed that corn planted into a living stand of unsuppressed subterranean clover (*Trifolium subterraneum*), a winter annual legume, yielded as well as or better than no-till, minimum till, or conventional till corn with conventional herbicidal weed control and no mulch. Compared to no-till plots with conventional herbicide treatments but without the cover crop, unsuppressed subterranean clover without any herbicide treatments gave comparable or better weed control. Subterranean clover can be planted in the fall, goes dormant during the winter, and resumes and completes growth during the spring, giving minimal competition with the corn. It leaves a weed-suppressive residue after its senescence and reseeds itself.

The choice of a cover crop with a winter annual life cycle seems logical for living mulch systems in the northeastern and north central United States. For the U.S. Corn Belt, lack of sufficient winter-hardiness is a major obstacle in further development of living mulch technology for weed control using winter annual species. Research is needed to select winter annual species with acceptable winter-hardiness, prostrate growth habit, effective weed suppression, early maturity, and reseeding capability. The interference of living mulches with crops, which appears to involve competition for water and/or allelopathy *(6, 8, 33)*, also poses a problem in using these crops for weed control.

Other research in the area of cover crops for weed control involves killed winter cover crops. Because these cover crops are killed at the time of corn or soybean planting, species unsuitable as living mulches due to tall growth habit and/or late maturity and senescence may be used. Thus, winter cereal grains such as rye and the relatively tall-growing winter annual legume hairy vetch (*Vicia villosa*) are suitable for this technology and can provide weed control through physical and/or allelopathic effects of their residues. Indeed, much research shows that fall-planted, spring-killed rye, wheat, oats, and barley can provide weed suppression *(5, 40, 43, 44, 58)*. There is evidence that part of the suppressive effect of rye may involve production of allelochemicals *(6, 57)*. Weston *(69)* found that rye and wheat gave better weed control than oats or barley and gave substantial weed suppression 45 days after kill. At 60 days after kill, however, significant weed pressure was present in rye and wheat residues.

Corn or soybean production in killed-rye cover crops sometimes results in yield losses. In Nebraska, Echtenkamp and Moomaw *(13)* found that a winter rye cover crop killed with glyphosate prior to corn planting reduced corn yield 34% and 37% in two out of their four experiments, and gave 60% to 95% control of weeds. In a 4-year Illinois study, Stoller et al. *(60)* found that fall-planted rye killed at or prior to corn planting depleted soil moisture and reduced crop yield in years when precipitation was below normal. They also found that rye was ineffective in controlling common lambsquarters (*Chenopodium album*), an early emrging weed, even with application of preemergence and postemergence herbicides.

Pasture species such as Italian ryegrass (*Lolium multiflorum* L.), perennial ryegrass (*Lolium perenne* L.), and creeping red fescue (*Festuca rubra* L.) were more difficult to kill than cereal grains *(69)*, but were more effective in suppressing weeds, probably due to competition from regrowth. However, row crops were more difficult to establish in pasture species than in cereal grains, with up to 50% stand losses observed in perennial ryegrass and creeping red fescue.

Echtenkamp and Moomaw *(13)* found that unsuppressed hairy vetch was effective in controlling weeds, but was overly competitive with corn. On the other hand, when treated with high rates of 2,4-D, the killed vetch disintegrated too quickly and its residue failed to provide adequate weed control. Janke and Peters *(30)* reported that hairy vetch that was flail-chopped after flowering in late May in Pennsylvania provided a dense thatch of dead mulch that suppressed weeds effectively for 6 weeks after corn was planted. Janke and Peters also found that delayed kill of hairy vetch resulted in greater weed suppression by the hairy vetch.

Hairy vetch seeded in late August in Ohio provided complete soil cover by mid-November and overwintered successfully *(27)*. In the spring, corn was planted at three successive stages of vetch growth: vegetative, late-bud, and mid-bloom. Prior to corn planting, vetch was either treated with glyphosate (2.5 pounds/acres), mowed once, or left untreated. Vetch was easily killed with glyphosate or mowing when at the bud or mid-bloom stage in late May and mid-June, respectively. However, while the vetch was still vegetative in late April, neither glyphosate nor mowing completely killed the vetch, and corn yields were reduced (Table 4), particularly in mowed vetch. Mowing was less effective in killing the vetch than was

Table 4. Effect of cover crop management and date of planting on corn grain yield.*

Vetch Kill Treatment	*Corn Grain Yield by Planting Date*		
	Late April	*Late May*	*Mid-June*
	bushels/acre at 15.5% moisture		
Glyphosate	127	122	90
Mowing	48	109	94
Untreated	2	117	104
Weedy check	106	110	91
Weed-free check	155	136	84

LSD (0.05) for comparing treatments within planting dates is 26.9.
LSD (0.05) for comparing planting dates within treatments is 27.6.

*Corn was grown in fall-established hairy vetch at Columbus, Ohio, in 1990. Corn was planted in late April, late May, and mid-June. Hairy vetch was killed with glyphosate (2.5 pounds/acre) or, by mowing (flail chop mower), or left untreated. The weedy check and weed-free check had no vetch cover; weeds were not controlled in the weed check. Weeds in the weed-free check were controlled with an application of glyphosate at 2.5 pounds/acre at corn planting and hand weeding thereafter.

glyphosate at this stage. Interestingly, when the vetch was at the bud or mid-bloom stage, the corn planting operation flattened the vetch, which resulted in 56% and 100% kill of the vetch for those two dates, respectively, without additional treatment to kill the vetch (data not shown). Yields of corn planted in late May and mid-June was not reduced in glyphosate-treated, mowed, or even uncontrolled vetch, compared with vetch-free controls, with the exception of a 20% corn yield reduction observed in mowed vetch for corn planted in late May (Table 4). This yield reduction was associated with a high level of weed biomass (Table 5). Weeding the vetch in glyphosate-treated, mowed, and uncontrolled vetch plots improved corn yields for all corn planting dates an average of 11% over unweeded vetch plots. Vetch residue from glyphosate-treated and mowed vetch did not control weeds when compared with vetch-free plots without weed control, but uncontrolled vetch reduced weed biomass an average of 80% (Table 5).

Table 5. Effect of cover crop management and date of planting corn on weed biomass.

Vetch Kill Treatment	*Weed Biomass by Planting Date** Late April	Late May	Mid-June	Mean
	pounds/acre			
Glyphosate	1,790	466	245	834
Mowing	1,747	1,520	103	1,124
Untreated	116	317	100	178
Weedy check	2,833	1,232	354	1,473

LSD (0.05) for comparing treatments averaged across dates is 883.

*Weed biomass was sampled at the end of the growing season in corn grown in fall-established hairy vetch at Columbus, Ohio. See table 4 for description of vetch treatments and weedy check.

Table 6. Mean number of adult seedcorn maggots per trap and soybean plant stand from a rye cover crop management study conducted near Wooster, Ohio (*19*).

Treatment	*1982* Maggots per Trap	*1982* Soybean Plants*	*1983* Maggots per Trap	*1983* Soybean Plants*
No rye	0.3d†	37.1b	4.2c	37.4a
Rye killed, surface	0.5d	43.0a	2.9c	31.3a
Rye killed, disked	5.0c	29.3c	12.7b	23.1b
Rye, disked	14.2b	21.1d	18.9a	16.8b
Rye, plowed	20.7a	13.3e	13.5b	20.3b

*Plants per 6-foot row.
†Numbers in the same column followed by the same letter are significant at the 5% level.

Table 7. Mean number of adult seedcorn maggots per trap from a cover crop study conducted near Wooster, Ohio (*19*).

*Cover Crop**	*Maggots per Trap* 1986	1987	1988
Bare soil	3.1c†	2.7c	1.8c
Soybean residue	14.3b	8.0b	4.1b
Corn residue	6.7c	3.6c	1.9c
Alfalfa	46.6a	15.3a	11.3a
Rye	21.1b	13.8a	8.4a

*Treatments are when cover crops were plowed and disked.
†Numbers in the same column followed by the same letter are significant at the 5% level.

In most cases, cover crops that suppress weeds the best also exert the greatest competition with the row crop of interest. Competition with the row crop seems to be associated with conditions of limiting precipitation. Mulches that are compatible with the row crop tend to give inadequate weed control. Residues from killed cover crops can provide good weed control for a short period of time but additional weed control measures may be necessary for longer periods of weed control *(69)*. Systems in which cover crop systems are combined with cultural practices, such as planting in narrow rows *(7, 11)* and using highly competitive cultivars *(16)* to improve crop competitiveness with weeds, need to be researched to alleviate the problems discussed above.

Insect control

Cover crops can have significant effects on soil and foliage arthropods. How we manage cover crops in the spring dictates the impacts that we observe and which arthropods are affected. Incorporation of the organic material provided by the cover crop into the soil is one way to kill the cover crop and prevent further competition to the primary crop. However, this alters the relationship between insects and the crop. For example, the incorporation of a green, living cover crop significantly increases the potential for damaging levels of seedcorn maggot (Table 6) *(19)*, with higher populations (Table 7) occurring when a legume, such as alfalfa, is incorporated compared with a grass, such as rye *(20)*. These higher populations have been shown to lead to reduced soybean-plant stands (Table 6). House and Alzugaray *(28)* also found a greater number of seedcorn maggots when they plowed various cover crops, although they did not separate the effects of differing types of cover crops. Significant stand reductions also have been seen in Ohio, when they planted soybeans in a field that contained spring-plowed alfalfa (unpublished data). The adult seedcorn maggot, a dipteran pest often associated with conservation tillage practices, is thought to be attracted for oviposition and/or feeding purposes to decaying organic material that soil-incorporated cover crops provide. The exact mechanisms involved in this relationship between the soil, decaying organic material, and insect are not known. Increases in maggot populations have not been observed, however, when a cover crop remains on the soil surface or when only previous crops residues are incorporated into the soil (Table 7) *(20)*.

With the majority of cover crops, the residue remains on the soil surface following herbicide application, which increases the overall diversity in the agroecosystem. The most pronounced effects are seen early in the season prior to, or immediately following, herbicide application. Studies have shown increases in the arthropod fauna, most notably soil predators, herbivores, and decomposers, with the use of cover crops, with differences between types of cover having an additional effect on arthropod diversity and numbers. For example, House and Alzugaray *(28)* found that hairy vetch supported higher belowground arthropod densities and a more diverse fauna than crimson clover or wheat. Many of these differences were observed to dissipate or reverse themselves by midseason. Gardner and All *(17)* reported greater damage by southern corn billbug adults to grain sorghum and corn with the use of various cover crops. Billbugs, which enter a field primarily by walking as compared with flying, are thought to be attracted to areas with residue. Gardner and All felt that increased adult billbug activity was correlated with the cover crop residue on the soil surface when overwintered beetles dispersed into the field. Having found greater damage to corn when clover was planted as compared with vetch, they suggested that the primary reason was due to the greater residue produced by clover.

Another possible impact from a cover crop following its killing by herbicides is on foliar arthropods, that is, those insects not normally associated with ground cover or residue. The presence of a secondary crop, albeit a dead or dying crop, can influence the population dynamics of pest and beneficial arthropods. Smith et al. *(59)* found that potato leafhopper populations in soybeans were consistently lower when rye cover crop residue remained on the surface. Highest numbers of leafhoppers were found in rye-free plots or where rye was plowed. This negative impact on potato leafhoppers from the presence of grassy residues corresponds to studies by others with alfalfa *(37, 38, 51, 50)* and soybeans relay-intercropped into winter wheat *(20)* where lower leafhoppers population were in mixed grass/legume systems. Grasses, a nonhost of potato leafhoppers, induce behavioral changes in the leafhopper via a mechanism that is not completely understood, which in turn reduces leafhopper numbers. These changes apparently can occur whether the grasses are living, or in the case of cover crops, dead or dying from a recent herbicide application. Additionally, Smith et al. *(59)*, found that numbers of Japanese beetles and bean leaf beetles were slightly higher in the rye cover crop plots.

The impact that cover crops have on soil and foliar arthropods depends not only on the arthropod and cover crop/main crop agroecosystem but also on the type (grass versus legume) and management of the cover crop. Knowing the influence that the cover crop might have on arthropods will assist growers in better managing their crop via alternative practices.

Cover crops and energy

Most Third World countries of the tropics and subtropics widely use crop residues as household fuel. With energy shortages and increasing demand on dwindling fossil fuel, biomass from cover crops also has potential to be used as fuel in Third World economies. Cover crops with a capacity to produce large quantities of stored solar energy in the biomass are potentially significant sources of renewable energy. The Office of Technology Assessment *(49)* estimated that biomass from grasses and legumes may produce as much as 5 quads (1 quad = 1,015 British thermal units) of energy by the year 2000. The heat energy content of most nonwoody biomass materials is about 7,500 British thermal units/pound of dry matter with an ash content of 2% to 8%. In contrast to forages, cover crops grown for fuel should be selected on the basis of their dry matter yield without regard to nutritional characteristics. Furthermore, biomass with lower ash contents tend to have slightly higher heating values.

Conclusions

Cover crops can play an important role toward achieving the objectives of sustainable agriculture. A vigorous cover crop is useful for providing a low-growing protective cover against raindrop impact and shearing the force of overland flow, improving soil aggregation and enhancing structural attributes, increasing infiltration capacity and decreasing risks of runoff and accelerated erosion, fixing plant-available N and recycling nutrients, suppressing weed growth, and reducing insects and pathogens through increasing biodiversity. The world's annual input from biologically fixed N by legumes is estimated at about 100 million tons *(32)*. Well-nodulated leguminous covers can fix up to 100 pounds of plant available N per acre, and reduce dependence on chemical fertilizers. Aggressively growing cover crops can also reduce dependence on herbicides, thereby reducing risks of contamination of surface water and groundwater. Cover crops also have a potential to be used for fuel.

Sustainable agriculture is a complex and multifaceted concept. Growing cover crops, although important, is a component of this complex whole. The usefulness of cover crops in sustaining agricultural production, preserving productivity of soil resources, and maintaining high environmental quality can be enhanced by a thorough understanding of the effects of cover crops on soil properties, hydrological processes, and water and air quality. Presently, there are several myths about the usefulness of cover crops. These myths should be replaced by facts through well-designed and long-term experimentation. These research experiments should preferably be multidisciplinary; jointly planned; and implemented by soil scientists, agronomists, hydrologists, plant protection specialists, engineers, economists, and social scientists.

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An Information data base on cover crops

Jill Shore Auburn and Robert Bugg

Cover crops, green manures, and living mulches are important parts of many farming systems, particularly those that are designed to enhance rather than degrade water and other natural resources. These materials are known by multiple terms that reflect their many functions in a wide variety of cropping systems. As cover crops, they prevent soil erosion and improve water infiltration and other soil quality factors; as green manures, they enhance soil productivity and reduce reliance on synthetic chemical fertilizers; and as living mulches, they can help control weeds. They also influence microclimate, water use, and a variety of soil and aboveground pests in both positive and negative ways.

Because of the interacting requirements and effects of cover crops, it is difficult for growers to choose and manage cover crops in the most environmentally and agronomically sound manner. The choice of a legume that is best for reducing reliance on purchased fertilizer, for example, may have negative side effects, such as a build up of plant-parasitic nematodes or increased water consumption. Recent research has shown a wide range of nematode tolerance and susceptibility among cover crops *(6)* and water consumption increases of 0% to 20%, depending upon cover crop material and management practices *(8)*.

Researchers and growers may obtain a wealth of older information, but much of it needs re-evaluation in light of current production systems and methods, such as seeding rates, inoculation methods, and improved cultivators. We need to coordinate information across cropping systems and disciplines, as well as to integrate old with new information.

Several recent efforts have pulled the literature together in the form of bibliographies, review papers, and extension publications. The National Agricultural Library has published a bibliography of citations on green manures and cover crops *(5)*. Lanini et al. *(4)* have written an extensive review paper on mulching trials in orchards in the United States. Recent extension publications on cover crops in California include a bulletin for orchards and vineyards from the Soil Conservation Service *(3)* and an updated University of California bulletin *(7)*. In spite of these efforts, it is difficult for a grower or researcher to find, in one place, information about all of the aspects of a particular cover crop that might be relevant to his or her situation.

Methodology

We began this project to improve access to information about cover crops, by organizing both literature references and their contents in data base form, so that useful information can be retrieved in meaningful fields, such as cover crop

Jill Shore Auburn is information systems manager and Robert Bugg is information analyst for the Sustainable Agriculture Research and Education Program (SAREP), University of California, Davis 95616

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material, management practices, cropping system, environmental conditions, and type of effect. This effort is underway at the Sustainable Agriculture Research and Education Program (SAREP) with funding from the U.S. Department of Agriculture's Low-Input Sustainable Agriculture program and the California State Water Resources Control Board.

In the fall of 1988, a group of about 20 researchers, extension personnel, and private consultants was asked to meet and provide SAREP with ideas on how to pull together cover crop information. The group recommended that we develop a data base with a number of fields spanning identification, environmental requirements, growth and management, and uses and effects of cover crops. The resulting data base includes 51 fields in these four groupings (Table 1). The purpose was to put information into a common format from widely varying sources (scientific and popular literature and observations and other expert opinion) so that areas of agreement and disagreement could be discerned. The group agreed that SAREP staff would "seed" the data base with information from a handful of sources, and the members of the group would act as reviewers and contributors of further information. Robert Zomer, a post graduate researcher, compiled many of the early entries into the data base; later entries were added by Robert Bugg, an information analyst.

Each paragraph is tagged with the relevant category or categories from table 1, plus the following fields: ID (unique identification code); CROP (cover crop name); SOURCE, LOCATION (tying it to a full reference in our literature data base); and, where appropriate, CULTIVAR and MAIN CROP (economic crop). The following two sample records illustrate the use of these fields:

ID CC 3027
CR Mustards
AB Mustard incorporated as a green manure failed to significantly increase infiltration of irrigation water, although barley, cereal rye, annual ryegrass, and 'Blando' brome did so.
SU Effects on Soil
SO Williams, 1966
LO CCZ.148
$

ID CC 3036
SO Pickel, personal communication
CR Mustards
SU Pest Effects, Insects
LO Pickel, Carolyn
AB Not recommended for apples where orange tortrix (apple skinworm) can be a problem, as the pest overwinters on the mustard.
MC Apples
$

With the information in data base form, we can search the contents (for example, for all references to a particular pest, or for all mention of drought tolerance). We can print out the entire data base in a variety of formats for review and use. We plan, during the coming year, to summarize the information into fact sheets for extension use and to develop a simple expert system for selecting a cover crop based on key characteristics.

Table 1. Categories (fields) in SAREP cover crop data base, and the number of entries per category.

Identification		*Environmental Requirements*	
Number	*Field*	*Number*	*Field*
85	Common name	119	Temperature
89	Scientific name	70	Geographic range
66	Cultivar	134	Water
100	Seed description	49	Nutrients
23	Seedling description	96	Soil pH
77	Mature plant description	150	Soil type
		16	Shade tolerance
		20	Salinity tolerance
		7	Herbicide sensitivity

Growth and Management		*Uses and Effects*	
Number	*Field*	*Number*	*Field*
104	Life cycle	184	Uses
166	Seeding rate	70	Mixtures
45	Seeding depth	101	Biomass
67	Seeding method	112	N contribution
98	Seeding dates	13	Non-N nutrient contribution
78	Inoculation	8	Effects on water
29	Seed cost	2	Effects on micro-climate
30	Seed availability	29	Effects on soil
113	Days to flowering	54	Effects on livestock
65	Days to maturity	7	Effects on workers
81	Seed production	117	Pest effects, insects
20	Seed storage	65	Pest effects, nematodes
89	Growth habit	39	Pest effects, diseases
65	Maximum height	57	Pest effects, weeds
52	Root system	6	Pest effects, vertebrates
29	Establishment		
32	Maintenance		
61	Mowing		
34	Incorporation		
20	Harvesting		
7	Equipment		

Results and discussion

Tables 1 and 2 show the coverage of the database as of early 1991. Information is abundant in the areas of material description (names, seed and plant description, life cycle) and basic management (seeding information temperature, water and soil requirements). Information is more scarce in key variables such as shade and salinity tolerance, management guidelines beyond basic seeding information, and effects other than biomass/nitrogen (N) contribution. There is a growing body of information on pest effects, particularly insect pests. More complete information on management possibilities and a wider range of effects is critical to the appropriate selection and use of cover crops today, particularly in California's varied environments and cropping systems.

Major uses in California. While soil conservation is a traditional use of cover crops, this is a less important use in California, except in the foothill areas. More commonly these days, we use cover crops to improve water infiltration, to provide habitat for beneficial organisms, and/or to provide a source of nutrients and organic matter to the soil.

Recent work in California has confirmed the ability of cover crops to provide sufficient N for following crops, such as corn and tomatoes *(7, 12)*, while providing additional benefits of soil improvement. The growing number of organic farmers in the state has increased the demand for N_2-fixing green manures, including summer covers that will fix considerable N with minimal water use. Grass covers, often used to reduce excessive vigor in vineyards in the North Coast, may see increased use as traps for nutrients that might otherwise pollute groundwater, as the state becomes increasingly concerned about nitrate pollution of groundwater from agricultural sources *(1, 11)*.

Twenty-three percent of California's irrigated cropland suffers from poor water infiltration, costing $500/acre or more *(9)*. Researchers in California have demonstrated well the ability of cover crops to improve water infiltration *(13, 2)*. More recent work has demonstrated this effect in almond orchards *(8)*.

In response to increase public and governmental scrutiny of pesticide use, the most dramatic increase in interest in cover crops in the last several years is as habitat for beneficial organisms.

Major constraints in California. Constraints to the growing interest in cover crops in California include four areas: water use, frost hazard, economics, and management requirements.

As the state enters its fifth consecutive year of drought, the irrigation needs of cover crops is a concern. The general rule of thumb often heard is that cover crops increase orchard water use by about 20%, but this rule of thumb, apparently based on earlier work with perennial covers, ignores differences due to species, management, and other factors. In one recent study in almond orchards, a winter annual (bromegrass) that was mowed and left on the ground acted as a mulch, with no net increase in water use over the season, whereas water use with either a perennial strawberry clover or the commonly used resident vegetation was substantially elevated *(10)*. These differences dramatically illustrate the need for detailed information by species and management practice, such as we are compiling in our data base. While management methods and more water-conserving species may minimize the effect of cover crops on total water use, the lack of rainfall in autumn in the last 2 years has been a major constraint to growers who use winter annuals in orchards and vineyards on low-volume irrigation, where the middle areas generally are not irrigated.

A second constraint in some tree and vine crops that are sensitive to frost has been the concern that vegetative cover would interfere with the earth's heat exchange and thereby increase the chances of frost damage. Management (e.g., species selection, mowing) can minimize this potential effect.

A third constraint, particularly in annual cropping systems, is economic: removing land from production of a marketable crop for even a short time is difficult to justify economically.

Finally, management skills have been somewhat constraining for growers newly interested in cover crops, particularly tree and vine growers. A cover crop takes knowledge, skill, and equipment for managing an agronomic crop.

The many uses of cover crops in California, and the constraints to be considered in their use, highlight the need to compile a wide variety of information in an organized form, such as we are doing in our data base effort.

Table 2. Major plant materials in SAREP cover crops data base.

Common Name	*Scientific Name*
Annual ryegrass	*Lolium multiflorum*
Austrian winter pea	*Pisum sativum*
Barley	*Hordeum vulgare*
Bell beans	*Vicia faba*
'Blando' brome	*Bromus mollis*
Cereal Rye	*Secale cereale*
Clovers (*Melilotus*)	
Sour clover	*Melilotus indica*
Sweet clover	*Melilotus alba*
Clovers (*Trifolium*)	
Berseem clover	*Trifolium alexandrinum*
Crimson clover	*Trifolium incarnatum*
Ladino clover	*Trifolium repens latum*
Rose clover	*Trifolium hirtum*
Strawberry clover	*Trifolium fragiferum*
Subterranean clover	*Trifolium subterraneum*
Cowpeas	*Vigna sinensis*
Medics	
Barrel medic	*Medicago truncatula*
Black medic	*Medicago lupulina*
Bur clover	*Medicago polymorpha*
Mustards	*Brassica spp.*
Oats	*Avena sativa*
Sesbania	*Sesbania spp.*
Sunn Hemp	*Crotalaria spp.*
Vetches	
Common vetch	*Vicia sativa*
Hairy vetch	*Vicia villosa*
Purple vetch	*Vicia atropurpurea*
Woollypod vetch	*Vicia dasycarpa*

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